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Inhibition in long-term memory

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**INHIBITION IN LONG-TERM MEMORY**

**Abstract**

The present thesis examined the issue of inhibitory processes in long-term memory. Several theoretical frameworks, which posit various loci of an inhibitory mechanism, have been examined. The locus of an inhibitory mechanism was investigated within the retrieval practice paradigm, in which inhibition is recruited against information that competes for memory access during retrieval, and within the list-method directed forgetting paradigm, in which inhibition is voluntarily recruited.

Experiments 1-8, with a total of 315 participants tested, focused on the cue-independence of forgetting in the retrieval practice paradigm. Experiments 1, 2, 4, 7, and 8 provided no evidence for the cue-independence. Although forgetting was documented when memory was tested with original cues (Experiments 1, 2, 3, 6), it failed to emerge with independent cues that were semantically related to several items in the memory set (Experiments 1 and 2), that were semantically related to individual items in the memory set (Experiments 2, 4, and 8), and that were only episodically related to individual items (Experiment 7). These findings do not support the theory of inhibition operating at the level of semantic features. Further, no support was obtained for the prediction that a broad spectrum of episodic associations established for interfering information is affected by inhibition (Experiments 4 and 7). Finally, the prediction of a constrained episodic account, according to which only the associative link directly responsible for interference is affected by an inhibitory mechanism, was assessed in Experiment 8. This hypothesis also did not gain empirical support.

Experiments 9-11, with a total of 141 participants tested, focused on the list-method directed forgetting paradigm. Within this paradigm two hypotheses about the locus of inhibitory processes were tested. Predictions of the retrieval inhibition account, which postulates the general effect of inhibition on all episodic associations created during study, were contrasted with predictions of a

constrained inhibitory model, according to which only episodic links directly responsible for interference are affected by inhibition. Experiments 10 and 11 did not provide support for the retrieval inhibition account, thus favouring a more constrained framework.

Together, the results of the present experiments can be interpreted in two ways. They can be used to specify an inhibitory mechanism as one of associative unlearning, operating only on the associations that are the cause of interference which needs to be resolved by inhibition (but see Experiment 8). Alternatively, the present results can be used to argue that the concept of inhibition is not needed to account for forgetting in the examined paradigms.

## List of Contents

1. The concept of inhibition	9
1.1 Inhibition: how the term is used	9
1.2 Inhibitory mechanisms	12
1.3 Memory inhibition: research paradigms	13
1.3.1 Procedures used to investigate inhibition in working memory	14
1.3.1.1 item-method directed forgetting	14
1.3.1.2 garden-path sentences	17
1.3.2 Procedures used to investigate inhibition in long-term memory	20
1.3.2.1 the think/no-think task	20
1.3.2.2 list-method directed forgetting	24
1.3.2.3 the retrieval-practice paradigm	28
1.4 Summary	31
2. Retrieval-induced forgetting	37
2.1 Introduction	37
2.2 Mechanisms of RIF	39
2.3 Empirical evidence for inhibitory and interference-based accounts of RIF	43
2.3.1 Active inhibition vs. passive interference	43
2.3.2 The role of retrieval in a final test	49
2.3.2.1 Implicit tasks	50
2.3.2.2 Recognition tests	59
2.3.3 Retrieval specificity of RIF	73
2.3.4 Competition dependence of RIF	84
2.3.5 Cue-independence of RIF	92
3. Directed forgetting	113
3.1 Introduction	113



3.2 Mechanisms of directed forgetting	114
3.2.1 Differential rehearsal	114
3.2.2 Retrieval inhibition	117
3.2.3 Context change	136
3.3 Summary	146
4. Experiments on RIF	149
4.1 Introduction	149
4.2 Experiment 1	154
4.3 Experiment 2	160
4.4 Experiment 3	167
4.5 Experiment 4	170
4.6 Experiment 5	175
4.7 Experiment 6	178
4.8 Experiment 7	181
4.9 Experiment 8	184
4.10 Discussion of the RIF experiments	191
5. Experiments on directed forgetting	198
5.1 Introduction	198
5.2 Experiment 9	203
5.3 Experiment 10	205
5.4 Experiment 11	213
5.5 Discussion of the directed forgetting experiments	221
6. Conclusions	226
7. References	237
8. Appendices	275

## Tables and Figures Contents

Table 1. Recall performance in Experiments 1-8	158
Table 2. Associative recognition performance in Experiments 10 and 11	209
Table 3. List discrimination performance in Experiments 10 and 11.	210
Figure 1. Possible loci of inhibitory processes.	153



## 1. The concept of inhibition

Memory inhibition is a process postulated in some memory models to be necessary for explaining why people forget information that has been already stored in memory. A variety of implementations of this basic idea have been proposed (see Anderson & Bjork, 1994, for a review) and within various models specific criteria for detecting inhibition have been developed. However, the common factor that links different definitions of the concept of inhibition is the idea that forgetting is an active process directed at to-be-forgotten information, rather than a mere by-product of the encoding and storage of the new information in memory (Bjork, 1989). The present chapter describes the most prominent theoretical implementations of the concept of memory inhibition, together with the experimental paradigms commonly used to examine those constructs. The ultimate aim of this overview is to formulate a definition of memory inhibition that will be applied throughout the studies described in the present work.

### 1.1 Inhibition: how the term is used

The term inhibition broadly has three different meanings within the cognitive literature. First, it can serve as a description of the pattern of empirical findings. Specifically, inhibition stands in opposition to facilitation and refers to a level of performance that is below a certain baseline. For example, in the literature on spatial attention the term *inhibition of return* was coined to describe a phenomenon of slowing when responding to the targets in a cued location compared to the baseline response time to the targets in an uncued location (Posner, Rafal, Choate, & Vaughan, 1985). The term *inhibition* can refer to this pattern of slowing in responding, but can also serve as a description of a mechanism responsible for such slowing. The second sense in which the term inhibition is used is therefore to describe the specific mechanism that is thought to account for some pattern of empirical data. In the case of inhibition of return it has been postulated that the aforementioned pattern of slowing in responding stems from a process which tags previously attended locations and prevents the return of attention to these locations (e.g. Rafal, Egly, & Rhodes, 1994). However, it has been

pointed out that such an inhibitory account of the observed pattern of results is not the only possible one and other non-inhibitory mechanisms, like the ballistic nature of attentional sweep, have been proposed (Pratt, Spalek, & Bradshaw, 1999). The inhibition of return is thus an example in which the term inhibition can be used in two of its primary functions, as a description of a phenomenon and as a description of a mechanism of this phenomenon (C. M. MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003).

The third meaning assigned to the term inhibition refers to mechanisms of interference resolution. In this case inhibition refers not to a particular pattern of below-baseline performance in a certain task or to a quite specific mechanism responsible for a particular pattern of results, but rather to a general class of processes that are responsible for dealing with all kinds of interference and helping to guide goal-oriented actions in the face of multiple distracters. A well-known example of such use of the term inhibition can be found in the framework developed by Hasher and Zacks (1988; see also Lustig, Hasher, & Zacks, 2007) to account for cognitive decline in old age. This inhibitory framework of age differences in cognition postulates that resolving the competition from distracters is more challenging for older than young adults, resulting in impaired performance on a variety of cognitive tests. Hasher and Zacks argue that such impaired performance in the presence of distractions is observable in a wide variety of tasks and thus can be assigned to a single factor of decline in inhibitory functions. However, both the tasks which produce results used to substantiate this claim and the cognitive processes responsible for performance in those tasks vary greatly, as described in a later part of this chapter, and hence the overarching term of inhibition used in relation to the effects in these tasks serves a descriptive rather than explanatory function. Performance in these tasks requires interference resolution but this resolution may be achieved in a variety of specific ways. One of these ways is to recruit a specific inhibitory mechanism but other, non-inhibitory mechanisms are also plausible. However, from the perspective of some theoretical frameworks, like the one developed by Hasher and Zacks, all mechanisms used to resolve

interference can be called inhibitory, whether they actually involve inhibiting a certain cognitive representation or not.

In the present thesis the term inhibition will be generally used as described in the second point, which is to refer to a specific mechanism postulated to account for particular effects, in this case the costs of list-method directed forgetting and a retrieval-induced forgetting effect. According to the first use of the term inhibition, both of these effects can simply be described as inhibitory as they refer to a phenomenon in which memory performance for some information stored in memory is worse when compared to the baseline. Indeed, examples in the literature on directed forgetting can be found in which the term inhibition is used exactly in this atheoretical way to describe the pattern of empirical results. An example of this approach can be found in the article by Basden, Basden, and Wright (2003) in which the authors state: "Although some researchers may use the term 'retrieval inhibition' to imply a particular mechanism, we, along with many others, use it in a theoretically neutral sense" (p. 355). Also according to the third point any mechanism responsible for these effects can be called inhibitory as both of these tasks include resolving interference from distracters already stored in memory. However, in the present thesis (except for the present chapter) the term inhibition will be used to refer to a postulated specific mechanism by which parts of representations stored in long-term memory and responsible for interference are inhibited. This mechanism could account for the pattern of costs of list-method directed forgetting and retrieval-induced forgetting. All other accounts of these effects that do not postulate changes to already stored memory representations that are responsible for interference will be called non-inhibitory.

It is worth noting, however, that the third formulation of the term inhibition can also be relevant to the present work. Analyzing situations in which interference from distracters needs to be resolved in service of on-going cognitive activity allows for formulating clear definitions of particular inhibitory mechanisms. By looking at frameworks that use the common term 'inhibition' to refer to many different psychological mechanisms, one can try to point to differences between particular mechanisms that are described with this common term. This enterprise is necessary

to avoid wrongful applications of the results of the experiments reported in the present work. These results are meant to speak of particular inhibitory mechanisms described for list-method directed forgetting and retrieval practice paradigms and are not necessarily relevant to inhibitory mechanisms operating in different situations. Description of differences between various inhibitory mechanisms should help to avoid such misunderstandings.

## **1.2 Inhibitory mechanisms**

The present effort to describe specific inhibitory mechanisms postulated in the literature will be achieved by scrutinizing situations in which interference needs to be resolved and by describing how active processes of inhibition may be responsible for this resolution. The obvious feature of the conceptual frameworks developed within the third approach to inhibition (see previous section) is that they describe the variety of manifestations or functions of inhibition. This follows directly from the fact that interference from distracters occurs in a variety of situations and, more importantly, at different levels of the cognitive system. Specifically, several classifications of inhibitory processes understood as interference resolution have been proposed. Nigg (2000) proposed that inhibitory functions can be divided into: (a) interference control which is triggered by stimulus competition; (b) cognitive inhibition triggered by irrelevant information in working memory; (c) behavioural inhibition triggered by competing responses and (d) oculomotor inhibition. Focusing on the first three functions described by Nigg, it could be argued that inhibition can occur early in perception, later at the stage of processing of information gathered in working memory or, finally, at the final stage of processing when a response has to be given (see also Friedman & Miyake, 2004).

A similar approach has been developed in the work by Hasher and her colleagues (Hasher, Zacks, & May, 1999; Hasher & Zacks, 1988; Lustig et al., 2007) who proposed that inhibition can serve the functions of (a) limiting access of irrelevant information to the resources of a cognitive system; (b) deleting irrelevant information that is already present in a cognitive system and (c) restraining prepotent candidates for responses. Again, this classification evokes the steps of

information processing, from encoding to emitting a response. The present thesis is concerned with inhibition in the memory system and thus the main focus is on the intermediate level of inhibitory functions, as described in the classifications discussed above. The interference resolution at the early stage of information processing is predominantly the target of scrutiny of perception studies and the interference resolution at the latest stage is addressed in the literature on motor performance. However, some aspects of those functions are addressed also in the literature on memory, as will be described later in the sections on item-method directed forgetting and think/no-think paradigms.

To focus on the intermediate level of information processing means to examine what has been referred to in the literature as cognitive inhibition (Nigg, 2000; Bjork, 1989). More specifically, this stage is concerned with controlling the contents of working memory. One way to control these contents is to remove distracters that are already present in working memory. This is a function of cognitive inhibition described in both the frameworks proposed by Nigg (2000) and Hasher and Zacks (1988). However, the second way to control these contents is to restrict access to working memory. Again, both frameworks mention such a function but they relate it to resolving interference which is perceptual in nature. As pointed out by Anderson and Spellman (1995), this does not have to be the case. These authors indicated that competition for access to working memory may come not only from the external environment but also from information already stored in long-term memory. Thus, inhibitory mechanisms can be recruited to act on information already present in working memory and information stored in long-term memory that competes for access to working memory. Both of these classes of processes can be referred to as memory inhibition, although they do differ in respect to the memory store they primarily operate on.

### **1.3 Memory inhibition: research paradigms**

In the following section of this chapter an overview of research paradigms in which memory inhibition has been postulated to play a prominent role is presented together with the characterization of different specific inhibitory mechanisms in the



human memory system and the most important pieces of evidence that speak to the presence of such inhibitory mechanisms. This overview is built around the distinction described above between the inhibitory processes working to remove information from working memory and the inhibitory processes working to restrict access to working memory for irrelevant information stored in long-term memory. As will be described in this chapter, this distinction is important for defining what memory inhibition is and what criteria should be used to reveal the contribution of inhibitory mechanisms. Importantly, this overview does not aim at describing in detail the results obtained in various paradigms but merely at presenting a variety of implementations of the concept of memory inhibition. Thus, non-inhibitory mechanisms that have been also postulated to play a role in these paradigms are described only when they are important for understanding inhibitory mechanisms.

### 1.3.1 Procedures used to investigate inhibition in working memory

#### 1.3.1.1 *item-method directed forgetting*

In the item-method directed forgetting paradigm participants are presented with a list of items, usually words (Bjork, 1970) but sometimes a series of non-verbal items (Hourihan, Ozubko, & MacLeod, 2009) or pictures (Quinlan, Taylor, & Fawcett, 2010). After presentation of each item a cue is presented which instructs participants if they should commit this item to memory or to try to forget it. Although participants are told that to-be-forgotten items will not be later tested, this promise is not fulfilled and in fact participants are tested later on both to-be-remembered and to-be-forgotten items. The usual finding from this procedure is that to-be-forgotten items are remembered worse than to-be-remembered items (see C. M. MacLeod, 1998 for a review).

The most prominent account of forgetting in the item-method directed forgetting paradigm is selective rehearsal (Bjork & Woodward, 1973). According to this hypothesis, participants presented with an item transfer it to working memory and await a subsequent cue. If the cue is to remember the item, they try to commit it to memory by employing elaborative rehearsal. However, if the cue is to forget the item, they stop rehearsing it. This selective rehearsal of to-be-remembered

items results in enhanced memory for them, compared to to-be-forgotten items. The main finding that supports the selective rehearsal account of item-method directed forgetting is that the effect occurs for both free recall and recognition, which suggests that the effect stems from encoding rather than retrieval factors (Basden, Basden, & Gargano, 1993).

Importantly, in the item-method directed forgetting paradigm to-be-forgotten items can be viewed as distracters that interfere with committing to memory to-be-remembered items. According to the selective rehearsal account, when rehearsal of to-be-forgotten items is stopped additional time can be devoted to rehearsal of to-be-remembered items. Indeed, a study on item-method directed forgetting conducted by Basden and Basden (1996) demonstrated the benefits of forgetting a subset of studied items for performance for the remaining to-be-remembered items. Thus, stopping rehearsal of to-be-forgotten items can be seen as one of the instances of interference resolution. However, the important point for the present considerations is whether an additional active inhibitory mechanism is necessary to account for the effects described here.

The inhibitory mechanism that is postulated for item-method directed forgetting is not in contradiction with the selective rehearsal account. It supplements it by considering the processes that enable selective rehearsal. Specifically, inhibitory processes have been postulated to be responsible for removal of to-be-forgotten items from working memory. The focus here is on the effects of “forget” instructions. A non-inhibitory account postulates simply that once a “forget” instruction is presented the preceding to-be-forgotten item is no longer refreshed which results in the decay of its representation in working memory or its overwriting by subsequently presented words (Bjork, 1972; C. M. MacLeod, 1999; Johnson, 1994). An inhibitory account postulates that in order to stop rehearsal of a to-be-forgotten item an active process needs to be recruited to discard this item from working memory (Geiselman & Bagheri, 1985).

The evidence for active discarding of to-be-forgotten words in item-method directed forgetting comes from both behavioural and neuropsychological investigations. Hourihan and Taylor (2006) demonstrated that successful forgetting in this paradigm crucially depends on the timing of a “forget” instruction.

Specifically, in their study (Experiment 2) forgetting of individual words was successful when an item-to-instruction delay was short (1 s) and was reduced or eliminated with longer delays (3 or 6 s). The authors argue that this result parallels the effects obtained with a stop-signal procedure in which participants are asked to stop a prepotent response (Logan, 1983). Thus, these results may indicate that a default mode of stimulus processing in working memory results in committing this item to long-term memory and an active process of inhibition can disrupt this default mode but only if it is recruited relatively quickly, before transferring of a given item to the long-term memory store is completed. This hypothesis is strengthened by a related study investigating item-method directed forgetting with the method of event-related potentials (ERPs). In the study by Paz-Caballero, Menor and Jiménez (2004) it has been demonstrated that yielding to an instruction to forget a certain item results in a rapid recruitment of frontal neural networks that are commonly associated with overriding prepotent responses (e.g. Shimamura, 1995). Thus, together, these findings suggest that forgetting in item-method directed forgetting is an active process.

Item-method directed forgetting has also been a focus of interest for research conducted within the inhibitory framework of cognitive aging (Hasher & Zacks, 1988). Specifically, Zacks, Radvansky and Hasher (1996) noted that if performance in this task depends on active discarding of information already present in working memory, then this process can be impaired in older participants suffering from a decline in effectiveness of inhibitory processes. Indeed, in their experiments Zacks et al. demonstrated that older adults were less successful in forgetting words in the item-method directed forgetting task which the authors interpreted as support for the inhibitory account of this effect.

The results briefly reported here strongly suggest that there is more to item-method directed forgetting than just letting to-be-forgotten items fade from working memory due to passive processes of decay or interference. Thus, if inhibition is defined as an active process of dealing with interference, then processes involved in dropping to-be-forgotten items from working memory in item-method directed forgetting can be termed inhibitory. Importantly, this formulation of inhibition puts stress on the process of stopping the cognitive

process of encoding of a certain item in long-term memory but it does not postulate inhibition of any type of representation of to-be-forgotten words that would already be stored in long-term memory. The main point is here that inhibition operates before to-be-forgotten words are fully committed to long-term memory. The function of inhibition in this formulation is to preclude the establishment of a certain memory representation rather than inhibiting one that is already established.

### *1.3.1.2 garden-path sentences*

In the garden-path sentences paradigm (Hartman & Hasher, 1991; May, Hasher, Zacks, & Multhaup, 1999) participants are first presented with a list of sentences from which the final words have been deleted. The sentences are predictive of the final deleted words so that the majority of participants produce the same word as an appropriate ending for each sentence. In one study phase participants are asked to generate an ending to each sentence. Following generation, participants are presented with experimenter-defined endings. Importantly, for critical sentences the experimenter-defined endings differ from the endings predicted by garden-path sentences. Participants are asked to remember only the endings provided to them by the experimenter and to ignore the endings that they generated themselves. In a test phase of this procedure participants are presented with a new set of stem sentences with deleted endings but this time the sentences are only moderately predictive of the endings. Importantly, some sentences can be completed with the endings generated by participants but disconfirmed by the experimenter, other sentences can be completed by experimenter-defined endings and yet other sentences that serve as a baseline condition can only be sensibly completed with novel endings. The focus of the procedure is on the number of sentences completed with previously disconfirmed endings and endings provided by the experimenter compared to the baseline level for novel endings.

The garden-path sentences paradigm has been used extensively to examine the predictions formulated within the inhibitory framework of cognitive aging (Hasher & Zacks, 1988). The paradigm was first introduced in a study by Hartman

and Hasher (1991), who used it to examine differences between young and older adults in their ability to discard self-generated endings disconfirmed by the experimenter. The authors have demonstrated that younger adults successfully restrict processing of the disconfirmed endings so that these endings are later produced as endings to a new set of sentences at the same rate as the baseline. Thus, for younger adults the disconfirmed endings behaved no differently from the endings that have never been presented in the experiment. This contrasted with the experimenter-defined endings that were provided at the test more often than the baseline endings. Importantly, the pattern of results was quite different for older adults who showed above-baseline and comparable completion rates for both the disconfirmed and the experimenter-defined endings. Thus, older adults were less able to restrict the processing of the disconfirmed endings.

Hartman and Hasher (1991) argued that restricting processing of the disconfirmed endings in the garden-path sentences paradigm requires the recruitment of an inhibitory process that is responsible for deleting the self-generated endings from working memory. They argued that processing the disconfirmed endings interferes with committing to memory the experimenter-defined endings that participants are instructed to remember. Thus, an inhibitory process needs to be recruited to stop processing these disconfirmed endings by deleting them from working memory. Thus again, the inhibitory process is engaged to resolve interference during encoding.

Support for the inhibitory mechanism in the garden-path sentences paradigm comes from a study by May and Hasher (1998). In this study the standard garden-path sentences paradigm was administered to both young and older adults. Importantly, an additional factor of time of testing was included in the design. May and Hasher built on the findings that people differ in their circadian cycles in a systematic way so that executive processes of young adults are more effective in the afternoons as opposed to older adults for whom executive processes are more effective in the mornings. May and Hasher administered their procedure to young and older adults at different times of day predicting that inhibitory effects would be enhanced when testing took place in the optimal part of day for each group of participants and would be impaired in the suboptimal parts of day. The results

reported in this study supported these predictions. Specifically, younger adults showed below-baseline performance for the disconfirmed endings and above baseline performance for the experimenter-defined endings when tested in the optimal part of day (in the afternoon) whereas performance was above baseline for both types of endings in the suboptimal part of day (in the morning). In contrast, older adults' performance for both types of endings was above baseline when tested in the optimal part of day (in the morning). When tested in the suboptimal part of day, older adults demonstrated above-baseline priming only for the disconfirmed endings and no priming for the experimenter-defined endings that they were actually instructed to remember.

Two main findings from the study by May and Hasher (1998) support the inhibitory account of the results obtained in the garden-path sentences paradigm. Firstly, the fact that older adults compared to younger adults showed systematically stronger priming of the disconfirmed endings fits well with the framework of impaired inhibitory mechanisms of older adults. It suggests that the disconfirmed endings are not simply dropped from further processing, an operation with which older adults should have no difficulties, but instead are actively removed from working memory once an experimenter-defined ending is provided. Secondly, and more importantly for the present purpose, the finding of below-baseline negative priming of the disconfirmed endings produced by young adults in their optimal time of testing implicates an inhibitory mechanism. The fact that young adults in a final test produced the self-generated and later disconfirmed endings at a lower rate than the novel endings never presented in the experimental procedure suggests that disconfirming certain endings triggered active processes and speaks against the hypothesis that the disconfirmed endings were simply not processed further after disconfirming.

It may seem that disconfirming a self-generated item serves a similar function as an instruction to forget an item in item-method directed forgetting. This function is to delete an item from working memory so that it would not be processed further. The inhibitory mechanism is triggered when new information is presented for encoding and serves the function of facilitating encoding by resolving interference from information that is no longer necessary for successful

performance in the task (to-be-forgotten items or disconfirmed endings). However, despite similarities, at least one important difference between results obtained with these two paradigms exists. Specifically, the aforementioned finding of below-baseline performance in the garden-path sentences paradigm (May & Hasher, 1998) has not been reported in the literature on item-method directed forgetting. Studies examining priming of to-be-forgotten items reported significant priming for to-be-forgotten items (Paller, 1990; Basden et al., 1993), although sometimes of a smaller magnitude than priming for to-be-remembered items (C. M. MacLeod, 1989). This significant priming for item-method directed forgetting suggests that certain information pertaining to the to-be-forgotten items is stored even when they are actively removed from working memory. In contrast, below-baseline priming in the garden-path sentences paradigm suggests that removing items from working memory not only precludes storing information related to this item in memory but also dampens the activation of already established representations that are related to this item, like the semantic or phonological record of a given word.

This discrepancy is an important one for the description of inhibitory mechanisms. As it will be presented in the section on inhibition in long-term memory, the below-baseline forgetting constitutes a borderline condition between inhibition understood merely as removing distracters from working memory and inhibition understood as a mechanism of shaping contents of a long-term memory store. The main focus of the garden-path sentences paradigm remains, however, on the contents of working memory. The finding of long-term consequences of recruiting such inhibitory processes is used as support for the inhibitory account but is not the main area of importance. Because of this balance of interest, the garden-path sentences procedure is described in the section on procedures oriented towards working memory. However, it is worth pointing out here that the procedures described in the subsequent parts of the present chapter take long-term consequences of inhibitory processes as the main target of inquiry.

### 1.3.2 Procedures used to investigate inhibition in long-term memory

#### 1.3.2.1 *the think/no-think task*

The think/no-think (TNT) task has been first described in a study by Anderson and Green (2001). In this task participants are asked to learn a list of cue – target pairs of weakly related or unrelated words. In the main phase of the experiment participants are presented with some of the cues in two different conditions. In the Think condition participants are asked to retrieve (covertly) a target associated with a given cue from the study phase. In the crucial No-Think condition participants are asked not to think of a target associated with a given cue. Each cue included in this phase is presented repeatedly in the same condition, sometimes for up to 20 presentations. The cues and their targets not presented in this phase serve as a baseline for comparison for pairs from the Think and No-Think conditions. Finally, a memory test is given in which participants are asked to recall targets for all cues.

The common finding from the TNT task is that performance in a final test for the Think condition is better than baseline whereas performance for the No-Think condition is actually worse than baseline (Anderson & Green, 2001; see Levy & Anderson, 2008, for a review). An inhibitory account of this effect postulates that during the TNT phase of the procedure participants develop a default mode of retrieval of appropriate targets from a long-term memory store when their cues are presented. This default mode is established because for at least half of the cues (and more in some variants of this task) in the Think condition participants are actually asked to provide a target thus making retrieval a prepotent response. In this situation an active inhibitory process needs to be recruited to stop retrieval of a given target for a cue assigned to the No-Think condition.

There are several details that differentiate the TNT task from the procedures of item-method directed forgetting and the garden-path sentences described above. Firstly, in the TNT task inhibition is not recruited to resolve interference which makes it slightly atypical against the background of all procedures described in the present chapter. Although it could be argued that to-be-inhibited targets from the No-Think condition interfere with the goal-oriented activity of not retrieving targets, this conceptualization is rather stretched and does not correspond in an obvious way to a situation in which to-be-forgotten items clearly interfere with a well-specified aim of committing to memory alternative to-be-remembered items or experimenter-defined endings, as in the procedures



described above, or with the retrieval of specified information, as in the retrieval practice paradigm described later.

Secondly, and more importantly for the present purpose, the TNT procedure is built around the assumption that inhibition needs to be recruited not only to remove items already present in working memory but also to stop retrieval of items that are stored in long-term memory. Thus, this procedure describes how inhibition operating in long-term memory is responsible for decreasing accessibility of items that should not access working memory. How can an active process of inhibition achieve such an aim? Describing this problem requires adopting assumptions about the nature of memory traces contained in a long-term memory store.

Memory models assume that the representations in memory consist of semantic representations of concepts linked by episodic associations (e.g. Norman & O'Reilly, 2003). Thus, a pair of items studied in the TNT paradigm can be schematically described as two separate semantic representations corresponding to semantically unrelated cue and target items linked by an episodic association created in the study phase. In the test phase a cue is presented that can trigger activation of the target with the help of an episodic link. When inhibition is recruited to preclude access to the semantic representation of a target, it can work in two ways. It can either reduce the amount of activation received by semantic representation of a target by an episodic link or it can change the threshold of activation that is necessary for a semantic representation of a target to be retrieved into working memory. Both of these conceptualizations of inhibition have been proposed. The former one is proposed by models that postulate inhibition operating in episodic memory (Racsmány & Conway, 2006; Norman, Newman, & Detre, 2007) and the latter one is referred to as the pattern-suppression model (Anderson & Spellman, 1995). The specifics of these ideas will be described in detail in the chapters devoted to the list-method directed forgetting paradigm and the retrieval practice paradigm. For the current purpose it is important to notice that both of these accounts postulate a lasting effect of inhibition on the strength of an episodic link or threshold of activation for semantic representations.

The lasting effects of recruiting inhibitory processes for representations stored in long-term memory determine the focus of the TNT procedure on the

effect of below-baseline forgetting, as assessed in the final test. However, it is worth noticing that such a long-term working of inhibition is not indispensable for the process of controlling the contents of working memory. It would be entirely conceivable that inhibition works for very brief periods of time by dynamically controlling episodic links and activation of semantic representations and thus gating access to working memory without leaving long-lasting marks on the contents of a long-term memory store. For the TNT task it would mean that inhibition could stop retrieval of to-be-suppressed targets but would not cause below-baseline forgetting in a subsequent test. Indeed, several failures to replicate below-baseline forgetting in the TNT task encouraged some researchers to investigate such fleeting inhibitory processes which are much alike inhibitory processes described for the item-method directed forgetting and the garden-path sentences paradigms in their function of controlling the contents of working memory (Bergström, de Fockert, & Richardson-Klavehn, 2009a; Mecklinger, Parra, & Waldhauser, 2009).

The episodic inhibition and the pattern-suppression models differ from the previously described conceptualizations of inhibition in their stressing of long-term consequences of recruiting inhibition. These models describe a dual function of inhibitory mechanisms. Firstly, they, like the conceptualizations described before, propose that inhibition controls the contents of working memory. Secondly, however, they also postulate that inhibition controls the contents of long-term memory and determines which information will be accessed in the future. The timescale of long-term consequences of recruiting inhibition is a matter for further debate. Sometimes it is assumed that inhibition is fleeting and release from inhibition occurs spontaneously with the passage of time (M. D. MacLeod & Macrae, 2001; Saunders & MacLeod, 2002). Sometimes it is assumed that inhibition has a permanent effect on information stored in long-term memory (Racsmány & Conway, 2006). Occasionally, some additional mechanisms are postulated to modulate the effects of inhibition over longer timescales, like neural processes that consolidate memory during sleep (Racsmány, Conway, & Demeter, 2010; Baran, Wilson, & Spencer, 2010). However, all of these approaches assume that inhibition that operates in long-term memory has consequences that can be detected as a pattern of forgetting after the episode of interference during which inhibition was

recruited is over. Thus, in this perspective inhibition serves both short-term and long-term functions in the human memory system.

Although both episodic inhibition and pattern-suppression models agree in describing a dual role of inhibition in long-term memory, they nevertheless differ substantially on the criteria they postulate need to be met to confirm the contribution of inhibitory mechanisms to memory performance. The episodic inhibition account postulates that inhibition serves to disrupt (or temporarily suppress) an episodic link between cues and to-be-suppressed targets in the TNT procedure. Thus, this account predicts below-baseline forgetting when the same cue is used to suppress targets in the TNT phase and to retrieve them in a final test. In contrast, the pattern-suppression model assumes that inhibition circumvents the level of episodic links and instead exerts its influence directly at the level of semantic representation of a to-be-suppressed target. Thus, this account predicts impairment in memory for to-be-suppressed targets that is independent of cues that can be used to access these targets. Indeed, studies using semantic associates of to-be-suppressed and baseline targets that were not included in the study or TNT phases (so called *independent cues*) revealed that impairment of memory for to-be-suppressed targets is general and not limited to the original cues (Anderson & Green, 2001; Anderson, Ochsner, Kuhl Cooper, Robertson, Gabrieli, Glover, & Gabrieli, 2004; Bergström, de Fockert, & Richardson-Klavehn, 2009b; Murray, Muscatell, & Kensinger, 2011), although this effect has not always been replicated (Bulevich, Roediger, Balota, & Butler, 2006). Thus, even though episodic inhibition models and the pattern-suppression framework are both meant to describe inhibitory mechanisms in long-term memory they differ in how they define inhibition and thus they differ in both criteria for detecting the operations of inhibitory mechanisms and predictions for experimental tasks like the TNT paradigm.

### 1.3.2.2 *list-method directed forgetting*

The list-method directed forgetting paradigm is a procedure in which participants are asked to forget information that has been presented to them, much like in the already described item-method directed forgetting paradigm. The

difference between these paradigms lies in the fact that whereas in the item-method variant participants are cued to forget individual words, in the list-method variant participants are cued to forget the whole list of presented words. Although initially both paradigms were discussed together, an important paper by Basden et al. (1993) pointed out that these procedures produce different results and thus different mechanisms may be at play when they are employed. Since then a consensus emerged according to which intentional forgetting results from the workings of different mechanisms in these two paradigms.

In the list-method directed forgetting paradigm participants are presented with two lists of words that they are instructed to memorize. In a forget condition after presentation of the first list participants are asked to forget it and focus their attention and resources on learning the second list. In a remember condition participants are asked to keep the first list in memory for the future test and also learn the second list. A common result obtained with this procedure is a cross-over interaction between conditions and lists. Specifically, memory for the first of the two presented lists is worse in the forget condition than in the remember condition but at the same time memory for the second list is better in the forget condition than in the remember condition. The impoverished memory for the first list due to provision of a forget instruction is referred to as costs of directed forgetting, whereas the improved memory for the second list is referred to as benefits of directed forgetting. The crucial difference between the list-method and item-method directed forgetting paradigms is that in the former participants are asked to forget a whole list of items already committed to long-term memory whereas in the latter participants are asked to forget individual, just-presented items that are present in working memory but not yet in a long-term memory store.

Initially, selective rehearsal of to-be-remembered items was endorsed as a common mechanism of forgetting in both item-method and list-method directed forgetting (Bjork, 1972). However, one important finding directed researchers' attention towards an inhibitory mechanism of list-method directed forgetting. Specifically, Geiselman, Bjork, and Fishman (1983) discovered that directed forgetting effects are obtained even when items from a to-be-forgotten lists are

studied with an incidental learning strategy. The selective rehearsal account would not predict directed forgetting effects in an incidental learning task as under such conditions participants are unlikely to rehearse any words. Geiselman et al. argued that retrieval inhibition of all words from the to-be-forgotten list is a mechanism that is able to account for directed forgetting effects under both incidental and intentional learning instructions.

Since the study by Geiselman et al. (1983) inhibition gained popularity as an explanation of the effects obtained in the list-method directed forgetting paradigm. Bjork (1989) proposed a first formulation of the postulated inhibitory mechanism. According to this formulation, an inhibitory process in the list-method directed forgetting is triggered to facilitate learning of the second list that follows the provision of a forget instruction. Thus, in this account costs and benefits of directed forgetting are tightly linked as forgetting of the to-be-forgotten list (costs) serves the purpose of enhancing memory for words from the to-be-remembered list (benefits). From this perspective words from a to-be-forgotten list serve as distracters that cause interference during encoding of a second list and an inhibitory process needs to be recruited to resolve this interference. Importantly, interference does not stem from the fact that words from a to-be-forgotten list are present in working memory due to their recent presentation. In contrast to item-method directed forgetting (and the garden-path sentences paradigm), words from a to-be-forgotten list do not occupy working memory by default. They can, however, gain access to working memory if learning of a second list of words is accompanied by covert retrieval of the words from a first list. Thus, the function of inhibition in list-method directed forgetting is not to remove items already present in working memory, but to deny access to working memory for items that are stored in long-term memory.

The inhibitory hypothesis of a mechanism of list-method directed forgetting is supported by several findings. Firstly, the studies show that costs of directed forgetting do not emerge if there is no new learning after the forget instruction (Pastötter & Bäuml, 2007), which suggests that items from a to-be-forgotten list are inhibited in service of new learning. Secondly, list-method directed forgetting costs

emerge in free recall tests but not in recognition tests (e.g. Basden et al., 1993; Benjamin, 2006; C. M. MacLeod, 1999), which suggests that directed forgetting impedes access to items from a to-be-forgotten list given self-generated cues but does not affect the strength of the representations of individual items. This dissociation could be accounted for by an inhibitory account which would postulate that the function of inhibition is to limit access to interfering to-be-forgotten items but not to wipe them out from memory entirely. The episodic inhibition described above postulates that inhibition disrupts episodic links for words from a to-be-forgotten list which is congruent with such a conceptualization of inhibition. Thirdly, also a more detailed analysis of recognition performance has been taken to support an inhibitory account of costs in list-method directed forgetting. Specifically, several lines of investigation have demonstrated that the instruction to forget impedes recollection of to-be-forgotten items but not their familiarity (Bjork & Bjork, 2003; Racsmány, Conway, Garab, & Nagymáté, 2008). Because recollection is assumed to be a cue-dependent process akin to recall while familiarity is thought to tap directly the strength of memory traces of individual items (e.g. Diana, Reder, Arndt, & Park, 2006), this dissociation parallels dissociation between recall and recognition.

The focus of the list-method directed forgetting paradigm is on the long-term consequences of recruiting inhibitory mechanisms. Thus, just as it is for the TNT paradigm, the most interesting finding in this task is below-baseline forgetting in which memory for to-be-forgotten words from the first list in a forget condition is impaired compared to the baseline of words from the first list in a remember condition. Thus, in this task inhibition again serves not only the purpose of limiting interference from no longer relevant information but also the purpose of shaping the contents of a long-term memory store by decreasing accessibility of items from a to-be-forgotten list in the long run.

However, there are also noticeable differences between this task and the TNT procedure. It is important to stress that in list-method directed forgetting the idea of covert retrieval stopped by an inhibitory mechanism is a post-hoc explanation for the observed pattern of forgetting in a final test and not a direct consequence of how the procedure is structured. Whereas the TNT task is intentionally designed to

make retrieval of to-be-suppressed items a prepotent response that needs to be circumvented with the help of an inhibitory mechanism, list-method directed forgetting is not designed to maximize interference from items included in a to-be-forgotten list. In the TNT task even the lack of below-baseline forgetting can be taken as evidence of the inhibitory stopping of retrieval, as long as performance for to-be-suppressed items is below the level of targets in the Think condition. Such a pattern of results may be taken to indicate that the stopping of retrieval of targets from the No-Think condition was successful, implicating inhibitory functions that control the contents of working memory. In contrast, in the list-method directed forgetting a lack of below-baseline forgetting is always taken as evidence of lack of operations of inhibitory mechanisms. Thus, the list-method directed forgetting paradigm is tuned exclusively to detect the long-lasting consequences of recruiting inhibitory mechanisms.

### *1.3.2.3 the retrieval practice paradigm*

The retrieval practice paradigm is a paradigm that from its conception serves to investigate the inhibitory processes in memory (Anderson, Bjork, & Bjork, 1994). In this task participants are usually presented with pairs of categorized words in which a category label serves as a cue and an instance of a category serves as a target. In a retrieval practice phase that follows the study, participants are presented with half of the cues from half of the studied categories together with the first two letters of their corresponding targets. The participants' task is to retrieve appropriate targets. The retrieval practice phase divides studied targets into three categories: practiced targets (Rp+), unpracticed targets from practiced categories (Rp-) and targets from unpracticed categories (Nrp). Finally, after a distracter phase participants' memory for all targets is tested. A common finding from this paradigm is that Rp+ items are recalled at a higher level than a baseline of Nrp items. The main effect of interest is, however, that Rp- items are recalled at a lower level than a baseline of Nrp items. This latter effect is referred to as retrieval-induced forgetting (RIF) as the impairment of memory of Rp- items is caused by the retrieval of related Rp+ items in the retrieval practice phase of the procedure.

The retrieval practice paradigm is widely used to investigate inhibitory processes in memory (see Verde, 2012, and Levy & Anderson, 2008, for recent reviews). Inhibitory accounts of RIF postulate that during the retrieval practice phase of the procedure access to to-be-retrieved Rp+ items can be impeded by interference from related Rp- items. To overcome this interference and to deny Rp- items access to working memory an inhibitory process is recruited. However, the fact that Rp- items are denied access to working memory is not enough to explain below-baseline forgetting for these items in a final test. For this reason, inhibitory accounts of RIF postulate that denying access to working memory has long-lasting consequences for memory representations of Rp- items. Two main implementations of the idea of memory inhibition that have been proposed are again the aforementioned episodic inhibition and pattern-suppression. Firstly, the idea of episodic inhibition (Racsmány & Conway, 2006) suggests that inhibition may disrupt associative links between Rp- items and their category cues which results in impaired memory when these cues are used to access Rp- items at test. Secondly, an idea of pattern-suppression suggests that in a retrieval practice paradigm activation of a stored representation of Rp- items becomes dampened and this effect persists for some time making Rp- items difficult to retrieve independently of cues used to access it (Anderson & Spellman, 1995).

Numerous findings from the literature support the inhibitory accounts of RIF. Two most important pieces of evidence come from studies employing independent cues and studies manipulating the amount of interference in the retrieval practice phase. Firstly, several studies have found that the RIF effect generalizes beyond the cues used in the retrieval practice phase which suggests that the effect can be best described as an inhibition of memory representation (e.g. Anderson & Spellman, 1995; Anderson, Green, & McCulloch, 2000; Camp, Pecher, & Schmidt, 2005). This cue-independent nature of RIF parallels similar findings obtained for the TNT task. Secondly, studies have documented that the RIF effect depends crucially on how much Rp- items compete during retrieval of Rp+ items. Specifically, a study by Anderson et al. (1994) has demonstrated that RIF occurs only for Rp- items of high



taxonomic frequency that are assumed to be easily activated by category labels that serve as cues in the retrieval practice phase.

Although inhibitory mechanisms postulated to account for RIF are based on the dynamics of the retrieval practice phase, the focus of the procedure is very much on long-term memory consequences of recruiting an inhibitory mechanism, just as for list-method directed forgetting and the TNT task. What brings the retrieval practice paradigm closer to list-method directed forgetting is the fact that competition for access during the retrieval practice phase is again rather a post-hoc assumption than something that is strongly imposed by the structure of the task. The way Rp+ items are commonly cued in the retrieval practice phase (with individual two-letter stems of to-be-practiced items) does not make retrieval of Rp- items a prepotent response in any obvious way. Thus, if no below-baseline forgetting occurred in this procedure, then there would be no evidence that Rp- items even competed in the retrieval practice phase and consequently there would be no need to postulate inhibitory mechanisms defined as stopping retrieval without consequences for long-term memory.

However, significant differences between list-method directed forgetting and retrieval practice paradigms exist. Firstly, in the retrieval practice paradigm interference has to be resolved during retrieval of Rp+ items whereas in list-method directed forgetting interference has to be resolved during encoding of new items that follows presentation of to-be-forgotten items. Although it has been argued that inhibition in directed forgetting is triggered due to an expectation of interference in a final test (Conway, Harries, Noyes, Racsmany, & Frankish, 2000), it remains the case that in this paradigm, unlike the retrieval practice paradigm, inhibition needs to be recruited before explicit retrieval takes place because during explicit retrieval items from a to-be-forgotten list are also to be retrieved and thus cannot be treated as distracters. Secondly, in the list-method directed forgetting paradigm participants are explicitly instructed to forget certain information and thus the recruitment of the postulated inhibitory mechanism is explicitly required by the task. In the retrieval practice paradigm there is no mention of Rp- items

during retrieval of Rp+ items and thus any inhibitory mechanism recruited against the former is not explicitly required by the task.

These differences may lie at the foundations of the different empirical results obtained with these two procedures. The most important of these differences is that the costs of list-method directed forgetting are usually not found in recognition (e.g. Basden et al., 1993) whereas RIF has been documented with recognition tests (e.g. Hicks & Starns, 2004; Sptizer & Bäuml, 2007). This discrepancy is likely the main reason why only one of the inhibitory mechanisms postulated to operate in long-term memory, namely episodic inhibition, is examined in the context list-method directed forgetting, whereas both episodic inhibition and pattern-suppression are researched within the retrieval practice paradigm. The studies presented in the current work will assess both inhibitory mechanism operating in semantic and episodic memory with the help of these two different tasks.

#### **1.4 Summary**

The brief overview of the main procedures used to investigate memory inhibition presented above serves to exemplify various ways which have been used to describe this concept in various theoretical frameworks. What is memory inhibition then? All formulations of this concept seem to agree that it is an active process directed against a certain subset of information that would otherwise interfere with a goal-oriented activity. Because memory inhibition is studied with memory tasks, it comes as no surprise that this goal-oriented activity is commonly operationalized as memory-related and can include either encoding of more relevant information, for example to-be-remembered items in both item-method and list-method directed forgetting or experimenter-defined endings in the garden-path sentences paradigm, or retrieval of more relevant information, for example Rp+ items in the retrieval practice paradigm.

The main issue that differs from one formulation of memory inhibition to the other is what becomes inhibited. Firstly, there are frameworks developed predominantly to describe inhibition at the level of working memory. These frameworks propose that inhibition is an active stopping of the processing of

interfering information. Whenever interfering information is already present in working memory or is on the verge of getting access to it, an inhibitory mechanism needs to be recruited to remove this information or deny it access to the stream of current processing, thus resolving interference. This approach does not need to postulate any additional long-term memory effects of inhibition, beyond the fact that stopping the processing of a certain item precludes establishing a representation of this item or at least leads to its impoverishment. Thus, although this kind of inhibition is assessed by long-term memory tests, the fact that performance for information against which inhibition was recruited is below the level of performance for relevant information is sometimes deemed sufficient to support an inhibitory account. This level of performance for interfering information can be also referred to a certain baseline performance for information that was either not presented at all during the experiment (as in the case of the garden-path sentences paradigm) or was not competing for access to working memory (as in the case of baseline in the TNT paradigm) but this comparison is often not crucial for the case of inhibition.

Secondly, there are inhibitory frameworks which are focused on how inhibition shapes the contents of long-term memory. The starting point of these conceptualizations is similar to the ones described above as it focuses on working memory. However, these frameworks concentrate on interference from information that has been already stored in long-term memory and is not present in working memory during goal-oriented activity. Thus, interference from this information is rather potential than actual. Nevertheless, inhibitory processes are assumed to be recruited to counteract this potential interference. Importantly, these inhibitory processes leave their marks on the already established memory representations which are detectable in a later test. For these conceptualizations the fact that to-be-inhibited items are not facilitated compared to some baseline level or are not facilitated to the same extent as items that were not subjected to inhibition is not sufficient to support an inhibitory account. What is needed is to reveal that at least under certain circumstances recruiting inhibition leads to impairment for to-be-inhibited items (Rp- items in the retrieval practice paradigm

or to-be-forgotten items in list-method directed forgetting) against the baseline level of memory for items for which inhibition was not recruited (Nrp items or items from the first list in a remember condition).

The differences between these approaches are not trivial and determine how a certain pattern of results is interpreted. This can be easily seen in the example of the TNT task which in some of its aspects lies on the borderline of tasks used to investigate inhibition in working memory and long-term memory. In this task several patterns of results can be taken to reflect inhibition, depending on a theoretical approach to this term. Firstly, the finding of below-baseline forgetting of items from the No-Think condition is obviously interpreted as supportive of inhibitory accounts by proponents of inhibition in long-term memory. However, when the level of performance is equal between the No-Think and Baseline conditions, a proponent of inhibition in working memory could argue that an inhibitory mechanism was successfully recruited to limit the access of to-be-suppressed items to working memory, precluding the establishment of additional memory traces for these items. Furthermore, even when performance for the No-Think condition is actually above the performance for the Baseline condition but still below the level of performance for the Think condition, it could be argued that the inhibitory mechanism was successfully recruited on some of the suppression trials. Thus, in this particular task a contribution from an inhibitory mechanism can be derived from almost any pattern of results.

The current thesis is concerned with inhibition in long-term memory. Thus, it is important to stress that the studies described here have no bearing on the inhibitory mechanisms defined merely as stopping or precluding processing of certain items in working memory. The present experiments were concerned exclusively with whether there is a need to postulate inhibition in long-term memory to account for the results described in the literature and do not allow for the drawing of any conclusions about the processes occurring at the level of working memory. The retrieval practice paradigm and list-method directed forgetting were used in the reported experiments and the hypothesis of involvement of inhibitory processes in producing below-baseline forgetting was

assessed against the competing hypothesis attributing below-baseline forgetting to non-inhibitory mechanisms. Importantly, any conclusions from this work pertain only to inhibition defined as disrupting representations stored in long-term memory.

The other important conclusion from the overview of the literature on memory inhibition is that even adopting a long-term memory perspective on inhibition does not end the problem with defining this term. The question remains which part of the representation of an item becomes inhibited. As presented earlier, some accounts argue that a semantic (and sometimes phonological, see Bajo, Gómez-Ariza, Fernandez, & Marful, 2006) representation of an item itself can be inhibited which is directly observable by the fact that access to this item is impaired independently of the cues employed (Anderson & Spellman, 1995). In contrast, other accounts suggest that some associative links created during the study become disrupted by an inhibitory mechanism (Norman et al., 2007). Again, adopting these two different perspectives leads to different interpretations of certain patterns of results. Using again the TNT task as an example (the same reasoning can be also applied to the retrieval practice paradigm), the first approach would argue that the lack of below-baseline forgetting with independent cues refutes an inhibitory explanation whereas the second approach would argue that below-baseline forgetting with cues used in the main TNT phase is sufficient to warrant the conclusion that inhibitory mechanisms were involved.

In the present work a definition of inhibition will be adopted by which inhibition is a process that is recruited in service of resolving interference during encoding or retrieval and which accomplishes this goal by changing some parts of representations of distracters that are responsible for interference. No assumptions are made here about the specific locus of the effects inhibition has on long-term memory representations. Changes to semantic and episodic representations of distracters will both be treated as satisfying the definition of inhibitory effects. Indeed, in the present thesis both approaches to inhibition in long-term memory are assessed. The overarching aim of this work is thus to establish what part of memory representation is affected by inhibitory mechanisms. To accomplish this

goal both the retrieval practice paradigm and list-method directed forgetting have been used. The former procedure was specifically introduced to assess memory inhibition defined as changing the threshold of activation of semantic features constituting a to-be-inhibited interfering distracter (Anderson & Spellman, 1995). The latter procedure has long been used to examine the predictions of the episodic inhibition account (often referred to as retrieval inhibition) in which inhibition is defined as the disruption of episodic links established during the study. The experiments reported in this thesis partly keep to this division and assess these two proposed inhibitory mechanisms with their appropriate tasks, focusing first on the pattern-suppression model with the use of the retrieval practice paradigm (although some variants of episodic inhibition are also tested within this paradigm) and then on episodic inhibition with list-method directed forgetting.



## **2. Retrieval-induced forgetting**

### **2.1 Introduction**

One part of the present thesis is devoted to retrieval-induced forgetting (RIF) and the issue of cue-independence of this effect. Much of the discussion about inhibitory processes in memory that is present in the literature concentrates on RIF and its cue-independence. Several researchers postulated that cue-independence is the sole criterion that can reliably distinguish between contributions of inhibitory and non-inhibitory mechanisms of forgetting information already stored in long-term memory (e.g. Anderson & Spellman, 1995; Aslan, Bäuml, & Pastötter, 2007). RIF is an effect for which the property of cue-independence has been most commonly reported (e.g. Anderson & Spellman, 1995; Anderson, Green et al., 2000, but see Anderson & Green, 2001, and Aslan, Bäuml, & Grundgeiger, 2007, for evidence of cue-independence of forgetting in the TNT task and the part-set cueing paradigm, respectively) and hence it is also a target of scrutiny in the present thesis. In the empirical section on RIF the tests of cue-independence of this effect will be performed to establish what part of memory representations are affected by a postulated inhibitory process. Cue-independence will be assessed as the main prediction of the pattern-suppression model which places the locus of inhibitory effects at the level of semantic features. Also the episodic inhibition models which try to account for cue-independence in terms of disruption of episodic links will be examined, as well as the covert cueing hypothesis which tries to account for cue-independence in terms of interference models.

This chapter presents an overview of the research on RIF with the aim of describing studies that can help elucidate the nature of the mechanism responsible for this phenomenon. It contains a comprehensive discussion of all types of evidence for the involvement of inhibitory processes in producing RIF. The chapter provides an analysis of the inhibitory account and a competing non-inhibitory account that assigns RIF to the workings of the mechanism of interference. It ends with a detailed discussion of the issue of cue-independence of RIF that is subsequently pursued in the empirical chapter devoted to RIF.



Anderson et al. (1994) were the first researchers to systematically investigate the effects of partial retrieval on memory for the not retrieved subset of information (but see Blaxton & Neely, 1983, for earlier attempts). For this purpose they designed a method called a retrieval practice paradigm, which consists of four phases: a study phase, a retrieval practice phase, a filler phase and a test phase. Firstly, participants are presented with category labels together with category instances (e.g. GREEN – lettuce, WEAPON – sword). The study phase is immediately followed by a retrieval practice in which participants are presented with category labels together with two-letter stems of category instances (e.g. GREEN – le\_\_\_\_, WEAPON – sw\_\_\_\_) and asked to retrieve appropriate targets. Importantly, participants in this phase retrieve only half of the items from half of the categories. This retrieval practice results in target items being divided into three sets. There are practiced items from practiced categories (Rp+), unpracticed items from practiced categories (Rp-) and unpracticed items from unpracticed categories called control items (Nrp). The retrieval practice is followed by a filler activity and then a final test in which participants are given category labels and are asked to retrieve all the items that had been studied. Two common results from this paradigm are that, firstly, memory for Rp+ items is improved relatively to Nrp items and, secondly, memory for Rp- items is impaired relatively to Nrp items. This latter effect is termed RIF and it constitutes a proof that retrieval can have a detrimental effect on memory for the not retrieved subset of information stored in memory.

Although RIF is usually investigated with this simple laboratory-based paradigm employing schematic materials of categorized lists of words, it has been also shown to be a phenomenon of wide prevalence outside the laboratory. RIF has been shown to play a variety of roles in outside-laboratory contexts, including educational settings (Carroll, Campbell-Ratcliffe, Murnane, & Perfect, 2007), eyewitness memory (e.g. M. D. MacLeod, 2002; Saunders & MacLeod, 2006; Migueles & García-Baros, 2007; Shaw, Bjork, & Handal, 1995), and social perception (e.g. Dunn & Spellman, 2003; Storm, Bjork, & Bjork, 2005). Besides categorized lists of words it has been obtained with materials as various as sentences (e.g. Anderson & Bell, 2001; Gómez-Ariza, Lechuga, Pelegrina, & Bajo, 2005), text passages (Carroll

et al. 2007), perceptual patterns (Ciranni & Shimamura, 1999), and descriptions of people (Macrae & MacLeod, 1999). Importantly, RIF is not limited to a basic design in which impairment is induced by deliberate and successful attempts to recall part of an event. The ways to induce this phenomenon include mental imagery of parts of presented materials (Saunders, Fernandes, & Kosnes, 2009) or generation of partial information from semantic memory (Bäuml, 2002; Storm, Bjork, Bjork, & Nestojko, 2006). RIF is thus quite an ubiquitous phenomenon present in multiple contexts, with various materials and various ways of eliciting partial retrieval.

## 2.2 Mechanisms of RIF

The mechanisms proposed to account for RIF can be broadly divided into two kinds, those that evoke a concept of interference and the ones that evoke the concept of inhibition. Starting with the interference-based approach to RIF, a detailed analysis of the blocking hypothesis (Rundus, 1973), a mechanism of this class which is most commonly evoked by researchers, has been presented in the first article introducing the retrieval practice paradigm by Anderson et al., 1994 (see Anderson & Bjork, 1994 for slightly different formulations of interference mechanisms). In this article a theory of interference-based explanation of RIF was developed by outlining three assumptions necessary to produce RIF by means of interference (p.1063): a) the *competition assumption* – that memories associated to a common cue compete for access to conscious recall; b) the *strength-dependence assumption* – that the cued recall of an item will decrease as a function of increases in the strengths of its competitors' associations to a cue; and c) the *retrieval-based learning assumption* – that the act of retrieval is a learning event in the sense that it enhances subsequent recall of the retrieved item. The model based on these three assumptions is according to Anderson et al. capable of producing RIF in the basic retrieval practice paradigm by causing a phenomenon of blocking of Rp- items by Rp+ items in a final test.

In the retrieval practice paradigm, retrieval of half of the items from half of the categories is practiced during the second phase of an experiment. The retrieval in this phase is prompted by a category label and two-letter stems of target items.

According to the retrieval-based learning assumption, such retrieval practice leads to the strengthening of links between Rp+ items and category cues used to prompt their retrieval. The same cues are used in a final test to access all items that were studied with these cues, Rp+, and Rp- items alike. Those items compete for access according to the competition assumption. Based on the strength-dependence assumption and the fact that associations between Rp+ items and their category cues have been strengthened, it can be predicted from the model that access to Rp- items will be impaired relatively to access to Nrp items that are associated to different category cues which were not used in the retrieval practice phase. Specifically, during a final test Rp+ items are retrieved by the use of a strengthened associative link and block access to Rp- items which are associated with the same cue. Similar blocking does not occur for Nrp items which are retrieved with the use of a different associative link. Hence, interference-based models can accommodate RIF in the basic retrieval practice paradigm.

The interference-based accounts are contrasted with inhibitory accounts which postulate that changes to representations of Rp- items stored in long-term memory underlie memory impairment observed for these items in a final test (Anderson & Spellman, 1995; Racsmany & Conway, 2006; Norman et al., 2007). Specifically, inhibitory accounts of RIF borrow the competition assumption from the interference accounts but discard the strength-dependence assumption. These accounts propose that during retrieval practice Rp- items compete for access with to-be-retrieved Rp+ items. This competition is resolved by an inhibitory mechanism which is recruited to dampen activation of competing Rp- items. The consequences of recruiting inhibition against Rp- items in the retrieval practice phase are long-lasting and detectable in the later final memory test in which performance for Rp- items is impaired compared to Nrp items that have never competed for access in the retrieval practice phase. Thus, according to inhibitory accounts, RIF stems not from strengthening of Rp+ items but from direct weakening of Rp- items.

There are several formulations of an inhibitory mechanism that have been proposed in the literature, as described in the previous chapter. The one that is most prominently used in the context of RIF is the pattern-suppression model

developed by Anderson and Spellman (1995). According to this model the inhibitory mechanism works during retrieval practice to suppress the semantic features of competing Rp- items. These suppressed features make retrieval of Rp- items more difficult in all types of tests that require access to these features. The other inhibitory accounts of RIF stress its episodic nature. According to the episodic inhibition proposed by Racsmany and Conway (2006), RIF stems from the pattern of activation and inhibition set during retrieval practice and encoded into episodic memory. This pattern is reinstated when an appropriate episode is accessed which results in prolonged RIF on subsequent tests. Somewhat similarly, the model developed by Norman et al. (2007) describes RIF as stemming mostly from an unlearning of episodic associations set at study, although this model allows also for small effects in semantic memory. The present chapter will concentrate mostly on the pattern-suppression model which is commonly equated with an inhibitory approach to RIF, although other models will be described in the section on the cue-independence of RIF as they provide different predictions concerning this main effect of interest for the empirical work described here.

There are several differences between inhibitory and interference-based accounts of RIF besides the issue of whether the effect arises due to the changes in the representations of Rp+ or Rp- items. These differences can be used to formulate contrasting predictions that would allow for resolving the issue of which class of mechanisms is responsible for producing RIF. The first difference is that whereas interference is a passive process in which impairment to Rp- items can be seen as a mere by-product of storing new information or updating already established memory traces of Rp+ items during the retrieval practice phase, the inhibitory mechanism postulate an active process directed against memory representations of Rp- items. Thus, the accounts presumably differ in the postulated involvement of active and hence resource-demanding processes in producing RIF. The second difference lies in the phase of the experiment in which the locus of the effect is assumed to lie. Interference-based mechanisms stress that RIF occurs due to the dynamics of a test phase. The retrieval practice phase serves to implement a strengthening manipulation but the actual impairment to Rp- items occurs only

during a final test. In contrast, inhibitory theories assume that memory representations of Rp- items become impaired in the retrieval practice phase and a final test serves only to reveal this impairment. The third difference lies in the role assigned to the retrieval practice phase. The interference-based account assumes that in order to obtain RIF a strengthening of cue-to-Rp+ links needs to occur in this phase but this account is seemingly mute on the way this strengthening should occur. Thus, from this perspective RIF should occur also when strengthening of cue-to-Rp+ associations is induced by additional presentations of intact pairs and not exclusively due to retrieval practice of Rp+ items. In contrast, the inhibitory model assumes that inhibition is triggered during competitive retrieval and thus makes a specific prediction that in order to obtain RIF the competitive retrieval of Rp+ items must occur to trigger inhibitory mechanisms and impair memory for related Rp- items.

Finally, the fourth difference, which is the most crucial from the perspective of the present experiments and results, lies in the breadth of impairment caused by interference and inhibition. The interference-based account makes a specific prediction that access to Rp- items will be impaired as long as the cues used at retrieval practice to access Rp+ items serve also as cues to access Rp- items in a final test. Only in this case Rp+ items can interfere and block retrieval of Rp- items. This, however, is not necessarily the case for inhibitory accounts. These accounts assume that representation of Rp- items become disrupted during retrieval practice and thus the generality of this impairment depends crucially on which part of representation of Rp- items actually becomes disrupted. One possibility is that inhibition serves to disrupt an associative link between the cue used at retrieval practice to access Rp+ items and competing Rp- items, the idea commonly referred to as associate unlearning (Melton & Irwin, 1940, as described in Anderson & Neely, 1996). In this case the inhibitory account would make the same prediction as the interference-based account, according to which RIF should be detectable only when the same cues are used during retrieval practice and a final memory test. However, it is also possible that inhibition disrupts not only these particular cue-to-Rp- associations but also other parts of memory representations of Rp- items. In this

case memory impairment should be more general and detectable also with cues other than the ones employed during retrieval practice. In the most extreme case, a semantic part of representation of Rp- items becomes disrupted by an inhibitory mechanism which leads to a prediction that RIF should be detectable with all kinds of cues that require access to semantic representations of Rp- items. This is the logic of cue-independence which, according to some authors (Anderson & Spellman, 1995), is the best test for contribution of inhibition to forgetting. It has to be noted, however, that not all formulations of inhibition predict such a property of RIF, which will be apparent in the later discussion on empirical findings concerning cue-independence of RIF.

### **2.3 Empirical evidence for inhibitory and interference-based accounts of RIF**

The differences between interference-based and inhibitory mechanisms that were discussed above serve as a basis for designing specific tests to disentangle these two classes of mechanisms that can be responsible for RIF. In the sections that follow, these tests and their results will be described. Four differences between interference-based and inhibitory accounts have been listed but the experimental designs that build on them will be described in five sections. Following theoretical considerations by Anderson (2003), the issue of the nature of retrieval practice (the third difference) will be addressed in two separate points, one focusing on the issue of whether retrieval practice leads to a qualitatively different pattern than strengthening cue-to-Rp+ associations by means other than retrieval (so called *retrieval specificity of RIF*), and the other focusing on competitiveness of retrieval practice (so called *interference dependence of RIF*).

#### **2.3.1 Active inhibition vs. passive interference**

A common feature of all inhibitory accounts of forgetting is that forgetting is not a mere by-product of storing new information, like forgetting due to interference, but it is an active process directed against interfering information. This feature of inhibition allows for formulating a prediction that people differ in their abilities to inhibit irrelevant or outdated information. Because inhibition is viewed as a precondition for effective operations of the cognitive system, it follows

that people with impaired cognitive functioning are most likely to have impaired abilities to recruit inhibitory processes. This kind of reasoning underlies the inhibitory framework of cognitive ageing (Hasher & Zacks, 1988) described in Chapter 1 which focuses on inhibition in working memory. Here the focus is on inhibition in long-term memory, as assessed in the retrieval practice paradigm, but the logic remains the same. If inhibition is a resource-demanding and adaptive process, then it should be possible to identify groups of people for which this process is less effective as revealed by their impaired cognitive functioning.

Several attempts to assess the effectiveness of inhibition in the retrieval practice paradigm in cognitively impaired groups have been undertaken but failed to produce consistent results. Initial studies have assessed the magnitude of RIF in patients suffering from schizophrenia and Alzheimer's disease, under the assumptions that these groups reveal a spectrum of deficiencies in memory functioning that could result from impairment in inhibitory mechanisms. However, a study comparing RIF in normally functioning older adults and patients with Alzheimer's disease demonstrated that both groups produce sizeable and comparable RIF (Moulin, Perfect, Conway, North, Jones, & James, 2002). Also three different studies assessing RIF in patients suffering from schizophrenia failed to reveal any impairment in inhibitory functions in this group (AhnAllen, Nestor, McCarley, & Shenton, 2007; Nestor, Piech, Allen, Niznikiewicz, Shenton, & McCarley, 2005; Racsmány, Conway, Garab, Cimmer, Janka, Kurimay, Pléh, & Szendi, 2008). Finally, a study looking at frontal patients demonstrated an intact RIF, suggesting that this effect is not necessarily dependent on frontal networks assumed commonly to participate in goal-oriented actions (Conway & Fthenaki, 2003). It would seem, then, that RIF is intact in patients who clearly suffer from impairments in memory and executive functions which runs counter to accounts postulating that active inhibition is needed to produce this effect.

However, there are also studies demonstrating that RIF can be reduced or eliminated in some clinical populations. For example, Amir, Badour, and Freese (2009) found no RIF in both patients suffering from posttraumatic stress disorder and a control group of traumatized participants, even though they demonstrated

reliable RIF for their non-traumatized controls. Similarly, Groome and Sterkaj (2010) found reduced RIF in clinically depressed participants compared to their controls and Storm and White (2010) documented similarly reduced RIF in patients suffering from attention-deficit/hyperactivity disorder. Thus, RIF seems to be limited in some clinical groups. However, lack of generality of this finding precludes strong conclusions that forgetting in the retrieval practice paradigm is an active and resource-demanding process.

Aside from clinical groups, the question of individual differences in producing RIF has also been examined with cognitively healthy participants. One line of research has been to look at the developmental trajectory of RIF. If RIF requires active inhibition then probably the ability to recruit this process is shaped as the cognitive system matures during childhood and declines during old age. Several studies compared the magnitude of RIF for children and young adults. For example, Ford, Keating, and Patel (2004) compared RIF for young adults and 7-year-olds and failed to reveal any difference in the magnitude of the effect between groups. Similar results have been reported for various age groups by Zellner and Bäuml (2005), Howe (2005), Knott, Howe, Wimmer, and Dewhurst (2011) and Conroy and Salmon (2005). However, a recent study by Aslan and Bäuml (2010) produced slightly different results. These authors tested both children in an early school age (7.5 years old) and pre-school age (4.6 years old) and compared their performance to the performance of younger adults. The results revealed that all three groups produced RIF in recall but RIF was absent from recognition in the youngest group. The authors suggested that recognition is an interference-free test and hence a better way to establish the contribution of inhibition to forgetting. The lack of RIF in recognition for the youngest participant was thus interpreted as supporting the hypothesis of developmental changes in inhibitory functions and thus, indirectly, also the inhibitory account of forgetting in the retrieval practice paradigm.

Studies examining RIF in older adults have also demonstrated a rather complex pattern of results. First attempts to establish whether RIF is present in older adults suggested that indeed it is. The aforementioned study by Moulin et al.



(2002) showed sizeable RIF for older adults, although the lack of a control group consisting of younger adults in this study precluded strong conclusions on whether the effect is relatively or absolutely preserved in this population. This has been remedied in a study by Aslan et al. (2007a) who demonstrated that RIF for older adults does not differ from RIF for younger adults. However, a new study by Ortega, Gómez-Ariza, Román, and Bajo (2012) sets a qualification for the earlier results. Specifically, these authors demonstrated that although RIF for older adults is preserved under conditions of standard retrieval practice, it becomes impaired when retrieval practice is made more demanding by introducing a secondary task in the retrieval practice phase of an RIF experiment. The authors argue that standard retrieval practice is not a sufficiently demanding task and thus even participants with deficits in executive functions are able to recruit inhibition under these standard conditions. Once, however, retrieval practice is made more demanding, the deficit may be revealed.

Finally, the issue of whether forgetting in the retrieval practice paradigm results from active inhibition or passive interference has also been addressed in research with healthy younger adults. Firstly, using the approach discussed above of making retrieval practice more demanding by introducing a secondary task, Román, Soriano, Gómez-Ariza, and Bajo (2009) demonstrated that RIF is indeed reduced when more resources need to be engaged during competitive retrieval. This effect has been recently replicated in the aforementioned study by Ortega et al. (2012) in which RIF was absent in the group of young adults under severe cognitive load during retrieval practice. Secondly, a recent study by Aslan and Bäuml (2011) has documented a positive correlation of working memory capacity and the size of RIF which suggests that the amount of cognitive resources at an individual's disposal determines how effective inhibitory processes are.

To sum up, although quite a number of studies have demonstrated a robustness of RIF against clinical conditions and developmental changes, more recent studies seem to suggest that RIF is sensitive to some inter-individual factors, although this feature may be relatively difficult to demonstrate under standard conditions and more sensitive procedures need to be employed to reveal it. Thus,

recent developments in this area seem to suggest that RIF may be dependent on the active forgetting of Rp- items and thus may in fact be a result of inhibitory processes.

However, the way the recent studies account for discrepancies in results summarized in this section is worth closer scrutiny. There are two ways in which proponents of inhibitory frameworks try to account for the abundance of research demonstrating preserved RIF in groups with limited executive functions. Firstly, they argue that this apparently preserved RIF is due to interference in a final test and hence only studies employing interference-free tests, namely recognition, should be of relevance to resolving this issue (e.g. Aslan & Bäuml, 2010). However, such reasoning is far from parsimonious. It needs to assume that two different mechanisms are able to account for RIF under commonly used conditions of recall testing, an idea that has been sometimes acknowledged by proponents of inhibitory frameworks (e.g. Spitzer & Bäuml, 2009) but which poses an important question, i.e. whether inhibitory processes are truly needed to account for forgetting. Moreover, this kind of reasoning is critically based on the assumption that RIF in recognition is in fact a pure measure of inhibition. It has to be noted that this latter assumption is not universally agreed on. As it will be described in detail in the section devoted to recognition testing, dual-models of recognition (Yonelinas, 2002) predict that interference plays an important role in shaping recognition performance. Hence, a question arises as to whether between group differences in the magnitude of RIF in recognition are truly due to the effectiveness of inhibition or whether they are due to differences in the amount of interference that occurs between groups. Why could interference differ between groups of participants? The dual-process view on recognition provides an answer according to which interference is present in recognition to the extent to which participants use a resource-demanding and strategic process of recollection (e.g. Cary & Reder, 2003; Norman, 2002). It may be hypothesized that the very young children tested by Aslan and Bäuml (and possibly other groups with limited effectiveness of executive functions like older adults) were not using strategic recollection as much as older children and adults which made them less prone to interference.

Secondly, the other way to account for discrepancies is to argue that the commonly used retrieval practice is not demanding enough to reveal differences in the effectiveness of inhibitory functions between groups of participants (Róman et al., 2009; Ortega et al., 2012). Here the focus is not only on comparisons of performance in a final test between groups but also on the observation that even a single group can vary in the size of RIF according to the demands posed by the retrieval practice. Since the manipulation occurs during the retrieval practice when inhibition is assumed to operate and not in a final test, which is assumed to be a domain of interference, the inhibitory mechanism seems to be implicated. Moreover, in both studies by Román et al. and Ortega et al. presumably interference-free tests of recognition were implemented strengthening the case for inhibition.

Can the interference account be of use in explaining this pattern? Again, this would necessarily require refuting the assumption that recognition is an interference-free test, which is discussed in the next section of this chapter. It would also require explaining how changes in retrieval practice could affect interference in a subsequent test. Interference is a function of strengthening of cue-to-Rp+ associations during retrieval practice. It seems conceivable that imposing a cognitive load during retrieval can disrupt such strengthening. As mentioned at the beginning of this chapter, the interference-based account of RIF crucially depends on the assumption of retrieval-based learning according to which retrieval of Rp+ items serve as a learning episode that leads to strengthening cue-to-Rp+ associations. Numerous studies have demonstrated that encoding is severely impaired by additional cognitive load (e.g. Fernandes & Moscovitch, 2000) while retrieval is relatively unaffected (e.g. Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). This dissociation could be used to predict, therefore, that new learning during retrieval practice would be abolished even in the face of high levels of retrieval of Rp+ items. This account, however, faces the problem of explaining why final performance for Rp+ items is not impaired by additional cognitive load introduced during retrieval practice (as reported by Róman et al., 2009, and Ortega et al., 2012). How can it be that learning is abolished and yet performance is just as

high as for conditions without cognitive load? Again, the dual-process perspective can offer an insight in this case. According to this perspective cognitive load impairs encoding processes that support subsequent recollection but not necessarily a more rudimentary automatic memory process (e.g. Jacoby, 1998) on which recall is also dependent (McCabe, Roediger, & Karpicke, 2011). These automatic processes may be strengthened by successful retrieval of Rp+ items even under a severe cognitive load. It is possible, then, that although interference is abolished by cognitive load due to impoverished encoding of associations supporting subsequent recollection, performance for Rp+ items is still supported by automatic processes which gain strength after each cycle of retrieval practice.

In summary, the question of mechanisms of RIF cannot be at present resolved based on research focused on individual differences. The empirical pattern is quite complex in this case. Some methodological advancements have been proposed recently which hold promise to account for the observed discrepancies but still the theoretical conclusions drawn from these recent studies are open to several lines of interpretation.

### 2.3.2 The role of retrieval in a final test

The second difference between inhibitory and interference-based accounts of RIF pertains to the phase of experimental procedure in which a mechanism responsible for RIF is assumed to operate. Inhibitory accounts postulate that forgetting stems from lasting after effects of resolving interference from competing memories of Rp- items during retrieval practice of Rp+ items. Interference-based accounts, in turn, postulate that forgetting occurs due to interference that takes place during a final test when strengthened Rp+ items occlude Rp- items. This latter account predicts that RIF should be detected only when tests sensitive to interference effects are employed, whereas the inhibitory account predicts that RIF should be quite general and should not depend on the contribution of interference to performance in a final test. Several researchers have argued that implicit tests and recognition tests could be used as interference-free tests to assess these

contrasting predictions and the results of the studies employing these tests are summarized in this section.

### *2.3.2.1 Implicit tasks*

Implicit tests of memory are tests that do not require conscious access to the study episode and are usually constructed in a way that hides the relationship between the test and the study session of an experiment (e.g. Richardson-Klavehn & Bjork, 1988, Roediger & McDermott, 1993; but see Richardson-Klavehn, Gardiner, & Java, 1996, for a different formulation). An experiment employing an implicit test contains a study phase and a memory task that is presented to participants as being unrelated to the study phase. In some of the implicit tests items studied earlier are presented among some novel items and participants are asked to perform a certain task concerning these items, as in the case of the lexical decision task. In other implicit tests, conditions are created under which items studied earlier constitute a possible response in an implicit test, as in the case of a free association task. In the former case, a priming effect on reaction times is usually measured by examining if studied items are processed faster compared to novel items. In the latter case, a priming effect on production rates is measured by examining if studied items are produced as a response at a higher rate than the baseline of previously not presented items. Importantly, implicit tests possess a feature that should minimize the contribution of interference in the retrieval practice paradigm. These tests often provide very specific cues for the assessed items. They either present these items outright (for tests measuring response latencies) or present specific cues that can be used to access appropriate words even without any awareness on the part of participants that these are the words that were earlier studied. Such specific cues should minimize interference from other related items that do not match these cues and thus RIF documented in these tasks could be assigned to some inhibitory mechanism. In the present section an overview of studies employing implicit tests is presented (with an exception of a study by Camp et al., 2005, which employed an independent cue methodology and thus is described in the section devoted to this technique) which is followed by theoretical considerations on mechanisms that produce the observed results.

The first study assessing RIF with an implicit task was conducted by Butler, Williams, Zacks, and Maki (2001). In this experiment several different tests were used in the otherwise standard retrieval practice paradigm. These tests included category-cued recall, word-fragment-cued recall, category-plus-fragment-cued recall, category-plus-stem-cued recall, and, of most interest for the present purpose, an implicit test of word fragment completion in which participants were provided with fragments of words and asked to complete them with the first word that came to their minds. In this test participants were not asked to retrieve items from the study phase. The authors failed to obtain RIF in their word fragment completion test. However, it is difficult to argue in this case that this failure stemmed from employing an implicit test because RIF also failed to materialize in all explicit tests used in this study with the exception of the most commonly used category cued recall. The authors concluded that the effect of RIF is of limited scope. However, it is also possible that particular materials and procedures employed by Butler et al. precluded strong RIF effects (see Goodmon, 2005, as discussed in Norman et al., 2007). Other studies employing category-plus-stem cued recall (e.g. Anderson et al., 1994) and category-plus-fragment-cued recall (Perfect, Stark, Tree, Moulin, Ahmed, & Hutter, 2004) did obtain RIF under these conditions of testing which may suggest that the procedures employed by Butler et al. were simply not sensitive to this phenomenon. In this light, the study by Butler et al. is not very informative on the issue of RIF with implicit tests.

Much more systematic examination of RIF in implicit test was undertaken by Perfect, Moulin, Conway, and Perry (2002). These authors examined RIF with various implicit tests, including category generation, category verification, perceptual identification and word-stem completion tasks. The results of this enterprise were quite complex. RIF was obtained with the category generation task in which participants were asked to generate exemplars to categories that were included in the study and retrieval practice phases (among other novel categories). Participants were shown to produce less Rp- items in this task compared to Nrp items. Similarly, RIF was present in a category verification task in which participants were asked to verify category membership of presented items that included Rp-

and Nrp items among novel distracters. In this task participants were slower to verify category membership of Rp- items compared to Nrp items. However, RIF was absent from the tests of perceptual identification in which participants were asked to identify degraded forms of Rp- and Nrp items, as well as from the test of word-stem completion in which participants were asked to complete stems provided to them with the first word that came to their minds. Several theoretical accounts of this complex pattern of results were considered by Perfect et al. The authors considered but rejected the idea that only tests that require retrieval of an Rp- item from memory given a certain cue elicit RIF. The argument was here that RIF was found in the category verification task in which the item itself was re-presented during the test which made its retrieval unnecessary. Also the idea that RIF is only present in tests during which category cues used at retrieval practice are re-presented was discarded by Perfect et al. because RIF was absent from the perceptual identification task also when category cues accompanied each trial of identification. Finally, the authors settled for a conclusion that the most comprehensive account of their results is offered by a transfer-appropriate processing framework.

The transfer-appropriate processing framework is a development of the encoding specificity hypothesis proposed by Tulving and Thomson (1973). The basic idea promoted in this framework is that performance in any given test depends crucially on the amount of match between study episode and the conditions of testing. The transfer-appropriate processing framework applies this basic idea to the issue of implicit tests. Based on this framework it is argued that what is important for performance in a memory test is not a distinction between implicit and explicit modes of assessing memory but rather a match between information required by a given test and conditions of encoding. Blaxton (1989) argued that most of the explicit tests require access to conceptual representation of studied words. To recall or to recognize a studied word during the test the meaning of this word usually has to be accessed. In this vein, the transfer-appropriate processing framework predicts that performance in explicit tests will be sensitive to all manipulations that affect the storage of conceptual representations of the studied

items. However, as argued by Blaxton, many of the implicit tasks do not require access to conceptual information and are instead driven by some perceptual features of studied items. For example, identifying a degraded word during an implicit test of perceptual identification does not require participants to access the meaning of this word. The transfer-appropriate processing framework predicts that performance in such a data-driven implicit test should not be sensitive to manipulations affecting conceptual representations but should instead be sensitive to manipulations that affect storage of more superficial features of the studied items. Importantly, there are also some implicit tests that do require access to conceptual representations and thus should behave similarly to conceptual explicit tests like recall or recognition.

Returning to the issue of RIF and implicit tests, Perfect et al. (2002) argued that the way to account for their results is to adopt a distinction between conceptual and data-driven implicit tests. It can be easily assumed that RIF affects conceptual representations in memory and thus according to the transfer-appropriate processing framework should be present only in conceptual implicit tests. From the inhibitory point of view it can be argued that Rp- items compete during retrieval practice due to the semantic features that they share with practiced Rp+ items and hence it is not surprising that inhibition works on these conceptual representations of Rp- items. On the other hand, the interference-based accounts postulate that RIF stems from the fact that Rp+ which share semantic features with Rp- items intrude when Rp- items should be retrieved. In any case, RIF seems to be in fact present in conceptual but not data-driven implicit tests. Both the category generation task and category verification task require access to conceptual representations that contain information of category memberships of items but such access is not required for successful performance in perceptual identification and word-stem completion tasks in which lexical information is sufficient for successful performance.

The distinction between conceptual and data-driven implicit tasks allows for an additional prediction that RIF in data-driven implicit tasks should be detected when retrieval practice affects lexical rather than conceptual information stored for



Rp- items. This prediction was indeed formulated and tested in a study by Bajo, Gómez-Ariza, Fernandez, and Marful (2006). These researchers modified the standard retrieval practice paradigm by using materials arranged in accord with a lexical rather than semantic principle. Specifically, instead of using semantic categories they used lexical categories in which all items started with the same two letters. These two-letter stems, which served to define categories, together with a unique third letter, were also used to elicit retrieval of Rp+ items during retrieval practice. In their Experiment 2 Bajo et al. employed a category-cued recall test (again, with two-letter stems serving as category cues in a final test) and demonstrated that RIF is present with such a design. More importantly for the present purpose, in their Experiment 3 Bajo et al. employed a data-driven implicit test of word-fragment completion and again obtained significant RIF. Thus, these results demonstrate that, consistently with the transfer-appropriate processing framework, RIF can be present in a data-driven implicit test as long as there is a match in the level of memory representation that is used to access Rp+ items during retrieval practice and that serves later as a basis for performance in a final implicit task.

One additional implicit task has been used to examine RIF producing results that are important for the discussion on the nature of this phenomenon. Veling and van Knippenberg (2004) conducted an experiment assessing RIF with a lexical decision task in which participants were presented with words and non-words and were asked to identify words. The authors demonstrated reliable RIF in this task as latencies to identify Rp- items as words were longer than the corresponding latencies to identify Nrp items. Because the lexical decision task requires access to semantic representations of the words and indeed manipulations of a conceptual nature, like semantic priming (e.g. Joordens & Becker, 1997), has been shown to affect performance in this task, the lexical decision task can be defined as a conceptual implicit task. In this light the finding of RIF in this particular task is in agreement with the conclusions reached by Perfect et al. (2002).

However, RIF in the lexical decision task was a target of scrutiny of yet another study which produced a somewhat more complex pattern of results.

Racsmány and Conway (2006) conducted three different experiments employing the retrieval practice paradigm and the lexical decision task and found that under standard conditions RIF is absent from this task but does occur when each trial of the lexical decision task is preceded with a presentation of a category cue that was earlier used at study and also at retrieval practice (in the case of Rp- items). In their discussion of these findings the authors argued that a simple characterization of conceptual representations that become affected in RIF is not enough to account for these findings and a more fine-grained analysis is required. Specifically, the authors argued that conceptual representations can be either purely semantic or can be set in some context and are thus episodic in nature. Furthermore, they argued that the standard lexical decision task utilizes semantic representation and does not require access to an episodic context of study or retrieval practice phases. As such the standard task failed to produce RIF, Racsmány and Conway argued that semantic representations are not affected in RIF. In contrast, the primed lexical decision task utilizes episodic representations as the context of study and retrieval practice becomes reinstated when the same cues used in these phases are presented at test. Because RIF is present in such a primed lexical decision task, it seems to indicate that episodic representations of Rp- items are indeed affected in this phenomenon.

The review of the studies employing the retrieval practice paradigm together with some kind of an implicit task presented here allows for the drawing of conclusions that seem to be quite consistently supported by the data. Specifically, it seems that the transfer-appropriate processing hypothesis can successfully provide an overarching framework for understanding when RIF may be present with implicit tasks and when it is unlikely to be reported. This seems to crucially depend on a match between the level of memory representation accessed during retrieval practice and during a final test. RIF can occur both in conceptual and data-driven implicit tests as long as the memory representation tapped by an implicit task is the same memory representation that underlies RIF in an explicit task.

The main question asked in the present section is whether results from implicit tests speak to the issue of the mechanisms of RIF. The transfer-appropriate framework helps to determine why RIF is sometimes present or absent from implicit tests but it does not answer the question of why access to either conceptual or lexical representation of Rp- items is impaired. It has to be noted that all results reported in this section have been typically discussed as supporting an inhibitory account of RIF. It has been argued that under conditions of standard retrieval practice Rp- items compete for access due to activation of their conceptual representations and thus this kind of representation becomes inhibited. When the basis of competition were changed in a study by Bajo et al. to lexical factors, also the locus of the inhibitory effect changed to lexical representations of Rp- items. The inhibitory account gives a very straightforward framework for analyzing RIF in implicit tasks. Can the interference-based framework also account for these results?

As it was mentioned earlier, interference-based accounts predict RIF only to the extent to which the association between Rp- item and a cue used as retrieval practice is activated during a final test. Only when these links are activated at test can competing and strengthened Rp+ items intrude and disrupt performance. Thus, to explain the pattern of results with implicit tasks an interference-based framework needs to explain why sometimes these links are used and sometimes they are not. The first issue such an account needs to deal with is the apparent consistency of the observed results with the transfer-appropriate processing framework. These results do not seem problematic for the interference-based accounts as these accounts can easily adopt the transfer-appropriate processing framework and predict that category-to-Rp- associations become activated during test only if this test is performed on the basis of the same type of information which is present in the association. If the associations are conceptual in nature, as in the standard case of semantic categories, then these associations can be activated only in the conceptual tests that require access to conceptual information. However, if the associations are lexical in nature, as in the study by Bajo et al., then they can be activated also in the task that builds on lexical information.

However, the more pertinent question for interference-based accounts is why the category-to-Rp- associations become activated during implicit tests at all when they do not need to be activated given the quite specific cues used in these tests and the lack of reference to the earlier phases of the procedure. The first thing to notice here is that RIF is actually quite often absent when specific cues are given at test. Most of the implicit tests providing specific cues are data-driven tests just because very specific cues allow for circumventing the access to conceptual representations of studied items. This is the case of word fragment completion or word stem completion tasks in which RIF has not been found (Perfect et al., 2002; Butler et al., 2001). On the other hand, most of the conceptual implicit tasks in which RIF has been demonstrated include tasks in which the same cue used at retrieval practice is also used as a cue in a final test. These include the category generation task and category verification task in which the categories for which membership needs to be judged are the same categories that were used as cues for Rp+ items during retrieval practice (Perfect et al., 2002). Also the study by Racsmány and Conway (2006) suggest that even in the lexical decision task RIF occurs only to the extent to which cues used at retrieval practice are used during the lexical decision task.

However, activating the associative link between cues used at retrieval practice and Rp- items is presumably not enough to produce interference. What interference-based accounts postulate is that blocking occurs when these cues are actually used to drive performance in the task because only then Rp+ items are accessed that occlude Rp- items. This description matches well the procedure of the category generation task in which exemplars need to be generated to the cues used in retrieval practice. In this case cues are clearly utilized and thus Rp+ items can be retrieved and occlude Rp- items. But why should Rp+ items be retrieved in other implicit tasks, like lexical decision or category verification tasks, in which participants are simply asked to produce a certain judgment for Rp- and Nrp items and they are not asked to use cues to produce any new items? The answer to this question may be linked to the question of whether retrieval is voluntary or not. There is no doubt that much of the processes involved in retrieval, like cue

elaboration (e.g. Spillers & Unsworth, 2011b), monitoring of retrieval processes (e.g. Dodson & Schacter, 2001) or output decisions (Koriat & Goldsmith, 1996), are controlled processes that are utilized only when participants deem them necessary for their performance in a task at hand. However, an argument has been also put forward that the core retrieval process of producing a matching memory trace to a given cue is automatic and involuntary (Moscovitch, 1992; 1994). According to this stance, retrieval can be described as automatic memory process and a set of controlled and resource-demanding working-with-memory processes. If a core retrieval process is automatic, then it seems probable that presenting category cues in an implicit task may trigger an involuntary retrieval of items that are associated with these cues and this retrieval may shape performance in these tasks.

It is worth noting that the implicit tasks in which RIF has been reported and which do not require participants to use cues to retrieve items were the tasks in which response latencies were measured, namely the lexical decision task and the category verification task. If the assumption of an automatic nature of memory retrieval is adopted, then it becomes problematic to see to what extent these tasks may be contaminated by interference (C. M. MacLeod et al., 2003). In these tasks a presentation of Rp- items together with a category cue that was used during retrieval practice may trigger automatic retrieval of Rp+ items that became strongly associated with this cue and this automatic retrieval can delay response in the task participants are requested to perform. Such an automatic retrieval should be less likely to occur for Nrp items for which cues were not presented during retrieval practice. Thus, even using an implicit task with the most specific cues possible, namely the items themselves, does not necessarily shield performance in this task from interference when category cues are also provided, as in the case of the category verification task or the lexical decision task in the study by Racsmány and Conway (2006). The principle of automatic retrieval can also potentially account for a single observation of RIF in a lexical decision task in which no cues were presented before to-be-judged items (Veling & van Knippenberg, 2004). In this case presentation of to-be-judged items might have triggered automatic retrieval of cues that were associated with these items in a study phase which in turn might have

slowed down responding. Importantly, this mechanism should be triggered more often for Rp- items than for Nrp item because the cues associated with the former were repeatedly presented during retrieval practice and hence are much more accessible than the cues associated with the latter.

#### Summary on implicit tests

The theoretical considerations presented above lead to a conclusion that the assumption that implicit tests are not contaminated by the process of interference may be incorrect. Most of the implicit tasks that reported RIF did actually employ the same cues that were used in retrieval practice and that could contribute to the observed results. In other cases these cues may have been retrieved automatically and also distort the results. Thus, it seems that these methods do not allow for resolving the issue of whether RIF is caused by interference or inhibition. Even though implicit tests are designed to limit the effects of interference, they can still be subjected to it, rendering strong conclusions about the mechanisms of RIF questionable.

#### 2.3.2.2 *Recognition tests*

Recognition tests provide a way to assess the mechanisms of RIF that is somewhat similar to the implicit tests described above. These tests also employ cues to assess Rp- and Nrp items, namely these items themselves, which are not directly related to Rp+ items and thus should minimize interference. A number of researchers have argued that observation of RIF with a presumably interference-free recognition test would provide evidence in favour of inhibitory formulations of RIF (e.g. Aslan & Bäuml, 2010; Róman et al., 2009). As described earlier, if interference during the final test is responsible for RIF then this effect should be eliminated in an interference-free test. However, if RIF arises due to inhibition of some kind of memory representation during retrieval practice, then it should be present in all tests that utilize this inhibited representation.

The first theoretical considerations concerning RIF in recognition tests were formulated in a seminal paper by Anderson and Spellman (1995) which introduced

the inhibitory framework for investigating RIF. However, contrary to what has been suggested above, this first formulation stated that RIF should not be present in recognition. This prediction was postulated on the basis of findings in paradigms other than the retrieval practice paradigm in which the inhibitory mechanisms were assumed to be implicated. Anderson and Spellman argued that the paradigms like the list-method directed forgetting or the A-B, A-C interference paradigms demonstrate forgetting that could be assigned to operations of some kind of inhibitory mechanism but this forgetting is not detectable in recognition tests (e.g. Basden et al., 1993; Postman & Stark, 1969). Consequently, Anderson and Spellman arrived at the conclusion that memory inhibition is a mechanism that resolves interference by limiting accessibility of interfering memories but it does not affect their availability (Tulving & Pearlstone, 1966). The inhibited memory cannot be retrieved given a certain cue associated to this memory but it remains in its full strength in a memory store and this strength can be assessed in recognition tests with the most specific cues that do not require associative retrieval. The first study concerning RIF and recognition seemed to support this formulation as it found no RIF in recognition. Koutstaal, Schacter, Johnson, and Galluccio (1999) used the retrieval practice paradigm with both recall and recognition tests to investigate forgetting of self-performed actions. Participants performed certain actions (e.g. draw a boomerang) in one session and then half of participants used photos to recall these actions in another experimental session (retrieval practice). The comparison of the level of free recall in this group to a control group which did not undergo retrieval practice revealed impaired memory performance. However, RIF was absent in the experiment in which memory was assessed with a recognition test.

However, in time, the growing body of empirical data and further theoretical development inspired by this data have changed the first intuitions about the relation of inhibition to recognition. Firstly, several studies have revealed that RIF is actually present in recognition tests when more common word materials (as opposed to self-performed actions used by Koutstaal et al., 1999) are presented for study. Specifically, Hicks and Starns (2004) obtained clear RIF in two

experiments employing standard categorized lists of words and a simple old/new recognition testing (as well as in a source test) and, similarly, Starns and Hicks (2004) documented reliable RIF in an experiment employing associatively related lists of words. Interestingly, this latter experiment found lower levels of recognition for both studied but unpracticed words from practiced lists (Rp- items) and for unstudied words that were strongly related to practiced lists (critical lures in the DRM paradigm). Since then, multiple studies have documented RIF effects in recognition, using both categorized lists of words (e.g. Róman et al., 2009; Aslan & Bäuml, 2010; see Veling & van Knippenberg, 2004, for RIF in recognition latencies) and associatively related lists of words (Spitzer & Bäuml, 2007) and also other materials like sentences (Gómez-Ariza et al., 2005).

Secondly, further theoretical work on inhibitory mechanisms of RIF led to a consensus that RIF should actually be present in recognition, if it really arises from the workings of an inhibitory mechanism. This issue is strongly related to a definition of inhibition that is usually adopted in the literature. This definition follows the ideas proposed by Anderson and Spellman (1995), according to which inhibition works by raising the threshold of activation for semantic features that constitute a to-be-inhibited competitor at retrieval practice. According to this idea, the semantic features of competitors become suppressed so that they are difficult to activate in a subsequent test no matter what cue is used to access the memory trace of a competitor. The specific formulations of this pattern-suppression theory will be described in detail in the section devoted to cue-independence of RIF, however at this point it is important to notice that inhibition of specific semantic features should lead to a decrease in memory signal even if an Rp- item itself is presented as a probe in a recognition test which in turn should lead to fewer hits for this particular class of items compared to uninhibited Nrp items. It should also be again noted that this specific formulation of inhibition is not the only one possible and indeed other formulations are in use in paradigms like list-method directed forgetting in which forgetting is usually absent from recognition tests. Here the focus is on the pattern-suppression model which is the most commonly used inhibitory framework in the context of the retrieval practice paradigm. For the



present purpose, therefore, it will be assumed that inhibitory framework does predict forgetting in recognition.

A number of researchers treat RIF in recognition as evidence of contributions of an inhibitory mechanism (Róman et al., 2009; Aslan & Bäuml, 2010). The one example that has been already described here pertains to the developmental study of RIF conducted by Aslan and Bäuml (2010) in which the authors argued that a lack of RIF in recognition for very young children proves that their abilities to inhibit interfering memories is underdeveloped, even though RIF was present for the same children in cued recall. Such a strong position requires, however, a closer look at studies in which RIF was absent from recognition. The first example of such a study by Koutstaal et al. (1999) has been already mentioned. There are also other failures to obtain RIF in recognition. Racsomány et al. (2008) conducted an experiment with a standard retrieval practice paradigm and a recognition test augmented by a remember/know procedure to investigate subjective experiences that accompany recognition in this paradigm. In the experiment in which recognition preceded recall (eliminating the possibility of carry-over effects) no RIF was found. Importantly, in this experiment a strong time pressure for responding in the recognition test was present as participants were asked to respond within 2 sec. The results reported in a recent paper by Verde and Perfect (2011) suggest that this time pressure could have been responsible for the failure to obtain RIF in the study by Racsomány et al. In their empirical investigation Verde and Perfect revealed that RIF is present in recognition without time pressure but does indeed disappear when recognition is paced. Although the time limit for responding in the study by Verde and Perfect was much shorter than the deadline used in the study by Racsomány et al. (750 ms vs. 2 s), it could be argued that participants in the study by Racsomány et al., being aware of the time pressure, tried to respond as quickly as possible, functionally shortening their response window.

The commonly used formulation of the inhibitory mechanism is not well-suited for explaining why RIF is sometimes absent from recognition tests. After all, this framework predicts that inhibition should be present in all tests that tap into an inhibited representation. One proposal on how to account for the discrepant results

has been outlined by Anderson (2003). Anderson noticed that suppressing semantic features of competitors from practiced categories should affect not only these competitors but also items semantically related to them that contain the same semantic features. In other words, inhibition should affect not only studied Rp-items but also other, not studied items that are semantically related to them by virtue of belonging to the same semantic category. It is worth noting here that the majority of recognition tests used to assess RIF employ foils that belong to studied categories. This methodological choice is obvious as using unrelated foils would render the recognition task far too simple and would probably result in ceiling effects across all conditions. However, using items from studied categories as foils, coupled with the mechanism of inhibition of semantic features, creates a situation in which foils are not comparable across different experimental conditions. If the measure of discriminability in a recognition task is adopted that relates hits to false alarms to compute a bias-free measure of recognition performance (like  $d'$ ), then performance for to-be-inhibited Rp-items is related to false alarms to foils that share inhibited features and performance for Nrp items is related to false alarms to foils that are not subjected to any effects of inhibition. If inhibition affects similarly Rp-items and their matched foils, a hypothesis which is in agreement with previously mentioned results of a study by Starns and Hicks (2004) documenting RIF for non-studied critical lures in the DRM paradigm, then the level of discriminability may be the same as for Nrp items and their matched foils which are both unaffected by inhibition.

The idea proposed by Anderson (2003) could suggest that obtaining RIF in recognition may not be an easy task even if RIF is in fact caused by the suppression of semantic features of competitors. However, this idea of inhibition affecting both Rp-targets and their foils is useful as long as a measure based on both hits and false alarms is used to assess recognition performance. When the simplest measure of hit rates is used instead, RIF should be revealed as a decrease in hit rates to Rp-items compared to Nrp items if the memory signal is indeed weaker for Rp-items due to suppression of their features. The studies that assessed RIF in recognition and failed to obtain this effect did not report any decrease in hit rates to Rp-items

(Racsmány et al., 2008; Verde & Perfect, 2011). Of course, hit rates are subjected also to effects of bias and it could be argued that differences in bias across conditions masks any differences in the strength of memory signal between Rp- and Nrp items. However, since Rp- and Nrp items are intermixed in a recognition test, the bias explanation would require adopting an assumption that participants change their bias on an item-by-item basis within one test. Numerous studies have demonstrated that participants are reluctant to make such changes (e.g. Morrell, Gaitan, & Wixted, 2002; Singer & Wixted, 2006). Moreover, this explanation would have to assume that participants become more liberal to call items from the practiced category “old” in order to compensate for weaker memory signal for Rp-items. This would mean that participants become more liberal for categories for which half of the items are extremely well encoded due to their additional retrieval practice which would be at odds with studies demonstrating that participants become actually more conservative for well encoded materials (Hirshman, 1995). Finally, this explanation does not predict when RIF should be found in recognition and when it should not be found. For example, there is nothing in this hypothesis to account for the results obtained by Verde and Perfect (2011) which concern the mediating role of the time pressure during recognition testing. In fact, if changes in bias were responsible for occasional failures to replicate RIF in recognition, then it would mean that participants in the study by Verde and Perfect changed their bias on the item-by-item basis in a speeded task but not in a self-paced task, an observation directly contradictory to previous work on such changes (e.g. Dobbins & Kroll, 2005).

In summary, it seems that the inhibitory account of RIF can account for the presence of RIF in recognition but it faces some difficulties in accounting for the fact that RIF in recognition is not ubiquitous. What does the interference-based account offer in this case? The interference-based accounts face a problem that is exactly opposing to the problem recognition data poses for inhibitory accounts. Specifically, interference-based accounts need to explain how RIF can occur in recognition tests which are quite commonly assumed to be interference-free tests. In order to do it, the interference-based account needs to explain how in a test in

which participants are given only targets and foils the associative links between these targets and their category cues become activated, leading to blocking of Rp- items by Rp+ items. The interference-based accounts can achieve this aim by referring to so called dual-process models of recognition.

The current models of recognition can be broadly divided into two types. There are models that postulate a unitary concept of memory strength that is computed by the matching of information that is contained in a memory probe to all information that has been stored in memory (e.g. Hintzman, 1988; Gillund & Shiffrin, 1984). The higher is the proportion of matching features and the lower is the proportion of mismatching features, the larger is the memory signal and hence, keeping the constant level of bias, the probability of an “old” response. In contrast, the dual-process models of recognition postulate that there are in fact two different memory processes that are jointly responsible for recognition performance (Yonelinas, 1994; Yonelinas, 2002; Diana et al., 2006). The automatic process, often referred to as familiarity, is akin to the matching process described above. It is, however, supplemented with a recall-like process, referred to as recollection, which allows for the retrieval of information associated with a probe. The interplay of these two processes is often assumed to be responsible for the conflicting results obtained in various paradigms employing recognition tests. For example, a testing effect in which memory is better for previously tested materials, just as it is for Rp+ items compared to Nrp items in the retrieval practice paradigm, is sometimes but not always present in recognition. Chan and McDermott (2007) proposed that this inconsistency stems from the fact that only recollection is augmented by previous retrieval and familiarity is not. In this case the testing effect would crucially depend on the contribution of recollection to recognition performance which was in fact demonstrated by Chan and McDermott.

Applying the logic of dual-process models of recognition to the findings in the retrieval practice paradigm, it could be argued that some conflicting results concerning RIF in recognition can be assigned to the workings of two separate processes that are differently affected by retrieval practice. Verde (2004) was the first researcher to argue that retrieval practice of Rp+ items affects recollection-

based recognition of Rp- items but not familiarity-based recognition. Importantly, it is the interference-based account of RIF that predicts such localized effects of retrieval practice. Recollection is a recall-like process that depends on accessing the association between tested items and any information accompanying these items during study (e.g. Criss & Shiffrin, 2005). Since this process is associative in nature it should be subjected to the effects interference. Indeed, one of the main arguments in favour of dual-process models of recognition and the importance of recollection supplementing familiarity is that the effects traditionally assigned to interference can be found in recognition tests. These include the list-length effect in which memory is progressively worse as the number of studied items increases and the list-strength effect in which memory for some items is impaired by the strengthening of other items presented in the same list. Firstly, the list-length effect in free recall is predicted because associating more items to the same contextual cue creates additional interference which makes sampling of all of the studied items less probable. Cary and Reder (2003) investigated the list-length effect in recognition with the help of the remember/know procedure (Tulving, 1985) and found that this effect is present but it is constrained to the recollection contribution to recognition performance. Secondly, the list-strength effect in free recall is predicted because strengthening some items by their multiple presentations strengthens their associations with the contextual cues that are later used to access non-strengthened items which creates additional interference for the latter. Norman (2002) investigated the list-strength effect in recognition and found it as long as recognition was highly dependent on recollection processes. More details on the list-strength effect will be provided in the section devoted to retrieval specificity of RIF.

The interference-based account of RIF predicts that RIF should be present in recognition to the extent to which a recognition test depends on recollection rather than familiarity. By using this simple rule, this framework can account for the discrepancies found in the studies employing recognition tests to investigate RIF that were described above. Firstly, it can quite easily account for the lack of RIF in the study by Koutstaal et al. (1999) that employed self-performed actions materials

and the usual presence of RIF in studies employing categorized materials. The thing to notice here is that objects used for self-performed actions in a study by Koutstaal et al. were not related to each other and hence a recognition test concerning actions performed with these objects could have been performed based on familiarity alone. In contrast, categorized words commonly used in the studies on RIF in recognition as targets and foils are strongly related to each other which makes it harder to rely solely on familiarity for distinguishing them. When the items are strongly related they share the majority of their features and thus any probe presented in a recognition test matches quite well both targets and foils alike, impairing discriminability. When the targets are strongly related to foils an additional process of recollection is often assumed to be recruited to augment discriminability (e.g. plurals paradigm, Hintzman & Curran, 1994; see Rotello, Macmillan, & Van Tassel, 2000). Thus, if recollection is impaired by RIF and familiarity is not, then it is predicted that RIF should be present when targets are strongly related to foils but may be absent when such relations are weak, consistent with the results reported by Koutstaal et al. Secondly, the interference-based account of RIF can also explain why RIF is present in self-paced recognition but is absent when recognition is speeded (Racsmany et al., 2008; Verde & Perfect, 2011). The dual-process formulations of recognition processes commonly assume that familiarity is a process which proceeds more rapidly than recollection (Yonelinas, 2002). Indeed, timing of recognition responses is one of the methods that have been commonly used to disentangle contributions of recollection and familiarity to recognition performance (e.g. Hintzman & Curran, 1994; Rotello & Heit, 2000). Thus, it is possible that studies that have failed to find RIF in recognition, which imposed a deadline on responding, limited the contribution of recollection to recognition performance and thus eliminated the effects of interference.

Although the interference-based account of RIF, coupled with the dual-process perspective, offers a framework that accounts for some of the discrepancies found in studies examining RIF in recognition, there are also studies that looked directly at the effects RIF has on recollection and familiarity that can

validate or refute this model. However, the results of these studies are again not completely consistent. The first study on RIF in recognition that adopted the dual-process perspective was conducted by Verde (2004). In two experiments Verde assessed RIF with an associative recognition task coupled with the remember/know procedure. The remember/know procedure in which participants are asked to indicate whether they can recollect specific details of the study episode (a “remember” response) or whether they just feel that an item is familiar (a “know” response) is commonly employed in recognition studies under the assumption that “old” recognition judgments accompanied with remember responses reflect recollection. In Experiment 1 Verde found RIF in remember responses but failed to obtain significant RIF in the measure of recognition based on old/new judgments. In Experiment 2 Verde controlled the contribution of recollection to recognition performance by manipulating the study duration for all presented items, under the assumption that recollection should be more effective for items presented for a longer time. Indeed, in this experiment RIF was obtained for both measures based on remember and old/new responses but only in the long study condition whereas it was again limited to remember responses for the short study condition. Verde concluded that RIF in recognition is limited to situations in which recognition is highly dependent on recollection, either because the recognition measure taps mostly this process, as it is for remember judgments, or encoding conditions are created which support recollection at test.

There are at least two other published experiments which looked at RIF with the remember/know procedure. However, their findings are different than the ones obtained by Verde (2004). Firstly, Racsmany et al. (2008) assessed RIF in recognition in two experiments. One of these failed to obtain RIF altogether under conditions of time pressure in the final test, as described earlier. In the other one, significant RIF was obtained under conditions of self-paced responding. However, in neither of these experiments did the type of response (remember and know) interact with the retrieval practice condition (Rp- and Nrp items). Thus, when RIF was absent from recognition it was also absent in both remember and know responses. In contrast, when RIF was present in recognition it affected remember and know responses to

the same extent. These results do not support the hypothesis according to which RIF should predominantly affect remember responses as they tap into the recollective processes that are affected by interference.

Yet another study on RIF in recognition from the dual-process perspective was conducted by Spitzer and Bäuml (2007). The results of their experiment employing the remember/know procedure are different from both the results obtained by Verde (2004) and the results obtained by Racsmány et al. (2008). In the study by Spitzer and Bäuml a significant RIF was found in recognition but this effect was not present when remember responses were analyzed separately. Thus, it would seem that in this study recollection of Rp- items was not affected by retrieval practice of Rp+ items even though RIF was obtained in recognition which constitutes a pattern of results that is directly contradictory to both the predictions of the interference-based account of RIF and the empirical results obtained by Verde.

There are many procedural differences between the three studies on RIF in recognition employing the remember/know procedure that have been described here. These studies employed different materials, pairs of categorized words in the study by Verde (2004), standard categorized words in the study by Racsmány et al. (2008) and associatively related words in the study by Spitzer and Bäuml. They also employed different formats of testing with Verde using an associative recognition test and the other two studies employing a standard old/new recognition tests. However, it is unclear how these procedural differences could account for discrepant results. It is also worth mentioning that the procedure of eliciting remember and know judgments to disentangle contributions of recollection and familiarity to recognition is not without its critics (e.g. Dunn, 2008, Wixted & Stretch, 2004).

Many researchers have argued that remember and know responses do not tap in qualitatively to different sources of information that stem from different memory processes but rather they result from different criteria that are placed by participants on the unitary axis of memory evidence (Donaldson, 1996; Dunn, 2004;



Wixted & Stretch, 2004). According to this hypothesis people demand a greater amount of evidence to give a remember response but evidence that supports these responses does not have to be qualitatively different than evidence that supports “know” responses. In this case any differences in the rate of remember responses between conditions do not have to reflect changes in recollection and may simply result from shifting the decision criteria for these responses between conditions. Importantly, the decision criteria for the practiced category may become more conservative relative to unpracticed categories, resulting in a drop in remember responses, as in the studies by Verde (2004) and Racsmany et al. (2008), but it may also become more liberal for these categories, resulting in the somewhat unexpected result of no difference in remember hits for practiced and unpracticed categories obtained by Spitzer and Bäuml (2007). The conclusion is that such a model is flexible enough to account for any pattern of results obtained with remember responses which consequently precludes strong conclusions reached with this measure. To circumvent this problem, Verde reported in his study not only remember hits but also a measure of discriminability for remember responses ( $d'$ ) which should constitute a bias-free measure of recollection. However, even this measure may be problematic due to floor effects in remember false alarms.

The problems with the remember/know procedure are well-known in the memory literature and thus studies employing this particular procedure usually employ additional methods to provide converging evidence on the issue of changes in recollection in familiarity. However, in the context of RIF only one additional method has been implemented to examine this issue, namely an analysis of receiver-operating characteristics (ROCs) performed by Spitzer and Bäuml (2007). In their Experiment 2 Spitzer and Bäuml collected confidence judgments for recognition decisions which were used to plot receiver operating characteristic curves (ROCs). The computational models of recognition memory were used to fit the observed ROCs, the dual-process model developed by Yonelinas (1994), which constitutes a computational implementation of the dual-process approach to recognition, and a signal detection model, a model which is commonly used in recognition studies and which does not make specific assumptions concerning

familiarity and recollection but instead assumes that recognition decisions are based on a single dimension of memory strength (or memory evidence, as described later). Spitzer and Bäuml found that the dual-process model accounts for the data by assuming that retrieval practice affects recollection but not familiarity, which agreed with the findings from the remember/know procedure reported in Experiment 1 of the same study. Moreover, the authors indicated that the signal detection model that does not assume equal variances for distributions of old and new items gives a better fit for the obtained data than the dual-process model. Because of this superior fit of the signal detection model and because the dual-process model fits the data by keeping the recollective parameter constant between Rp- and Nrp items which would seem to be at odds with the finding of impaired recall for Rp- items, Spitzer and Bäuml concluded that the dual-process approach does not give a good account of the findings concerning RIF in recognition and thus should be rejected in favour of a single-process approach in which overall memory strength of Rp- items is affected by retrieval practice of Rp+ items.

The conclusion reached by Spitzer and Bäuml (2007) amounts to a general rejection of the dual-process approach to recognition. However, there is ample evidence that recognition does indeed depend on two different processes (see Yonelinas, 2002, for a review). The question is whether a single study concerning quite a specific effect like RIF should be considered sufficient to reject a whole theoretical framework that provides novel insights into effects for which the simpler model endorsed by Spitzer and Bäuml fails. Alternatively, it is possible that the procedures and models fit by Spitzer and Bäuml do not address the fundamental issue of the effect of retrieval practice on recollection and familiarity. In other words, it is possible that these methods simply do not allow for clear separation of these processes.

The main problem lies in the assumption made by Spitzer and Bäuml (2007) that a unitary dimension underlying recognition decision described in the signal detection model arises due to a single memory process. Although this assumption is made in previously mentioned single-process models of recognition memory (e.g. Hintzman, 1988), it is not the only theoretical option that can be adopted. In fact, it

has been proposed in the literature that the unitary dimension used in signal detection modeling stems from multiple memory processes (Wixted, 2007; Wixted & Mickes, 2010). According to this view, recognition decisions are made by summing evidence from various different sources, like processes of recollection and familiarity. The products of these processes are merged to create a single dimension of strength of evidence on which recognition decisions are made. In this formulation there is nothing contradictory in adopting the dual-process theoretical perspective and the signal detection model as a methodological tool. If such a dual-process perspective on signal detection model is endorsed, there is nothing in the results reported by Spitzer and Bäuml that would contradict the prediction that recollection rather than familiarity of Rp- items is impaired by retrieval practice of Rp+ items. Hence, the results of Spitzer and Bäuml do not appear to support exclusively the inhibitory approach to RIF as they can be fully consistent with the interference-based approach.

#### Summary on recognition tests

To sum up all considerations on RIF in recognition, this field still requires additional studies that could elucidate the specifics of the nature of RIF in recognition. As it stands now, neither of the theoretical frameworks of RIF are able to account for all data reported in the literature. The inhibitory account formulated as the pattern-suppression model predicts RIF in all recognition tests but this effect is not consistently obtained. The interference-based account of RIF provides the means to account for discrepant results obtained when examining RIF in recognition by adopting the dual-process perspective on recognition and assuming that RIF stems from impairment in recollection but not in familiarity. However, the specific tests of the predictions formulated on the basis of these accounts fail to produce consistent results, probably due to the use of techniques that do not allow for clear separation of contributions of recollection and familiarity to recognition performance.

### 2.3.3 Retrieval specificity of RIF

The third difference between inhibitory and interference-based accounts of RIF lies in the role assigned to retrieval practice of Rp+ items. The interference-based account of RIF assumes that during this phase an association between an Rp+ item and a cue used to access this item is strengthened, which results in interference when the same cue is later used to retrieve Rp- items. However, according to this account retrieval practice is probably not the only way to strengthen the cue-to-Rp+ associations. Presumably, additional presentations of intact cue and Rp+ pairs should result in such a strengthening and lead to interference and thus RIF. In contrast, the inhibitory account of RIF proposes a quite unique role of retrieval practice in producing RIF. In this approach inhibition occurs to resolve interference during competitive retrieval and thus retrieval constitutes a necessary condition for observing RIF. According to this approach alternative ways of strengthening Rp+ items should not result in RIF.

The retrieval specificity is a property of RIF that has been documented in several experiments (Ciranni & Shimamura, 1999; Anderson, Bjork, & Bjork, 2000; Bäuml, 2002). These studies have contrasted the conditions in which strengthening of cue-to-Rp+ items was caused by retrieval practice or additional presentations and they strongly suggest that RIF does indeed occur only when retrieval practice of Rp+ items is used in the experimental procedure. The first study that reported such a contrast was conducted by Ciranni and Shimamura (1999). These researchers employed an episodic version of the retrieval practice paradigm in which categories consisted of geometrical shapes of presented perceptual patterns whereas individual features of each pattern were defined with the use of colour and location on the screen. In the second phase of the procedure the association between shapes and some of the colours (Rp+ condition) was strengthened either by retrieval practice, when participants retrieved colours cued with the shape and location, or additional presentation when participants were presented outright with the complete stimuli. Under these conditions Ciranni and Shimamura documented RIF, as evidenced by impaired retrieval of colour for items of practiced shapes that were not practiced themselves (Rp- items) compared to items of unpracticed

shapes (Nrp items), but only when retrieval practice was employed and not when complete stimuli were presented. In a similar vein, Bäuml (2002) tested the hypothesis of retrieval specificity of RIF with the standard categorized lists of words as materials and retrieval practice involving retrieval of novel items from some of the studied categories or their intact presentation. In this study again retrieval practice resulted in RIF but additional presentations of cues and novel exemplars from practiced categories did not (see also Staudigl, Hanslmayr, Opitz, Mecklinger, & Bäuml, 2010).

A somewhat different pattern of results was obtained in a study by Anderson and Bell (2001). In this study sentences were used as materials for investigating RIF. In their Experiment 5 Anderson and Bell contrasted retrieval practice of the elements of sentences with additional presentations of the whole sentences and found significant RIF effects in both conditions. However, the procedure used by Anderson and Bell included also a self-assessment questionnaire that was given to participants after the retrieval practice paradigm was administered. In this questionnaire, a question concerning a strategy of covert retrieval was included in which participants were asked to rate how often they engaged in additional retrieval practice during the extra-study trials. Anderson and Bell used the ratings provided as responses to this question to divide their participants in two groups that differed in the reported frequency of using the covert retrieval strategy. They found that RIF in the retrieval practice condition was obtained for both low- and high-covert-practice participants whereas in the extra-study condition RIF was found only for high-covert-practice participants. These results were taken by Anderson and Bell as evidence that RIF stems from retrieval practice and is present in the extra-study condition only to the extent to which participants engage in retrieval practice even when they are not required to do so.

It is important to notice that the results concerning retrieval specificity obtained in the retrieval practice paradigm have much bearing on results in similar paradigms in which forgetting has been commonly assigned to workings of interference. If inhibition is in fact a general property of the memory system, then it should be responsible for various manifestations of forgetting beyond the retrieval

practice paradigm (Anderson, 2003). In the strongest version of the inhibitory framework, all forgetting that occurs in long-term memory is caused by retrieval practice and extra-study manipulations by themselves should not result in forgetting. If this strong hypothesis is correct, then also in the paradigms other than retrieval practice paradigm in which forgetting is observed retrieval practice should be implicated. However, several paradigms take advantage of extra study to manipulate interference and forgetting is found in these paradigms. The examples of such paradigms are the paradigms used to investigate the list-strength effect (Tulving & Hastie, 1972) and the part-set cueing effect (Slamecka, 1968). The proponents of inhibitory mechanisms used their theoretical frameworks to account for all of these effects by suggesting that procedures used to investigate these effects involve either test-order biases that cause impairment to target items by earlier overt retrieval of non-target items or covert retrieval practice, a mechanism evoked also by Anderson and Bell to account for their surprising effect of RIF caused by the extra-study manipulation.

The part-set cueing effect refers to a finding that providing some of the studied items as cues during a test impairs memory for the rest of the studied items compared to a condition in which no items are reinstated at testing (see Nickerson, 1984, for a review). There are several explanations of this effect which evoke either the concept of interference (Rundus, 1973; Watkins, 1975) or the idea of disruption in memory search strategies (Basden, Basden, & Galloway, 1977; Basden & Basden, 1995). Importantly, Bäuml and Aslan (2004) proposed that also inhibitory mechanisms may be responsible for forgetting in this paradigm. These authors suggested that although in the part-set cueing paradigm studied items are presented outright during a final test, they are presented as cues with the instructions to use them to retrieve additional items from memory. These particular instructions cause retrieval of cues during the test which is similar to the retrieval practice necessary for obtaining RIF. In essence, this hypothesis is the same as a mechanism of covert retrieval proposed by Anderson and Bell (2001). Bäuml and Aslan tested this hypothesis of covert retrieval in the part-set cueing paradigm by manipulating instructions provided to participants. They did obtain standard

forgetting when participants were explicitly asked to retrieve some of the items before a final test (a condition akin to the retrieval practice paradigm) and also when instructions asked to use items provided as cues during the test but they failed to obtain forgetting when participants were asked to treat presentation of some items as an additional study opportunity. According to Bäuml and Aslan these results indicate that additional presentations of some of the studied items are not sufficient to cause forgetting in the part-set cueing paradigm and covert retrieval practice of these items during the test is necessary to obtain the part-set cueing effect.

Yet another example of forgetting due to additional presentations of some of the studied items can be found in the studies on the list-strength effect (LSE). In the studies examining LSE participants are presented with three different lists. In the pure weak list all items are presented once. In the pure strong list all items are strengthened, commonly by the means of additional presentations. Finally, the mixed list consists of half of the items presented in the same way as items from the weak list and half of the items presented in the same way as items from the strong list. The common finding from this paradigm is that when asked to free recall the studied items participants recall more weak items from the pure weak list than from the mixed list and more strong items from the mixed list than from the pure strong list (e.g. Wixted, Ghadisha, & Vera, 1997). These effects are commonly assigned to interference by which strong items interfere more than weak items with retrieval of other items from a particular list by virtue of their strong association to a common contextual cue. This additional interference from strong items impairs retrieval of weak items from the mixed list and also retrieval of strong items from the strong list (Raaijmakers & Shiffrin, 1981).

To explain forgetting in the LSE paradigm the proponents of the inhibitory account need to argue that strengthening of items by additional presentations or longer presentation times leads to a retrieval practice for these items that is responsible for forgetting. Bäuml (1997) noticed that the LSE effect is present in free recall in which the experimenter has no control over the output order of remembered items in a final test. It is worth noting that LSE effects are either

absent or reduced in test formats that control for output order like recognition or cued recall (Ratcliff, Clark, & Shiffrin, 1990). Bäuml proposed that no control over output order effectively means that stronger items are recalled at the beginning of a test and this initial retrieval rather than strengthening *per se* may be responsible for forgetting in the LSE paradigm. In his empirical investigation Bäuml showed that the LSE is indeed eliminated when the output order was controlled.

The case for retrieval practice in the LSE paradigm is, however, not settled yet as there are studies demonstrating LSE even when the possibility of retrieval of stronger items during the final test is minimized. For example, Norman (2002) documented LSE in two recognition experiments (see also Diana & Reder, 2005). In a recognition test the order of the probe presentation is controlled and thus retrieval of strengthened items should not precede queries concerning non-strengthened items. In fact, in the study by Norman strong items were never tested at all and LSE was assessed exclusively for weak items. LSE was, however, found under these conditions that should minimize any contribution of retrieval practice, which seems to be at odds with the predictions of inhibitory theories. Importantly, the LSE obtained by Norman was most apparent under conditions in which the contribution of recollection to recognition performance was maximized (in remember judgments and the plurals paradigm) which converges with both the theoretical considerations presented in the previous section on RIF in recognition, according to which interference can be detected in recognition through its effects on recollection, and the empirical findings documenting such interference effects on recollection in the context of the retrieval practice paradigm (Verde, 2004; Verde & Perfect, 2011).

Another study recently conducted by Verde (2009) provides converging evidence on the presence of LSE when the chances of covert retrieval practice are minimized. Verde employed in his study a cued-recall testing procedure, which also allows for controlling the output order. In five different experiments Verde documented reliable LSE in cued recall caused by additional presentations of pairs even when these additional pairs were not tested and thus were not overtly retrieved. Moreover, across different experiments Verde employed several



measures to minimize the effects of covert retrieval, that included using different grouping of strengthened items during the study, incidental study instructions and surprise testing, and found no effects of these procedural changes which argues against the contribution of covert retrieval to the LSE obtained in this study. Together with the results of Norman (2002), the results obtained by Verde strongly suggest that additional presentations of intact studied items can result in forgetting that can be assigned to passive interference.

The interference-based frameworks predict results in the LSE paradigm that the inhibitory frameworks cannot account for but this in itself does not rule out the possibility that both interference and inhibition may be the sources of forgetting and that one of these mechanisms, interference, is responsible for forgetting in some variants of the LSE paradigm (Norman, 2002; Verde, 2009) and the other one, inhibition, is responsible for forgetting in the retrieval practice paradigm and, with the help of covert retrieval or output-order biases, some of the studies employing the LSE paradigm (Bäuml, 1997) and the part-set cueing paradigm (Bäuml & Aslan, 2004). However, this solution obviously lacks parsimony and a single-process account of the effects of strengthening some items on the memory for other, related items would be preferred.

Apart from its empirical contribution, the study by Verde (2009) provides also theoretical considerations on the nature of interference. Verde noticed that strengthening may not lead ubiquitously to interference during testing. Firstly, previous research has documented that the way strengthening is implemented is significant for the amount of interference that eventually occurs. Malmberg and Shiffrin (2005) demonstrated that interference caused by contextual associations is likely to occur when strengthening is implemented through additional spaced presentations but not when strengthening is obtained by longer presentation times, massed repetitions or level-of-processing manipulations. Verde noticed that the study by Bäuml (1997) that has been cited as evidence in favour of covert retrieval explanation of LSE varied presentation time to manipulate strength. According to the model developed by Malmberg and Shiffrin, this manipulation should not produce the interference-driven LSE and thus it comes with no surprise that

additional mechanisms, like output-order bias, needed to be involved to actually produce this effect. However, it remains an open question as to whether retrieval of strengthened items before non-strengthened items produced LSE in this study because it involved retrieval or because this retrieval served as spaced practice, a pre-condition for obtaining contextual interference in the model by Malmberg and Shiffrin.

Secondly, Verde (2009) questioned whether the materials and procedures that are commonly used in the retrieval practice paradigm yield themselves to interference effects under conditions of extra-study. Verde noticed that the amount of interference in the retrieval practice paradigm should depend on three interlinked factors of the type of association that is used to impose a category-like structure on the materials presented to participants, the overlap between studied items and the amount of strengthening that occurs during retrieval practice. The first factor is important as it determines the third factor. Specifically, if cue-to-items associations used as a categorical structure are very strong, then the amount of strengthening these associations undergo during retrieval practice should be minimal. The second and third factors are important as they directly affect the amount of interference. The amount of interference depends on the overlap between studied items as only when overlap is sufficiently high do strengthened items compete during retrieval of weaker items and may block them. If overlap between items is low, then strengthening of some items may actually serve to differentiate them from non-strengthened items and thus reduce interference. Finally, the amount of strengthening obviously determines the intrusiveness of strengthened items and thus the magnitude of impairment for non-strengthened items. Overall, these three factors can be used to predict when strengthening of some items may or may not produce interference and impairment of non-strengthened items. Verde argues that the procedures used in the retrieval practice paradigm create conditions in which these factors may work against interference in the extra-study condition.

The first thing noticed by Verde (2009) is that studies on RIF commonly employ categorized lists of words in which associations between studied items and

category labels used as cues are very well learned. In fact, it is common practice in studies on RIF to use as materials items that are most strongly associated with their categories which is done to increase competition from Rp- items during retrieval practice, as will be described in the section on the competition-dependence of RIF. It is doubtful whether additional presentations of such well-known category-item associations during retrieval practice constitute a sufficiently strong manipulation to induce strengthening of these associations and consequently interference in a final test. This point refers also to the study by Bäuml and Aslan (2004) on inhibitory mechanisms in part-set cueing in which categorized lists were used as materials. According to Verde, this methodological choice could undermine the chances of finding interference in the extra-study condition. The second thing noticed by Verde pertains to a study by Ciranni and Shimamura (1999), which is commonly cited to support retrieval specificity of RIF. In this study episodically associated patterns of shapes, locations and colours were employed which are immune to the argument of strong pre-experimental associations precluding effects caused by interference. However, Verde noticed that a particular cueing procedure used by Ciranni and Shimamura in the retrieval practice phase involved cueing with both a shape that was common for Rp+ and Rp- items but also location which was individual for each item. As was mentioned above, individual properties of items that minimize their overlap can reduce interference because strengthening items in this case involves also their differentiation. Verde argues that lack of RIF in the extra-study condition of the study by Ciranni and Shimamura could have stemmed from these two opposing tendencies of increased interference from strengthening the associations between shapes and Rp+ items and increased differentiation from strengthening the associations between individual location and Rp+ items.

The conclusion from all these considerations is that interference should not always be predicted when the strengthening of some items occurs and thus interference-based accounts of RIF should not be rejected solely because additional presentations of Rp+ items and their cues do not lead to forgetting in this paradigm. However, it remains the case that retrieval practice does lead to RIF and hence a question arises as to whether the interference-based framework is able to account

simultaneously for the lack of RIF in the extra-study condition and reliable RIF in the retrieval practice condition.

There seem to be at least two mechanisms described in the literature that can serve to achieve this goal. The first one builds on the previously mentioned third factor affecting the degree of interference, namely the degree of strengthening of associations due to different types of manipulations. Numerous studies in the literature document that retrieval practice benefits memory more than additional study (e.g. Wheeler, Ewers, & Buonanno, 2003; Roediger & Karpicke, 2006). It can be argued that this retrieval practice superiority is caused by more strengthening to cue-to-item associations for items retrieved than presented intact with their cues. It makes intuitive sense that the relationship between a cue (e.g. FRUIT) and a target (e.g. apple) is more apparent to participants when they are asked to retrieve a target given a stem, in which case they need to focus on a cue to complete the task rather than when they are presented with the target together with its cue, in which case participants can focus on the individual properties of the target that differentiate it from other studied items and ignore the common cue. In this scenario retrieval practice leads to interference when additional presentations do not because the more strengthening that cue-to-target associations receive from retrieval practice makes  $Rp+$  more intrusive in a final test.

In the RIF literature the commonly used argument against such an account postulating different levels of strengthening due to retrieval practice and extra-study opportunity states that these two manipulations lead to the same benefit for  $Rp+$  items in a final test which suggests an equal level of strengthening due to both of these manipulations (e.g. Anderson & Bell, 2001). This argument is, however, questionable in the light of results of numerous studies on the testing effect documenting that the benefits of retrieval practice over relearning depend on a wide variety of conditions. For example, it is well known that benefits of retrieval practice outweigh benefits of extra-study opportunity only when the final test is delayed but extra-study may yield equal or even more benefits for memory performance assessed immediately after the study phase (e.g. Wheeler et al., 2003). It is, therefore, difficult to argue that performance in a final test always

reflects the degree of strengthening the Rp+ items receive. It is conceivable that although retrieval practice produces more strengthening than extra study, this may be revealed only under quite specific conditions. In the recent work on the testing effect Bjork and his colleagues (Halamish & Bjork, 2011; Kornell, Bjork, & Garcia, 2011) argued that the relative performance for retrieval practice and extra-study conditions depend crucially on the success rate during retrieval practice and the difficulty of the final test. In this so called bifurcation framework of the testing effect it has been argued that retrieved items are strengthened much more than restudied items but non-retrieved items receive no strengthening at all. As a result a bimodal distribution of items' strengths is created in the retrieval practice condition. In contrast, for an extra-study condition all items receive a small amount of strengthening. If a final test is easy, then this little additional strength for all restudied items goes a long way and aids performance for the majority of them. If a final test is difficult, then a little additional strength due to extra-study is not enough to support memory. In this case the benefits of the much greater strengthening of retrieved items in the retrieval practice condition take over which results in the testing effect. This framework can account neatly for the dissociation between the immediate and delayed test by assuming that delayed tests are more difficult than immediate ones. Importantly for the present purpose, it can also provide insight on why retrieval practice does not lead to benefits over extra-study in the retrieval practice paradigm. From this perspective it would have to be argued that the final tests employed in this paradigm are not difficult enough to reveal such testing effects. When one considers that typical tests in the retrieval practice paradigm are category cued recall tests in which participants can recall what was presented to them but can also generate appropriate targets from semantic memory, such an assumption about difficulty seems quite tenable. The similar arguments concerning the retrieval practice paradigm have been made by Norman et al. (2007) who developed a framework which clearly predicts more strengthening for retrieved items than restudied ones and recently by Raaijmakers and Jakab (2012).

Another approach to this problem was proposed by Perfect et al. (2004), who developed a transfer-appropriate forgetting framework to address the issue of retrieval specificity of RIF. According to these researchers, it is not the extent to which practiced items are strengthened during retrieval practice and extra-study but the match in processes engaged during retrieval practice and the final test that is responsible for retrieval specificity of RIF. Perfect et al. noticed that retrieval practice is much more similar to the final test than extra-study opportunity to which it is compared to. It can be hypothesized that the type of task participants are required to perform after study is encoded in the memory traces as context information (e.g. Jacoby, Shimizu, Daniels, & Rhodes, 2005). If participants are asked either to retrieve items or study them they create appropriate memory traces in which the very processes that they performed are present as context features. Later, during a final test, participants try to access their memory with the cues provided to them but also with the context that in this case contains features of a memory retrieval task. This context matches well the context encoded during retrieval practice which augments interference from memory traces created during this task for Rp+ items and leads to blockage of Rp- items. However, this context is a poor match to the extra-study task, which in effect reduces interference from Rp+ items. As a result, RIF is present when Rp+ items are strengthened by retrieval practice but may be absent when these items are strengthened under conditions of extra-study that do not match the task participants are asked to perform in a final test.

To sum up this section, it has been argued that RIF is retrieval specific which implicates inhibition responsible for resolving interference during retrieval as a mechanism of this effect. This hypothesis is supported by results showing that RIF is caused by retrieval practice and not by extra-study presentations of cues and Rp+ items and that previous results showing interference due to extra-presentations in tasks like the LSE paradigm or the part-set cueing paradigm stem from overt or covert retrieval present in these procedures. However, some studies clearly document interference effects in studies in which chances for covert or overt retrieval were minimized (e.g. Norman, 2002; Verde, 2009). Moreover, several

arguments have been made according to which interference-based accounts do not necessarily predict forgetting due to an extra-study manipulation (Verde, 2009). Finally, the recent developments in the literature on the testing effect (Halamish & Bjork, 2011) or the transfer-appropriate forgetting framework (Perfect et al., 2004) provide accounts of results supporting retrieval specificity of RIF that are consistent with the interference-based account of RIF. Thus, the bulk of the research seems in fact consistent with both approaches and cannot be used to resolve the issue of mechanisms of RIF.

#### 2.3.4 Competition dependence of RIF

The issue of retrieval specificity of RIF is closely related to another property described in the inhibitory framework of RIF, namely its competition dependence. According to the inhibitory account, retrieval of  $Rp+$  items in itself is not sufficient to trigger inhibition of  $Rp-$  items. What is needed is a competition from  $Rp-$  items during retrieval of  $Rp+$  items that requires resolving by the mechanism of inhibition. If retrieval of  $Rp+$  items is not competitive, then inhibition should not be recruited and hence no RIF should be observed. This prediction is very specific to inhibitory accounts of RIF as the interference accounts do not assign any specific role to retrieval in producing RIF (with the exception of the transfer-appropriate forgetting framework, as described in the previous section), and thus are mute on the question of the competition during retrieval.

Several experiments support the contention that RIF does not occur without competition from  $Rp-$  items during retrieval of  $Rp+$  items. The very first study on this issue is the study by Anderson et al. (1994) in which the retrieval practice paradigm was introduced. In this study Anderson et al. manipulated the taxonomic frequency of category exemplars employed as materials. In their Experiments 1 and 2 Anderson et al. discovered that RIF is present for categories composed of strong exemplars but not for categories composed of weak exemplars. In their crucial Experiment 3, in which taxonomic frequency was manipulated orthogonally for  $Rp+$  and  $Rp-$  items, they found that the magnitude of the RIF effect depends on the taxonomic frequency of  $Rp-$  items but not on the taxonomic frequency of  $Rp+$

items. Specifically, reliable RIF was present when exemplars of high taxonomic frequency were used as Rp- items which contrasted with the condition in which exemplars of low taxonomic frequency were used as Rp- items in which marginally significant facilitation for Rp- items relative to Nrp items was found. Anderson et al. argued that RIF is present for strong Rp- items because these items compete during retrieval of Rp+ items and thus need to be suppressed by an inhibitory mechanism. In contrast, weak Rp- items do not compete for access and hence are not inhibited and may in fact be even facilitated by virtue of automatic activation spreading from related Rp+ items.

Since the study by Anderson et al. (1994) at least two different studies have employed the manipulation of taxonomic frequency of category exemplars to investigate the assumed mediating role of competition during retrieval on the amount of forgetting. Firstly, Bäuml (1998) examined the role of taxonomic frequency in producing the output order effect. It is a well-known observation that the probability of recall of an item decreases with its serial position in the testing sequence (e.g. Roediger & Schmidt, 1980). This effect has been commonly assumed to reflect interference from already recalled items but Bäuml proposed that it could also stem from inhibition. According to this proposal, retrieval of items early in the testing sequence is achieved with the help of an inhibitory mechanism that suppresses competing items. The more items are recalled, the more suppression is exerted on yet-to-be-recalled items, which results in declining performance as retrieval progresses. Bäuml tested this idea by examining the competition dependence of the output order effect. He used two categorized lists of words that included moderate and strong or moderate and weak exemplars as defined by taxonomic frequency. For both conditions moderate items were recalled first. This created a situation in which moderate items needed to be recalled either before weak or strong exemplars that competed for memory access. According to the inhibitory framework, only strong exemplars should produce a sufficient amount of competition to trigger an inhibitory mechanism. Thus, this account predicts that the output order effect should emerge in the moderate-strong condition but not in the



moderate-weak condition and that was indeed the pattern of results observed by Bäuml.

Secondly, Williams and Zacks (2001) conducted a study in which they tried to replicate the results observed by Anderson et al. (1994). In two experiments they manipulated the taxonomic frequency of exemplars presented for study by varying it either between categories (Experiment 1) or within-categories (Experiment 2). In both experiments they found no effects of taxonomic frequency of the exemplars on the magnitude of the RIF effect. Indeed, in their study RIF was present for both weak and strong exemplars, which is inconsistent with the results reported by Anderson et al. The question arises as to how general the effect for weak competitors may be. Although only the three described experiments addressed the issue of the role of taxonomic frequency in forgetting due to retrieval practice directly, other experiments that focused on different topics may prove informative in this respect. Specifically, Perfect et al. (2004) discussed the competition dependence assumption in the light of studies focusing on cue-independence of RIF, the topic of the next section of the present chapter. In these studies RIF is assessed for items that belong to two different categories, one for which label is used during retrieval practice and one which is used to assess memory in the final test. Perfect et al. discussed the results of a study by Anderson and Spellman (1995) and noticed that in this study RIF was obtained for items which seemed quite low in taxonomic frequency. Indeed, the procedure for assessing cue-independence of RIF that requires studied items to be exemplars of two different categories imposes constraints on the chosen materials that are difficult to meet even for quite weak exemplars of any given category. The solution to this problem is usually not to use categorical norms as a source of materials but rather to choose words from very broadly defined categories that are not present in these norms. For example, Anderson and Spellman used in their study categories such as RED and FOOD (with exemplars like “apple” or “cherry”) or FLY and ANIMAL (with exemplars like “butterfly” and “ladybug”) for which quite a variable set of items could be used as exemplars. However, the result of using such broad categories is that the chosen exemplars are probably low on the dimension of taxonomic frequency. The fact

that in such studies RIF is sometimes observed (e.g. Anderson & Spellman, 1995; Camp et al., 2005) speaks against the crucial role of taxonomic frequency and hence competition during retrieval practice for eliciting RIF, as noted by Perfect et al.

The other way to manipulate competitiveness of retrieval practice by choice of materials would be to make Rp- items more similar to Rp+ items. After all, competitiveness of retrieval should depend on the distinctiveness of Rp+ items among related distracters (e.g. Brown, Neath, & Chater, 2007). The more similar Rp+ items are to Rp- items, the more difficult it should be to retrieve them and hence inhibition should play a larger role in facilitating retrieval of Rp+ items. However, the empirical results concerning this subject point to the conclusion that bringing Rp- closer to Rp+ items reduces rather than augments the RIF effect. Bäuml and Hartinger (2002) conducted two experiments that manipulated similarity between to-be-retrieved and competing items. In Experiment 1, which employed the retrieval practice paradigm, participants studied categories with four exemplars that were divided into two subcategories with two exemplars each. In the experimental condition participants performed retrieval practice for one of the items from all studied categories, creating Rp+ items and for each category one Rp- item from the same subcategory as a practiced Rp+ item and two Rp- items from a different subcategory. Performance for these items was compared to performance for Nrp items from a control condition in which retrieval practice was not performed. In this design Bäuml and Hartinger discovered that RIF occurs when Rp+ items and Rp- items come from different subcategories but not when they come from the same subcategory. Thus, in this experiment RIF failed to emerge for items that should compete the most with the retrieval of Rp+ items by virtue of belonging to the same subcategory. In their Experiment 2, Bäuml and Hartinger extended this finding to the output order effect.

The findings of Bäuml and Hartinger (2002) are surprising if one is willing to assume that RIF is indeed competition-dependent but they can be accounted for by the additional mechanism of integration which has been postulated to play an important role in the studies on RIF. Several different studies have documented that RIF is sensitive to the amount of integration among studied items. Specifically,

Anderson and McCulloch (1999) examined the role of instruction on the size of the RIF effect and found that instructions that require participants to rehearse several studied items together reduce RIF. They found also that increases in study time may lead to spontaneous integration of studied items, as assessed by a post-experimental questionnaire, which in turn is also related to the reduction of RIF. A further study by Anderson, Green et al. (2000) pointed to a specific role of integration of Rp+ and Rp- items in reducing RIF. These authors found reliable RIF when participants were asked to integrate Rp- items and Rp+ items separately but they found significant reduction in the size of the RIF effect when participants were asked to integrate Rp+ items with Rp- items. The number of other studies have also documented the role integration plays in shielding memory for Rp- items from RIF using a variety of materials and methods imposing integration (Miguelles & Garcia-Bajos, 2007; Garcia-Bajos, Miguelles, & Anderson, 2009; Goodmon & Anderson, 2011). The conclusion from all these studies is that bringing Rp- items closer to Rp+ items results in more integration rather than more competition during retrieval practice and hence less rather than more RIF. Anderson (2003) pointed out that the relationship between the similarity of Rp+ and Rp- items may be curvilinear. If these items are very similar to each other, they become integrated and retrieval of an Rp+ item may cause activation rather than inhibition of related Rp- items. However, if there is very little similarity between Rp+ and Rp- items, no competition from Rp- items during retrieval of Rp+ items should occur and thus no RIF should be expected. RIF should thus be expected only at the intermediate levels of similarity between Rp+ and Rp- items. A similar point has recently been made also by Norman et al. (2007) who argued that in some cases too much competition may lead to inefficient inhibition (see also Anderson & Levy, 2010).

Although the curvilinear relationship between the similarity of Rp- and Rp+ items can account for the overall pattern of results concerning competition dependence of RIF, it does so at a cost of making the theory overly flexible. If the relation is curvilinear it can be used to account for any possible single dissociation found in the results. This in itself would not be a problem if there was empirical evidence pointing to the curvilinear nature of the relationship between the

similarity of Rp- and Rp+ items and the magnitude of the RIF effect. However, at present there is no study documenting such a relationship within the single design, most likely due to difficulties with controlling the theoretical construct of similarity with the crude measures provided by categorical and associative norms. Moreover, one part of this relationship is equally well explained by the interference-based account of RIF. Specifically, the prediction according to which RIF should decrease with increasing integration of Rp+ and Rp- items is not specific to inhibitory mechanisms and has indeed been postulated on the basis of research on interference (e.g. Radvansky & Zacks, 1991). In the inhibitory account integration reduces RIF because when integration of Rp+ and Rp- items is so high that they constitute a single unit in memory, Rp- items can serve rather as cues for related Rp+ items than as competitors. This means that integration precludes interference during retrieval practice and makes inhibition unnecessary for retrieval. However, if the inhibitory account assumes that integration reduces interference during retrieval practice, it also needs to assume that it reduces interference in the final test, in which the interference-based account sees the source of RIF. This indeed is consistent with the results of Bäuml and Hartinger (2002) who showed that the similarity of items that are retrieved and items that are related to them plays the same role in the output order effects as in the retrieval practice paradigm. Thus, based on the findings concerning integration it cannot be concluded whether integration removes RIF by abolishing interference during retrieval practice, as the inhibitory account of RIF would postulate, or during the final test, as the interference-based account would postulate.

The methodological and theoretical problems of studies examining the role of competitive retrieval in RIF can be addressed with additional studies that employed different methodologies to examine this issue. An experiment that is commonly cited to support the assumption of competition-dependence of RIF was conducted by Anderson, Bjork et al. (2000). In this experiment, competition during retrieval was experimentally manipulated by varying the conditions of retrieval rather than changing stimuli between conditions. For the competitive retrieval condition Anderson et al. used the standard retrieval practice paradigm with

categorized lists of words as materials. They contrasted this condition with a non-competitive retrieval condition in which the retrieval practice phase was modified. In this novel condition participants were presented for retrieval practice with complete exemplars and the first two letters of a label of the category they belonged to (e.g. FR\_\_\_\_\_ - apple) and were asked to retrieve the appropriate category label. Anderson et al. reasoned that in this modified condition there would be no competition as category labels were not related to each other and hence no inhibition should be recruited and no RIF should be obtained. Indeed, in their experiment RIF was obtained in the standard competitive retrieval condition but not in the novel non-competitive retrieval condition, which was taken by researchers as support for the competition-dependence of RIF and the inhibitory account of this effect. It is important to note here also that the level of facilitation of Rp+ items was equal between competitive and non-competitive practice conditions. This was taken as evidence by Anderson et al. that the degree of strengthening of Rp+ items between conditions was equal and thus it does not determine variability of RIF between conditions.

In the section devoted to retrieval specificity of RIF it has been argued that performance in the final test is a crude measure that does necessarily have to be sensitive to the degree of strengthening of cue-to-Rp+ items associations. This point has been made on the basis of recent research on the testing effect, which demonstrates how the combination of low difficulty of the final test and less than perfect retrieval rate can result in equal memory performance even when retrieval does strengthen retrieved items more than extra-study opportunity (Kornell et al, 2011). The same logic may be applied to the study by Anderson, Bjork et al. (2000) to argue that the equal level of performance for competitive and non-competitive retrieval conditions reported in this study does not speak unequivocally on the issue of the degree of strengthening of associations during retrieval practice. If it is assumed that competitive retrieval strengthens associations more than non-competitive retrieval, then the results of Anderson et al. can be accounted for by interference which is dependent on the degree of strengthening of associations. This argument has been recently put forward by Raaijmakers and Jakab (2012) who

followed up on the results of Anderson et al. to examine the competition dependence of RIF in more detail. In their study Raaijmakers and Jakab took steps to make non-competitive retrieval more similar to the standard competitive retrieval in terms of difficulty, under the assumption that tasks that are equally difficult should lead to an equal degree of strengthening of associations used during these tasks. To this aim, several steps were undertaken to make retrieval in the non-competitive retrieval condition more demanding. These included changing the materials from semantic categories to sets defined by a common property (e.g. ROUND – button) and using “exemplars” of low frequency. Additionally, in this study feedback was provided after retrieval attempts to provide strengthening to all associations used in the retrieval practice phase. With these changes to the procedure Raaijmakers and Jakab obtained reliable RIF in two experiments. The finding of RIF in the design in which participants are not required to retrieve Rp+ items under conditions of competition from Rp- items suggests that RIF is not competition dependent and instead depends crucially on the amount of strengthening of cue-to-Rp+ associations which is consistent with the interference-based account but not with the inhibitory account.

The conclusions formulated by Raaijmakers and Jakab (2012) are strengthened by converging evidence from their earlier study (Jakab & Raaijmakers, 2009) in which competition dependence was also scrutinized. This earlier study used two direct manipulations of the competitiveness of Rp- items. In Experiments 1 and 2 the competition from Rp- items was manipulated by varying the serial position of Rp- items within their categories at study. Jakab and Raaijmakers built on a classic finding by Wood and Underwood (1967) according to which recall of items presented early within a category is better than recall of items presented later within this category. Jakab and Raaijmakers reasoned that if items presented earlier are better encoded, then they should also compete for access more than items presented later for which encoding is impoverished. However, when they analyzed RIF as a function of within-category serial position, they failed to find any evidence for variability in the size of the RIF effect which led them to conclude that RIF is not sensitive to the amount of competition exerted by Rp- items during

retrieval practice of Rp+ items. In Experiment 3 Jakab and Raaijmakers applied a similar logic but changed the way competition was manipulated. In this experiment they repeated some of the Rp- items (and their corresponding Nrp items) twice during the study phase to make them more accessible at retrieval practice. Again, this manipulation failed to affect RIF, which was found to be of the same magnitude for Rp- items presented once and twice. Altogether, the results of experiments reported by Jakab and Raaijmakers are inconsistent with the assumption that RIF depends on the amount of competition exerted by Rp- items during retrieval of Rp+ items and thus do not support the inhibitory account of RIF. They are, however, fully consistent with the interference-based account of RIF which does not assign any special role to competition during retrieval practice in producing the RIF effect.

To sum up, the current state of knowledge on the competition dependence of RIF does not allow for clear conclusions about the mechanism of this effect. Although there are studies that by showing that forgetting is specific to strong exemplars of studied categories suggest that RIF is dependent on competition during retrieval practice (Anderson et al., 1994; Bäuml, 1998), there are also some failures to replicate these results (Williams and Zacks, 2001). Other manipulations have been used to investigate this issue (Anderson, Bjork et al., 2000; see also Storm, Bjork, & Bjork, 2007) but they are flawed by a limited control over the degree of strengthening that occurs during retrieval practice between different conditions which can be responsible for varying levels of RIF according to the interference-based account of this effect. On the other hand, recent studies by Raaijmakers and Jakab (2012; Jakab & Raaijmakers, 2009) indicate that RIF is not competition dependent which contradicts the results obtained in studies manipulating competition by using words with different taxonomic frequency.

### 2.3.5 Cue independence of RIF

Cue independence is the property of RIF that has been first proposed by Anderson and Spellman (1995) as an ultimate standard that allows for distinguishing between inhibitory and interference-based accounts of RIF. As has been described in the introduction to the present chapter, the interference-based

account makes a quite specific prediction that RIF should be detected only when the same cues are used to access memory during retrieval practice and a final test. However, the inhibitory account of RIF is not constrained in such a way and is free to postulate much more general impairment to memory for Rp- items. According to Anderson and his colleagues, (Anderson & Bjork, 1994; Anderson & Spellman, 1995) inhibition should be defined as suppression of semantic features that are included in the representation of Rp- items. In this so called pattern-suppression model activation of Rp- items that compete during retrieval practice of Rp+ items is dampened by an inhibitory mechanism that suppresses the individual features of Rp- items that differentiate them from Rp+ items. Importantly, this account predicts a very general impairment to memory that should be reflected in virtually every test that taps into these suppressed features. Curiously, this theoretical formulation does not even postulate that forgetting should be limited to Rp- items alone and instead predicts that RIF could be detected even for items which are semantically related to Rp- items by virtue of containing the same suppressed features. The most important prediction of this account is, however, that impairment to memory should be revealed not only with cues for which different associations were strengthened during retrieval practice of Rp+ items but with all cues that are used to access suppressed semantic features. Thus, according to the pattern-suppression model of inhibition, impairment of Rp- items in the retrieval practice paradigm should be cue-independent.

It is again important to stress at this point that the formulation of Anderson and Spellman (1995) constitutes a quite specific implementation of the idea of inhibition. In this thesis inhibition is defined as an active mechanism that is recruited to resolve interference from information stored in long-term memory which results in changes to the patterns already stored in long-term memory that can be subsequently detected in memory tests. This formulation does not require the assumption that changes necessarily pertain to representations of the items themselves rather than to the associations between cues and items. Thus, even if RIF was not cue independent, it could still be assigned to the workings of an inhibitory mechanism according to this definition. However, it remains the case that



if RIF is indeed cue-independent then the interference-based accounts could not account for it and hence some type of inhibitory mechanism would seem indispensable for the theories of memory.

The question is then whether RIF is in fact cue-independent. This question has been first addressed empirically by Anderson and Spellman (1995) who designed the independent cue methodology to answer it. In this methodology items belonging to two different categories are used for all crucial comparisons. In the variant of methodology proposed by Anderson and Spellman, participants studied four categories composed of six exemplars each. For each participant two categories were related so that half of the items from one of these categories belonged also to the other category, for example the category RED contained items like “apple” and “cherry” which could be classified also in a studied category FOOD, which in turn contained items like “radish” and “ketchup”, which could also be classified as RED. These items were referred to as “similar”. The other half of the items, referred to as “dissimilar”, could be classified only in the category in which they were studied, for example “blood” for category RED and “bread” for category FOOD. For each participant the remaining two categories were not related and did not contain any items that could be classified into two different categories. These unrelated categories contained also similar and dissimilar items but by the use of a counterbalancing scheme they were paired in such a way that even similar items belonged to only one category (thus, they were functionally also dissimilar). In this design participants performed retrieval practice for one related and one unrelated category. Importantly, for the related category only dissimilar items were practiced. Finally, participants were given a category-cued recall test in which they were asked to recall all studied items. The design of the experiment was 2 x 4 with both relatedness and item type (Rp+, Rp-, Nrp-similar, and Nrp dissimilar) manipulated within-participants. With this design Anderson and Spellman obtained the usual RIF effect in the unrelated condition (which was identical to the standard retrieval practice paradigm). Of more importance, in the related condition performance for Rp- items was identical to performance for the Nrp-similar items and significantly lower than performance for Nrp-dissimilar items. In other words, retrieval practice

for dissimilar items like RED – blood impaired memory not only for Rp- items that were studied in the same category, like RED – apple, but also for Nrp-similar items that semantically belonged to the category RED but were actually studied and tested with a cue FOOD, like FOOD – radish. Importantly, the cue used to access Nrp-similar items was not used during retrieval practice and thus should not have been subjected to interference arising from any strengthening that might have occurred in this phase. In other words, impairment for Nrp-similar items appeared to be cue-independent.

Anderson and Spellman (1995) termed this novel finding of reduced memory performance for Nrp-similar items *cross-category impairment* as retrieval practice of Rp+ items from one category impaired related items that were studied and tested as part of a different category. However, Anderson and Spellman also pointed out the weakness of this particular design. Specifically, in this design Nrp-similar items semantically belonged to two different categories that were included in the study phase and participants may have been confused as to under which label they were studied. Such confusion may have led participants to withhold answers that they did remember which would have resulted in reduction in performance compared to the baseline of Nrp-dissimilar items for which such confusion could not have occurred. These considerations led Anderson and Spellman to develop an alternative version of the independent cue methodology in which the independent cue used in the test was not present during the study. In this version of the procedure the items from related categories belonged together in the third category which was not present during the study at all. For example, participants studied related categories GREEN and SOUPS. The category GREEN contained similar items like “lettuce” and “pepper” and dissimilar items like “dollar”. Also the category SOUPS contained similar items like “onion” and “tomato” and dissimilar items like “chicken”. The main change compared to Experiment 1 was that similarity of items meant not that the items belonged to two different studied categories (i.e. “lettuce” does not belong to the category SOUPS) but that they belonged to a common third category, in this case VEGETABLE (which includes “lettuce”, “pepper”, “onion” and “tomato”). These covert categories,

which were embedded in the design but were not mentioned during study or retrieval practice, were employed in the final test to assess memory for all similar items, whether they were studied in the related or unrelated condition. With this design Anderson and Spellman obtained two important results. Firstly, they showed impairment for Rp- items compared to Nrp-similar items in the unrelated condition even when participants were tested with covert categories. This finding indicates that impairment for Rp- items generalizes to independent cues. Secondly, they documented impaired memory performance for Nrp-similar items in the related condition relative to performance for the same items in the unrelated condition. This latter effect was present both when Nrp similar items were tested with the cues that they were studied with and when they were tested with covert categories. Because none of these cues were present in retrieval practice or in any way related to Rp+ items, both of these results can be taken to prove that impairment for Nrp similar items was cue-independent.

This impairment for Nrp similar items, referred to here as *second-order impairment* (instead of the original term “second-order inhibition” which confounds the effect with its postulated mechanism), is particularly interesting as it served to establish the tenets of the pattern-suppression model of inhibition. To reiterate, the second-order impairment describes impairment to memory for items that belong to the same semantic category as Rp- items but do not share any semantic relationship directly with Rp+ items. Using the examples given earlier, Anderson and Spellman (1995) documented that retrieval practice of a pair GREEN – emerald reduced accessibility of an item “onion”, independently of whether memory for this item was assessed by the cue SOUPS under which it was studied or the independent cue VEGETABLE. It would seem that “onion” was impaired solely by virtue of its belonging to the same semantic category of VEGETABLES together with Rp- items. Anderson and Spellman proposed that the way to account for these findings is to assume that inhibition works to suppress individual features of Rp- items competing for access during retrieval of Rp+ items. Importantly, these suppressed features are included in the number of other concepts that are thus also affected by inhibition, even though they do not compete for access during retrieval practice. Moreover,

suppression of features in semantic memory means that accessibility of items that contain these features is lowered independently of the cues used to access these items. Thus, the pattern-suppression model accounts for both second-order impairment and the fact that it is detectable with independent cues.

In the literature there are two published attempts to replicate the counterintuitive finding of cue-independent second-order impairment. Firstly, Saunders and MacLeod (2006, Experiment 2) adapted the design introduced by Anderson and Spellman (1995) for an eyewitness scenario. In this study participants read two narratives concerning burglaries of two houses in which several items had been stolen. The two houses served as an analogue of semantic categories, commonly employed in the retrieval practice paradigm. In the retrieval practice phase participants were asked to retrieve information about half of the items from one the houses (Rp+ items). The stolen items were arranged according to a similar scheme which governed the materials used in the study by Anderson and Spellman. Of most interest for the present purpose is that some of the items in the unpracticed house were similar to Rp- items from the practiced house by virtue of belonging to the same semantic category (e.g. jewelry) but they were not related to Rp+ items. Impairment of memory for such items would be indicative of second-order impairment. Indeed, in their experiment Saunders and MacLeod revealed such impairment for Nrp items similar to Rp- items compared to the baseline of dissimilar items. Furthermore, since Saunders and MacLeod used independent cues for their final test, the impairment proved to be cue-independent, exactly as postulated by Anderson's and Spellman's pattern-suppression model.

However, the results by Saunders and MacLeod (2006) may be less than clear-cut after closer scrutiny. The authors noted that the design they used did not implement counterbalancing of items between conditions and thus different items served as Nrp items similar to Rp- items and dissimilar Nrp. In principle, thus, the second-order impairment documented by Saunders and MacLeod could stem from an item selection artifact which made Nrp items similar to Rp- items more memorable than Nrp dissimilar items, as acknowledged by the authors themselves. To remedy this interpretational problem Saunders and MacLeod included also a

control group in their design in which no retrieval practice was performed. Also for the between-participants comparison for Nrp items similar to Rp- items the researchers documented reliable RIF. However, in this case the interpretation of this comparison crucially depends on the assumption that cueing for Nrp items does not activate Rp+ items that could interfere with retrieval and produce the RIF effect. Saunders and MacLeod employed semantic categories to differentiate Nrp items from Rp+ items and to cue memory in the final test. They reasoned that if participants are asked for “earrings” with the semantic cue “jewelry”, this should not activate an Rp+ item like “painting” that belongs to the category “art”. However, this assumes that participants use only the cues that are provided to them. In RIF literature it has been repeatedly argued that this does not have to be true. Several authors have pointed to the idea of covert cueing by which participants can try to use original cues to aid their performance in the final test in which only independent cues are provided by the experimenter (Perfect et al., 2004; Camp, Pecher, Schmidt, & Zeeleneberg, 2009). In the case of the study by Saunders and MacLeod such covert cueing could be an important factor as this study employed only two categories (two different houses). It is conceivable that participants in this study tried to recall all the items they could remember from both houses and only then do a check with the cues provided to them to see if any of the recalled items can be given as a response to a given cue. In this scenario the interference-based account of RIF would predict reliable RIF for the experimental condition due to interference from strengthened Rp+ items. Of course, the interference-based account would predict equal RIF for all types of unpracticed items in such a between-participants comparison, Nrp similar and dissimilar alike, whereas the inhibitory account would predict only the effects for Nrp similar items (both to Rp- and Rp+ items). However, Saunders and MacLeod reported only the results for Nrp similar items and not for Nrp dissimilar which precludes clear interpretation of these results. Thus, although the study by Saunders and MacLeod replicates the most telling result of cue-independent second-order impairment documented by Anderson and Spellman (1995), the interpretation of this result is clouded by methodological issues.

The second attempt to replicate the results obtained by Anderson and Spellman (1995) was undertaken in the study by Williams and Zacks (2001). Besides the already described issue of competition dependence, these authors addressed also the issues of cue-independence and the pattern-suppressions model by conducting a replication of the design employed by Anderson and Spellman. Williams and Zacks employed the methodology using the covert categories to organize materials and did obtain the standard RIF effect for Rp- items which were cued with the original cues used in the retrieval practice phase. However, no effect emerged for Nrp similar items which were related to Rp- items by virtue of belonging to the same covert category but were not related to Rp+ items. Williams and Zacks did not use labels of the covert category as Anderson and Spellman did, so their results are mute on the issue of cue-independence of impairment of Rp- items but they are inconsistent with the idea of second-order impairment and thus with the important piece of evidence used to support the pattern-suppression model. It is important to notice that the study by Williams and Zacks used a larger number of items per condition and a larger number of participants than Anderson and Spellman did and thus their null finding is unlikely to stem from a lack of statistical power.

The question arises why the results of the studies by Anderson and Spellman (1995) and Williams and Zacks (2001) produced inconsistent results. This question was addressed in the detailed discussion of the issue of cue-independence presented by Perfect et al (2004). These authors analyzed in detail the results obtained by Anderson and Spellman by comparing levels of recall in control conditions in various experiments conducted within their study. Besides already mentioned experiments that assessed cross-category and second-order impairments, Anderson and Spellman conducted an experiment which was designed to address the issue of the role of retrieval practice in producing the aforementioned effects. Anderson and Spellman were worried that some features of their materials may produce impairments that emulate RIF which have nothing to do with retrieval practice of Rp+ items. To address this issue they conducted an additional experiment in which retrieval practice was eliminated and discovered

that the RIF effect were absent after this change. Perfect et al. noticed that this control experiment allows for comparing the level of performance for both Nrp similar and Nrp dissimilar items with the baseline that could not have been affected by retrieval practice. They discovered that although the second-order effects reported by Anderson and Spellman were 12% and 15% across their two different experiments, when the same second-order impairments for Nrp similar items were assessed against the novel baseline provided by the experiment without retrieval practice the sizes of the effects were reduced to only 3% in the test in which output order was controlled and 9% for the test without such control. This great reduction in the sizes of the second-order effects could be traced to differences in baseline performance between studies. Specifically, although the baseline performances for Nrp similar items in the unrelated condition for the two experiments employing retrieval practice were 52% and 57%, the performance for the same items in the control experiment was only 48%. Thus, Perfect et al. concluded that the bulk of the second-order effects found by Anderson and Spellman stems from inexplicably high levels of baseline performance rather than reduction in the performance for items similar to Rp- items.

To sum up, although the second-order impairment would provide strong argument for the inhibitory account of RIF, the empirical results concerning this issue are scarce and the published studies are inconsistent and open to alternative explanations. However, it is important to note that although the second-order impairment is predicted by the pattern-suppression model and served as the major source of evidence for this model, it is not the only cue-independent effect that has been found in the retrieval practice paradigm. Indeed, the majority of studies assessing cue-independence of RIF focused not on the second-order effects but rather on the nature of impairment to memory for Rp- items. In the study by Anderson and Spellman (1995) the usual impairment of Rp- items has been found to be cue-independent as Rp- items were still impaired relative to the Nrp baseline when covert categories were used to cue memory. Also the documented cross-category impairment by which items semantically related to the practiced category but studied and tested under a different label constitutes evidence for cue-

independence. The remaining part of the present section will describe the studies concerning the impairment to Rp- items which has been the focus of all remaining studies on cue-independence.

There are several published reports that document cue-independence of impairment to Rp- items in the retrieval practice paradigm. Most notably, Anderson, Green et al. (2000) provided results supportive of the cue-independence of RIF with the novel paradigm that focused exclusively on impairment to Rp- items. In this paradigm participants studied several categories for which half of the items could be classified also as members of another covert semantic category (e.g. RED – apple – FOOD). In contrast to the procedure developed by Anderson and Spellman (1995), in the design proposed in this study each covert category was related to only one studied category. Thus, rather than to have items from both practiced and unpracticed categories belonging to a single covert category, in this study items from practiced categories belonged to different covert categories than items from unpracticed categories. For practiced categories participants were asked to retrieve items that did not belong to any covert categories (e.g. RED – fire). Memory in the final test was assessed only with the covert categories and thus only for Rp- and Nrp items. Using this design Anderson et al. examined the influence of encoding similarities between different studied items on the size of the RIF effect. Participants studied all items twice, once under instructions directing participants to relate studied items to cues and once under instructions directing them to encode either similarities between Rp+ and Rp- items or between different Rp- items (Experiment 1) or to encoding unique properties of different items (Experiment 2). In both experiments Anderson et al. documented reliable RIF with independent cues, with the exception of the condition stressing the encoding of similarities between Rp+ and Rp- items. Other examples of demonstrations of the cue-independence of RIF come from the study by Aslan et al. (2007b) who observed cue-independent RIF for older and younger adults, the study by Johnson and Anderson (2004, Experiment 2) in which retrieval of some exemplars of several categories from semantic memory caused cue-independent forgetting of the strongest but not practiced items from practiced categories and the study by



Anderson and Bell (2001) in which cue-independent RIF was found for fact knowledge.

An interesting case for the discussion on the cue-independence of RIF is provided by a study conducted by Camp et al. (2005). In this study the design proposed by Anderson and Spellman (1995) was implemented and the finding of cue-independent forgetting of Rp- items was replicated in Experiment 1 (the authors did not report the data relevant to the possible second-order impairment). Experiment 2 used the same design but changed the explicit test of cued recall to implicit test of category generation. Participants were given covert categories and asked to generate six exemplars for each category. Crucially, Camp et al. included in their procedure a questionnaire assessing awareness of the connection between the test and earlier phases of the experiment. When the answers provided in this questionnaire were taken into account, reliable RIF was obtained for aware participants but not for unaware ones. Thus, in this study evidence for cue-independence of RIF was obtained but, interestingly, this impairment was present in an implicit test only for participants who reported that they were aware of a connection between study and retrieval practice on one hand and the implicit test on the other. This result is revisited later when possible explanations of discrepancies in results concerning the cue-independence of RIF are discussed.

Unsurprisingly, there are also studies in the published literature in which RIF was not found with independent cues. Shivde and Anderson (2001) reported experiments concerning RIF in memory for homographs. In this study participants studied triplets of pairs of words in which one pair described a dominant meaning of a homograph (e.g. arm – shoulder), one pair described a subordinate meaning of a homograph (e.g. arm – missile), and one pair provided an independent cue for assessing a dominant meaning in a final test (e.g. satchel – shoulder). In this design participants repeatedly practiced retrieval of a subordinate meaning (e.g. cued with arm – m\_\_\_) with a varying number of retrieval practice trials (0, one, five and 20 trials). In Experiment 1 in which memory for a dominant meaning was assessed with a homograph itself (an analog to original cues in the standard retrieval practice paradigm) significant impairment was found for all levels of retrieval practice

compared to the baseline of no retrieval practice trials. However, in Experiment 2, in which memory was assessed with an independent cue, no below-baseline forgetting was observed. Instead, a curvilinear relation of a number of retrieval practice trials to memory performance was found by which recall of dominant meaning increased relative to baseline after a single retrieval practice trial but was reduced to the baseline level after 20 retrieval practice trials for a subordinate meaning. The finding of a curvilinear relation of a number of retrieval practice trials and memory for a dominant meaning of a homograph when independent cues are employed at test was replicated in the study by Johnson and Anderson (2004, Experiment 1). The important point is here that according to the results obtained by Shivde and Anderson the impairment due to retrieval practice appears to be different when original cues or independent cues are used at test, an observation difficult to reconcile with the account according to which impairment stems solely from the operation of an inhibitory mechanism at the level of memory representation but not at the level of associations.

The materials and procedures employed by Shivde and Anderson (2001) were different from those commonly employed in the research on RIF. However, there are also studies which employed standard materials and also failed to obtain evidence for the cue-independence of RIF. In a series of experiments conducted by Perfect et al. (2004) episodic independent cues were used. Perfect et al. argued that independent cues that are semantically related to to-be-retrieved items can be considered independent only in the weak sense by which they are not included in the retrieval practice phase. However, these cues are still similar to original cues as they are related by virtue of being associated to common items. To use the example of materials employed by Anderson, Green et al. (2000), the category FURNITURE, which was used as an independent cue for items presented originally under the category WOOD (like “bench” or “desk”), is itself related to this original cue. This, according to Perfect et al., raises the possibility that given an independent cue FURNITURE participants try to aid their recall of individual exemplars by recalling first the original cue WOOD and then using this cue during retrieval. This account has been mentioned earlier in respect to results obtained by Saunders and

MacLeod (2006). Perfect et al. argued that in order to properly assess the cue-independence of RIF the cues that are independent in a strong sense, namely the cues that are in no way semantically related to the original cues, should be used to assess memory in a final test.

Perfect et al. (2004) presented three experiments with cues that were only episodically related to items studied in the retrieval practice paradigm and thus bore no relationship to the original cues. In Experiments 1 and 2 Perfect et al. associated studied items with individual faces. Thus, on each study trial participants saw a category label together with an exemplar of this category and an individual face. Subsequently, participants practiced retrieval of Rp+ items when cued with category labels (Experiment 1) or with category labels and individual faces (Experiment 2). Finally, participants were tested for their memory of studied items with tests that either employed category labels alone, faces alone or category labels and faces together as cues. In Experiment 1 reliable RIF was obtained only when participants were cued with category labels and in Experiment 2 it was obtained when participants were tested either with category labels alone or with category labels and faces together. From these results Perfect et al. concluded that RIF is obtained when cues used at test match the cues that are employed at retrieval practice and thus RIF is not cue-independent. In their Experiment 3 Perfect et al. tested this idea again with the procedure employing only words as materials. Specifically, in the pre-study session each studied item was associated with an unrelated word that later served as a cue during the final test in the independent cue condition. In this experiment RIF was present when memory was tested with standard category cues but failed to emerge when memory was tested with episodic independent cues, once again providing evidence against the cue-independence of RIF.

Another study that failed to support the cue-independence hypothesis was conducted by Camp, Pecher, and Schmidt (2007). These researchers used independent cues that were semantically related to to-be-retrieved items but, importantly, each cue was associated to only one studied item. In the majority of previous studies examining the cue-independence of RIF, semantic cues were

related to several items either simultaneously from both practiced and unpracticed categories (Anderson & Spellman, 1995; Camp et al., 2005; Saunders & MacLeod, 2006) or to one of these categories alone (Anderson, Green et al., 2000). This multiple associations could increase the chances of using the covert cueing strategy during a final test because the larger is the number of items common to the studied and covert categories, the greater is the chance that participants spot the interdependencies in the studied materials. For example, if participants study four exemplars of category WOOD that are also members of covert category FURNITURE, they may notice this relationship and later attempt to utilize it by recalling the original cue WOOD to aid recall performance. Camp et al. reasoned that participants will be unable to encode any relationship between independent cues and studied items when each would be related to only a single item in a set which should minimize the effects of covert cueing. Under these conditions Camp et al. failed to obtain RIF with independent cues, although they documented reliable RIF using the same materials when original cues were used at test.

To sum up, the literature on the cue-independence of RIF is not entirely consistent. Several studies have documented the cue-independence of RIF which has been taken as the main piece of evidence for the contribution of inhibition to forgetting in the retrieval practice paradigm but several studies found that RIF was in fact limited to tests employing cues present at retrieval practice and did not generalize to independent cues. There are two ways to resolve these discrepancies. Firstly, the already mentioned hypothesis of covert cueing proposes that independent cues may sometimes not be truly independent since they can be in some way related to original cues. This relationship may be noticed by participants and utilized to retrieve original cues which are in turn used to search for the studied items. According to this explanation, RIF is not cue independent and is constrained to situations in which cues used at retrieval practice are also used during a final test. Furthermore, RIF can appear to be cue-independent when participants provided with independent cues retrieve the cues used at retrieval practice to aid their memory performance. Of course, the explanation from covert cueing is consistent with the interference-based account of RIF. It may also be consistent

with inhibitory frameworks that do not postulate cue-independence. Specifically, it is consistent with the constrained episodic inhibitory model which assumes that inhibition operates solely on the episodic associations that link an Rp- item to its original cue. Such episodic association could be unlearned as an effect of recruiting the inhibitory mechanism which would result in impaired performance for Rp-items whenever original cues are used to access these items.

The covert cueing hypothesis was first discussed by the Anderson and his colleagues (Anderson, Green et al., 2000; Anderson & Bell, 2001) who argued that this hypothesis is not able to account for the overall pattern of results obtained with independent cues. One of the arguments against this hypothesis was that when participants were given a post-test questionnaire to assess the strategies they adopted in the test, the magnitude of the RIF effect was not related to the self-rating of frequency of using the covert-cueing strategy (Anderson, Green et al., 2000). However, as pointed out by Perfect et al. (2004), results obtained with such questionnaires are not able to resolve the discussion on the covert cueing hypothesis as participants may be unable or unwilling to correctly report on the strategies they used in the test. Moreover, the results obtained by Anderson et al. suggest that participants do indeed use covert cueing strategies, which makes the use of independent cueing procedure questionable. This point has also been recently raised by Camp et al. (2009), who provided empirical support for the hypothesis of covert cueing (but see Huddleston & Anderson, in press, for a different view). In their study participants studied pairs of weakly related words (e.g. rope – sailing, sunflower – yellow) and then recalled the second words from each pair when cued with either with the first word from this pair (Experiments 3 and 4) or an independent semantic cue (e.g. sport, colour, Experiments 1, 2, and 4). Importantly, for half of the pairs the first word of a pair was presented twice even before the main study phase within an ostensibly unrelated task. Using this design Camp et al. documented increased recall performance for pairs with strengthened cues when independent cues were employed at test. This result suggests that participants provided with independent cues recalled original cues to aid memory performance, a strategy that proved to be more effective when these original cues

were strengthened by additional presentations. Importantly, no benefits of these presentations were observed when recall was assessed with original cues which ruled out any possible explanations of the effect obtained with independent cues in terms of encoding benefits. Thus, the results of this study strongly suggest that the independent cue methodology may be flawed because even when participants are provided only with independent cues they still use original cues to aid their performance. It remains, however, the case that no study documented that this covert cueing mechanism is indeed responsible for RIF when independent cues are employed at test. The study by Camp et al. documented that participants can use covert cues in the independent cue test but it did not employ the retrieval practice paradigm and thus it does not link the mechanism of covert cueing to impairment in memory for Rp- items.

The second way the discrepant findings observed with independent cues can be accounted for is also offered by the episodic inhibition framework. Specifically, it is possible that RIF is caused by changes to memory representations due to operations of an inhibitory mechanism that stretch beyond the original cue-to-Rp- items associations but not all cues tap into the affected parts of memory representations. The well-specified implementation of this variant of the episodic inhibition idea was proposed by Norman et al (2007). In their computational model they proposed that RIF is caused by unlearning of episodic associations as well as unlearning of associations between features stored in semantic memory. The unlearning is caused by an adaptive mechanism which is recruited during retrieval practice to simultaneously strengthen the to-be-retrieved Rp+ items and weaken the competing Rp- items. Importantly, Norman et al. argued that due to a much higher learning rate of episodic compared to semantic associations, RIF, as observed in standard episodic tasks such as the retrieval practice paradigm, is mainly due to changes in the episodic rather than semantic networks. Although this model is not inhibitory in nature according to the formulations proposed by Anderson and Spellman (1995), as it concerns associations between items rather than representations of the items themselves, if a broader definition of inhibition is adopted, as in the present work, then the model can be treated as inhibitory.

According to this model forgetting results from an active process that is targeted against competing items stored in long-term memory and which results in long-lasting consequences for memory representations of these items.

Norman et al. (2007) applied their model of RIF to account for discrepancies found in the literature concerning the cue-independence of RIF. They argued that their model is able to account for the cue-independence of RIF as long as episodic associations between Rp- and Nrp items and their respective independent cues are created in the retrieval practice paradigm. Conducting simulations with their model, they showed that when participants try to retrieve Rp+ items and Rp- items compete for access, the activation from a semantic representation of Rp- items spills to episodic memory records in which Rp- items are represented and this activation triggers an inhibitory mechanism that weakens activated episodic links. If episodic memory contains records linking Rp- items and their independent cues, these episodic associations become disrupted during retrieval practice of Rp+ items which results in the apparently cue-independent forgetting in the final test. This mechanism can account for RIF observed with some independent cues. It can easily account for the cross-category impairment observed by Anderson and Spellman (1995) by assuming that items semantically belonging to a practiced category but studied within a different category compete for access during retrieval practice and thus an episodic link between these items and categories within which they are studied becomes disrupted. However, it is worth pointing that this model has no way to account for the finding of second-order inhibition (Anderson & Spellman, 1995) as in this case impairment is found for items that are unrelated to a practiced category and thus which are unlikely to become activated during retrieval practice, which is in this model a precondition for observing inhibitory effects.

As for the most important issue of cue-independence of impairment to Rp- items, the model proposed by Norman et al. (2007) provides a somewhat mixed account. The first thing to notice is that this model focuses on the unlearning of associations that are present in episodic memory. Thus, in order to account for any effect found with independent cues it requires that these cues are encoded into episodic memory. However, the majority of studies that documented cue-

independent impairment for Rp- items did not present independent cues during study or retrieval practice and introduced them only during the final test (Anderson, Green et al., 2000; Camp et al., 2005; Aslan et al., 2007b; Saunders & MacLeod, 2006), although there are also exceptions to this rule (e.g. Anderson & Bell, 2001). In order to account for the effects found with independent cues introduced only at test, this model needs to postulate that these cues are in fact identified and linked to Rp- and Nrp items already during the study phase. This idea brings this account close to the covert cueing hypothesis which, as discussed above, also postulates that participants identify independent cues during the study phase, but rather than stressing creation of associations between these identified cues and Rp- items, it stresses associations between identified cues and original cues. In effect, the solutions the episodic inhibition model offers to problems that perplex the literature on cue-independence are sometimes similar to the ones offered by the covert cueing hypothesis. Specifically, this model predicts that RIF was not present in the study by Camp et al. (2007) because semantic independent cues that were related to only one item in a studied set could not have been identified during study and thus no episodic links were created that could have been disrupted by inhibition.

Another challenge for the model proposed by Norman et al. (2007) comes from the results obtained by Perfect et al. (2004) in which no RIF was observed with independent cues that were episodically linked to Rp- and Nrp items. In discussing this study Norman et al. argued that although episodic links were present in this case, they were not activated by semantic representations of Rp- items in the retrieval practice phase. For Experiments 1 and 2 this failure to activate episodic representations stemmed from the use of faces as independent cues as this type of stimuli mismatched the format that was sought after in the retrieval practice phase. However, in relation to this point it is worth noting that Norman et al. discussed it only briefly and did not address it with a computation analysis. It is not entirely clear why mismatching format would prevent activation of episodic links that involve faces when this activation starts in semantic memory which does not contain information about purely episodic features like the format of presentation.



It is, however, possible that participants are able to restrict a search of memory to certain types of stimuli, a possibility supported by studies examining models of memory monitoring and retrieval orientation (Jacoby et al., 2005; Budson, Droller, Dodson, Schacter, Rugg, Holcomb, & Daffner, 2005). If this was the case, then faces were possibly not activated during retrieval practice because participants were able to restrict the memory search to words when looking for Rp+ items. For Experiment 3 from the study by Perfect et al. the argument was different and focused on contextual cueing. Specifically, Norman et al. proposed that the amount of activation of episodic associations is gated by the contextual match between the episode in which association was created and the episode of retrieval practice. When participants try to recall Rp+ items they use contextual information from the study phase to augment the retrieval process. This contextual cueing increases activation of all associations created in this context but works against activation of associations created in a different context. In Experiment 3 from the study by Perfect et al. words used as independent cues were associated with studied items during the pre-study phase and thus in a different context to the one used to cue Rp+ items in the retrieval practice phase. This mismatching context was, according to Norman et al., responsible for the lack of activation of associations between Rp- items and their independent cues during retrieval practice of Rp+ items and thus for the lack of cue-independent RIF in this experiment.

#### Summary of cue independence studies on RIF

To summarize all considerations on the cue-independence of RIF, the overall pattern of results is still open to various interpretations. There are findings like second-order inhibition which seem to be consistent exclusively with the pattern-suppression inhibitory model (Anderson & Spellman, 1995) but which may be difficult to replicate (Williams & Zacks, 2001) and which may stem from some methodological oddities within the designs (Perfect et al., 2004). In contrast, there are successful replications of findings supporting the cue-independent nature of forgetting to Rp- items (Anderson, Green et al., 2000; Camp et al., 2005; Aslan et al., 2007; Anderson & Bell, 2001). However, there are also failures to obtain this effect with some variants of the independent cue methodology (Perfect et al., 2004; Camp

et al., 2007). Two main proposals that could account for these discrepant findings are the covert cueing hypothesis, which is consistent with the interference-based account of RIF, and the episodic inhibition hypothesis. Regarding the covert cueing hypothesis, some research has indicated that people use this strategy when provided with independent cues (Anderson, Green et al., 2000; Camp et al., 2009). However, it is still an open question whether covert cueing may indeed lead to RIF with independent cues. Regarding the episodic inhibition hypothesis, the specific computational model developed by Norman et al. (2007) implements this idea and can possibly account for observed discrepancies. However, this model still lacks empirical support and it remains to be shown whether or not it is capable of correct predictions concerning the cue-independence of RIF.

The experiments presented in the empirical part of the present thesis address the issue of cue-independence of RIF by examining RIF for Rp- items with various types of independent cues, including category independent cues related to multiple items in the memory set (Experiments 1 and 2), item-specific semantic associates of individual items (Experiments 2, 4, and 8) and episodic associates of individual items (Experiment 7). The experiments aim also to address the episodic inhibition account of cue-independence (Experiments 4 and 7), as well as the covert cueing hypothesis (Experiment 8).



### **3. List-method directed forgetting**

#### **3.1 Introduction**

The second paradigm that is widely used to examine inhibitory processes in long-term memory is list-method directed forgetting (Bjork, LaBerge, & Legrand, 1968). In this paradigm two lists are presented to participants. In the Forget condition participants are instructed after the presentation of the first list that they should forget it in order to facilitate learning of the second list (Mulji & Bodner, 2010). Memory performance for these two lists is compared to memory performance for two lists presented in the Remember condition in which participants are instructed to remember both of the presented lists. Memory is usually assessed with a free recall task. The common finding from this paradigm is a crossover interaction of condition and list by which memory performance for list 1 items is worse in the Forget condition than in the Remember condition, which is referred to as costs of directed forgetting, but performance for list 2 items is actually improved in the Forget condition relative to the Remember condition, which is referred to as benefits of directed forgetting. The focus of the present chapter will be on costs of directed forgetting which are thought to reflect the operation of an inhibitory mechanism. Thus, the term directed forgetting effect will be used to denote the decreased memory performance for items from list 1 in the Forget condition compared to the Remember condition, unless otherwise noted. However, the considerations on the benefits of directed forgetting will also be occasionally presented because of a strong assumption of an inhibitory account that links costs and benefits, as described later.

An important feature of the list-method directed forgetting paradigm is that instructions to forget list 1 are commonly administered only after the whole list has been presented to participants under conditions of intentional study (but see Bjork & Bjork, 1996, for an exception). It is assumed that participants commit the items from list 1 to long-term memory and thus the instruction to forget them affects the contents of long-term memory store. This feature of the list-method directed forgetting differentiates this procedure from the item-method directed forgetting

paradigm described in the first chapter, in which processes of intentional forgetting pertain to information present in working memory but not necessarily in long-term memory.

List-method directed forgetting (referred to as directed forgetting for the rest of this chapter) is a phenomenon usually investigated with simple laboratory procedures with students as participants but this phenomenon is not without important consequences for memory outside of the laboratory. Several lines of investigation sought to link directed forgetting effects to real-life phenomena. One such approach is to consider instructions presented during a court trial to discount inadmissible evidence as an instantiation of intentional forgetting of already stored information (e.g. Johnson, 1994). Another important approach is to look for relationships between directed forgetting and clinical conditions under the assumption that processes involved in regulating the contents of memory are altered in different groups of patients (e.g. Racsmany et al., 2008). Also studies implementing the variants of the directed forgetting paradigm to investigate autobiographical remembering found that participants can in fact intentionally reduce accessibility of the whole of autobiographical events (Joslyn & Oakes, 2005; Barnier, Conway, Mayoh, Speyer, Avizmil, & Harris, 2007; El Haj, Postal, Le Gall, & Allain, 2011).

## **3.2 The mechanisms of directed forgetting**

### **3.2.1 Differential rehearsal**

Three different mechanisms have been proposed to account for the directed forgetting effects, differential rehearsal, retrieval inhibition and context change. Historically, the first proposed mechanism was one of differential rehearsal of to-be-forgotten and to-be-remembered items. In the early era of research on directed forgetting, the list-method and the item-method were treated as a single type of procedure with a common explanatory mechanism. Bjork (1970; 1972) proposed that presentation of the forget instructions results in two effects. Firstly, participants create two different groupings of items, one that encompasses all items that should be remembered and the other encompassing all items that

should be forgotten. Secondly, participants devote all their rehearsal operations to to-be-remembered items at the cost of to-be-forgotten items. In the list method directed forgetting performance in the Forget condition is compared to performance in the Remember condition, in which this rehearsal-borrowing does not occur and participants rehearse items from both lists to a similar degree, even favouring items from list 1, as evidenced by a commonly obtained list 1 items memory superiority (Lehman & Malmberg, 2009).

The differential rehearsal hypothesis was popular at the early stages of research on directed forgetting but lost most of its appeal when a growing body of data indicated that it does not provide a good account of the list-method directed forgetting effects (although it remains the popular explanation applied in the item-method directed forgetting studies). The evidence considered to be deciding for refutation of the differential rehearsal account of directed forgetting was presented by Geiselman et al. (1983). In their study Geiselman et al. investigated the effects of directed forgetting for items that were learned incidentally. In three experiments the study session was composed by mixing two different orienting tasks. Participants were presented with words which they were either asked to remember for a future test or were asked to judge for pleasantness. In the Forget condition participants were asked to forget the words from list 1 they were initially asked to remember and in the Remember condition they were asked to remember the studied words for the final test. Importantly, no mention was made about the words presented within the pleasantness judgment task as participants were never instructed to remember these words in the first place. However, the results revealed that instructions to forget affected not only intentionally learned items but also incidentally learned items for which both the costs and the benefits of directed forgetting emerged. These effects for incidentally learned items (replicated recently by Sahakyan & Delaney, 2005) were taken by Geiselman et al. to suggest two things. Firstly, this effect seems to run counter to the simple explanations of directed forgetting in terms of demand characteristics. Participants should not withhold the incidentally learned items which they were not actually asked to forget. Secondly, and more importantly for the present discussion, these results for

incidentally learned items are inconsistent with the prediction that could be derived for the differential rehearsal account of directed forgetting. Specifically, there is no reason to expect participants to rehearse words that were not presented to them for intentional study and thus according to the differential rehearsal account no directed forgetting effects should be present for these items because they should not be affected by the changes in rehearsal strategies.

Recently, MacLeod and his co-workers (C. M. MacLeod et al., 2003; Sheard & MacLeod, 2005) argued that differential rehearsal should be reconsidered as a mechanism of directed forgetting. The argument in support of this mechanism involved new evidence from a delay manipulation as well as a new set of analyses on the effects of directed forgetting at different serial positions of the to-be-forgotten list. In one set of experiments the delay between study phase and a free recall test was manipulated (see also Basden & Basden, 1998). It was found that for well performing participants delay increases the effect of instructions to forget, except for a situation in which participants are given a warning before the delay that both to-be-forgotten and to-be-remembered items will be tested in which case directed forgetting effects are eliminated. According to MacLeod and his colleagues these results can be accounted for by assuming that during the delay high performing participants who are capable of implementing efficient learning strategies continue rehearsing to-be-remembered items at the cost of to-be-forgotten items which leads to exaggerated directed forgetting effects. The warning provided before the delay changes rehearsal strategies so that both sets of items are rehearsed which abolishes directed forgetting effects. The other line of evidence has been based on the findings concerning serial position effects. In the experiments described by MacLeod and his colleagues instruction to forget affected primacy and recency effects for list 1 items but had no effect on items presented in the middle of the list. This would be predicted by differential rehearsal hypothesis if it is assumed participants are prone to rehearse items from beginning and end of the presented list.

Despite the arguments presented by Sheard and MacLeod (2005) differential rehearsal is still seldom used as an explanatory framework for directed

forgetting. Several factors contribute to this state of affairs. Firstly, the new findings concerning serial position effects reported by Sheard and MacLeod came from a comparison between list 1 and list 2 which is sometimes used in the studies on directed forgetting but which has been often criticized due to confounds it involves (like presence of proactive and retroactive interference, see Anderson, 2005 for a discussion). The commonly used design with two separate lists in Forget and Remember conditions failed to produce directed forgetting costs in the experiment reported by Sheard and MacLeod, precluding the meaningful analysis of serial position effects. The recent study by Lehman and Malmberg (2009) provided new data on serial position effects, showing that instructions to forget eliminate the primacy effect on list 1 recall but it also affects two thirds of the entire list of 16 words, a finding difficult to reconcile with differential rehearsal hypothesis which would need to assume that participants are capable of rehearsing 10 words from one list, a number far exceeding the capacity of working memory. Secondly, although the results concerning warning manipulation suggest that selective rehearsal of to-be-remembered items can exaggerate directed forgetting effects, it does not prove that it is responsible for the effects in the common delay-free procedure. Thirdly, the new evidence supporting the differential rehearsal account does not address the results provided by Geiselman et al. (1983) which was responsible for the decline of this account in the first place. Fourthly, the selective rehearsal account is not consistent with the common observation that directed forgetting costs are absent in recognition (e.g. Basden et al., 1993; Benjamin, 2006). Selective rehearsal is an encoding mechanism which should give rise to directed forgetting independently of the conditions of retrieval. Together, these arguments suggest that differential rehearsal does not provide a comprehensive account of directed forgetting effects, although some variant of this encoding mechanism may contribute to the directed forgetting phenomenon, as discussed later in relation to the dissociation between directed forgetting costs and benefits.

### 3.2.2 Retrieval inhibition

The popularity of the directed forgetting paradigm stems to a certain extent from the fact that it is one of a few paradigms which are used to support the notion



of inhibition in long-term memory. The suggestion that the directed forgetting paradigm may involve the process of active suppression of to-be-forgotten items was first proposed in the work by Weiner (1968; Weiner & Reed, 1969), who drew a theoretical link between the effects of directed forgetting and the concept of repression present in clinical psychology (see also Erdelyi, 2006, for a discussion of relationship between inhibition and repression). However, the increased interest in the inhibitory mechanisms of directed forgetting came with the already described work by Geiselman et al. (1983). In this paper Geiselman et al. provided evidence contradicting the predictions formulated by the differential rehearsal account of directed forgetting and postulated that the effects are better described within an inhibitory framework. In this view the instruction to forget triggers an inhibitory mechanism that minimizes interference from outdated information that could impede learning or recall of more relevant to-be-remembered items (see Bjork, 1989, for a more detailed instantiation of this hypothesis). Geiselman et al. presented the first two pieces of evidence that in their opinion supported the inhibitory account. Firstly, they observed that an instruction to forget impairs memory for list membership. Participants given instructions to forget were more prone to erroneously assign the recalled items from a to-be-forgotten list to list 2. Secondly, Geiselman et al. analyzed the output order of recalled items and discovered that the output order of items from a to-be-forgotten list showed less correspondence to the original presentation order than items from a to-be-remembered list. Together, these two findings were taken to suggest that instruction to forget results in the impaired access to the whole episode of studying the to-be-forgotten list, consistently with the idea that this episode is inhibited.

The inhibitory mechanism thought to be responsible for the directed forgetting effects is commonly referred to as retrieval inhibition (Bjork, 1989). This term describes a process which impairs retrieval of to-be-forgotten information without affecting the strength of a memory trace. In other words, retrieval inhibition affects accessibility of stored information given a certain set of cues but it does not affect availability of the memory trace which is reflected in memory performance independently of cues used at retrieval (Tulving & Pearlstone, 1966).

However, as already discussed in the first chapter of the thesis, the term inhibition is used in various ways, sometimes to refer to a pattern of empirical findings and sometimes to refer to a mechanism responsible for a certain pattern of findings. This confusion can be traced in the directed forgetting literature. There are a number of mechanisms that can affect the accessibility of a memory trace. The next section will describe the mechanism of context change which stipulates that directed forgetting effects are due to a mismatch in the type of cues used to access memory in the Remember and Forget conditions. Because this explanation considers cues used at retrieval, it describes the directed forgetting effects as changes in accessibility of to-be-forgotten information. The other proposal is that instructions to forget disrupt the effective retrieval strategy that participants would employ for a to-be-forgotten list (Basden & Basden, 1998). If retrieval inhibition is used as a term describing the pattern of reduced accessibility of memory traces, then both the context change and strategy disruption hypotheses may be equivalent to the retrieval inhibition account. Indeed, the proponents of the strategy disruption hypothesis seem to use the term retrieval inhibition as a synonym of their account of directed forgetting (Basden et al., 2003) and some researchers argued that context change may be a mechanism of retrieval inhibition (Lehman & Malmberg, 2011). However, this treatment of retrieval inhibition makes this term redundant and strips it of any explanatory power. On the other hand, the majority of recent studies devoted to directed forgetting treat retrieval inhibition as a mechanism that is qualitatively different from other mechanisms that lead to changes in accessibility of to-be-forgotten traces, like the context change mechanism (e.g. Spillers & Unsworth, 2011; Mulji & Bodner, 2010). This is the approach that is adopted here. It is assumed here that retrieval inhibition should not be defined as a change in the cues or strategies used at retrieval due to provision of instructions to forget but instead it is a mechanism which results in a direct change in the memory representation that decreases the effectiveness of cues in providing access to these representations.

The main challenge that any inhibitory framework faces is to describe what becomes inhibited. As discussed in the previous chapter, in research concerning RIF

this question has been answered in two ways, one suggesting that the semantic features of items become suppressed (the pattern suppression model of Anderson and Spellman, 1995) and the other suggesting that associative links created during study become disrupted (the models proposed by Norman et al., 2007, and Racsmány and Conway, 2006). Both of these possibilities have been also explored in relation to directed forgetting effects.

Concerning inhibition of semantic features, the studies relevant for assessing this kind of inhibition include the procedures of assessing directed forgetting with recognition or implicit tests. As described in the chapter devoted to RIF, inhibition of memory semantic representations should cause impairment on any test that requires access to these representations. According to the transfer-appropriate processing framework (Blaxton, 1989; Morris, Bransford, & Franks, 1977), the explicit test of recognition and conceptual implicit tests require such access and thus directed forgetting effects should be found in these tests, if suppression of semantic features is indeed responsible for these phenomena. Regarding the implicit test, several studies have documented that directed forgetting effects are not present with this kind of test. Bjork and Bjork (1996) used an implicit test of word-fragment completion and found no effects of directed forgetting in this task. This null finding was interpreted by Bjork and Bjork as suggesting that inhibition in directed forgetting serves to limit the conscious access to the episode of studying list 1 but does not affect semantic representations of individual items. However, it could be argued that word-fragment completion is not a conceptual implicit test as providing an answer in such a test requires access only to phonological representation and not semantic representation (Bajo et al., 2006). On the other hand, there are also studies in which conceptual implicit tests were employed. Firstly, Basden et al. (1993) employed a word association test in which participants are given word cues and are asked to produce semantic associates to these cues. Using this procedure Basden et al. observed reliable priming for to-be-forgotten and to-be-remembered items with no difference in the magnitude of the priming effect, which suggests that instructions to forget did not affect conceptual representations. Secondly, Racmány and Conway (2006) investigated directed

forgetting with an implicit task of lexical decision. In this task directed forgetting effects again failed to emerge, although they were present in free recall test administered both before and after the lexical decision task.

Regarding recognition tests, it is widely acknowledged that directed forgetting generally does not emerge with such tests. Indeed, the findings of recognition testing obtained by Basden et al. (1993) were decisive for developing a new conceptual framework in which different mechanisms are responsible for list-method and item-method directed forgetting. Basden et al. conducted several experiments and consistently obtained directed forgetting effects in recognition with the item-method directed forgetting, supporting the notion that the encoding mechanism of differential rehearsal is responsible for the effects obtained with this method, but no effects with list-method directed forgetting. The lack of the effects in recognition in the list-method directed forgetting was retrospectively confirmed in previous studies in the era before a distinction between item-method and list-method (e.g. Elmes, Adams, & Roediger, 1970) and was also replicated in subsequent investigations (e.g. Benjamin, 2006).

However, a more recent investigation of directed forgetting did reveal such effects with recognition procedures. Firstly, Bjork and Bjork (2003) conducted a directed forgetting investigation using the false fame paradigm developed by Jacoby and his colleagues (Jacoby, Woloshyn, & Kelley, 1989; Jacoby, Kelley, Brown, & Jasechko, 1989). The details of this study will be provided later and for the present purpose it is important to note that in Experiment 2 of this study participants were asked to indicate if studied items were studied within list 1, list 2 or were never studied. Bjork and Bjork found that directed forgetting caused both forgetting of list membership of to-be-forgotten items and increased omission rates. In other words, participants failed to acknowledge that to-be-forgotten items were present in the to-be-forgotten list and sometimes they also failed to recognize that these items were presented at all. Secondly, Lehman and Malmberg (2009) conducted three different experiments involving recognition testing, two of which included a simple recognition test in which participants were asked to endorse items from both presented lists (inclusion condition) and one which included

instructions asking participants to endorse only items from the to-be-forgotten list. The directed forgetting costs were present in both types of recognition procedures but they were markedly stronger in the exclusion condition. It is worth noting that completing the exclusion condition requires retrieval of list membership of presented items, a function that is impaired in the directed forgetting procedure, as evidenced by the results of the studies conducted by Geiselman et al (1983). However, it remains unclear why costs emerged in the inclusion condition which is a basic recognition procedure in which directed forgetting costs are not commonly obtained. The procedure used by Lehman and Malmberg differed in some respects from the commonly used directed forgetting task as several changes were implemented to eliminate some of the confounds identified in this task. The to-be-forgotten list was preceded by one more list to elicit proactive interference for the first list and a delay was inserted before the final test to eliminate recency effects for list 2. These procedural differences could be responsible for obtaining directed forgetting costs in recognition.

The question arises if discrepant findings observed with recognition testing could be assigned to workings of an inhibitory mechanism operating in semantic memory, despite the lack of directed forgetting in conceptual implicit tests. It seems that a simpler solution would involve evoking the dual-process models of recognition. As was argued in the chapter on RIF, the inconsistent findings concerning recognition can be reconciled if a dual-process perspective is adopted and an assumption is made that a given manipulation affects only one process. In this case the effect would be predicted only if recognition relies mostly on the affected process but no effect should be predicted when the unaffected process is mainly involved in supporting recognition performance. From this perspective it can be argued that directed forgetting affects recollection but not familiarity. The retrieval inhibition in episodic memory makes exactly this prediction as will be described later. It is thus worth considering if procedures used by Bjork and Bjork (2003) and Lehman and Malmberg (2009) could render their recognition tests recollective-driven. It does, indeed, seem to be the case. In the study by Bjork and Bjork participants were queried simultaneously for old/new status and list

membership of the presented probes. Such a testing procedure could induce participants to rely on a recollective process that could establish the list membership of probes. On the other hand, the procedure used by Lehman and Malmberg involved a delay between the study phase and the final test. It is commonly assumed that the level of familiarity of studied items decreases markedly soon after the study episode whereas recollection reveals a much smaller decline in the same time (e.g. Hockley, 1992) and thus delaying the test leads to an increase in the contribution of recollection to recognition performance.

One final piece of evidence concerning the issue of semantic inhibition in directed forgetting comes from studies examining the effects of instructions to forget on false memories. Several different studies have examined the directed forgetting effects in the context of the DRM procedure (Kimball & Bjork, 2002; Seamon, Luo, Shulman, Toner, & Caglar, 2002; Knott et al., 2011). These studies investigated whether directed forgetting of a list of associates affects false memories for non-presented critical lures on which all to-be-forgotten associates converge. It is well known that associative illusion researched within the DRM paradigm is dependent on both semantic and episodic processing. The study of semantic associates leads to false memories for critical lures either because the representation of these lures is semantically primed (Seamon, Luo, & Gallo, 1998) or because the semantic representation of these lures fits the gist of the study list (Brainerd & Wright, 2005). The episodic information, in turn, leads to a reduction in false memories by providing details of the study episode that may lead to successful monitoring of semantically-driven errors (Watson, McDermott, & Balota, 2004). In the studies on the DRM paradigm it has been found that recall of studied associates is negatively related to false alarms to non-presented critical lures which is explained by assuming that episodic retrieval of associates provides information that helps participants to decide that critical lures are new (Roediger, Watson, McDermott, & Gallo, 2001). If retrieval inhibition affects semantic representations, then directed forgetting effects should affect studied and non-studied items in the same way, decreasing both correct recall and false memories. However, if retrieval inhibition affects episodic representations of a studied item, then reduced access to

such episodic information coupled with unimpaired access to semantic information should lead to opposite effects for studied items and critical lures. While losing the access to episodic representations should lead to directed forgetting costs for studied items, the related reduction of monitoring function should lead to an increase in false memories. Indeed, studies examining the relationship between directed forgetting and the DRM procedure found that instructions to forget lead to poorer recall of studied associates but have an opposite effect on false alarms to non-studied critical lures, leading to an increase in false memories. It is worth noting that this increase in false memories stands in direct contrast to studies on the RIF effect which show that false memories are affected in the same way as studied Rp- items in the retrieval practice paradigm (e.g. Bäuml & Kuhbandner, 2003; Starns & Hicks, 2004).

The studies summarized above indicate that semantic representations of items from a to-be-forgotten list do not become inhibited in the directed forgetting paradigm. This conclusion indicates that the mechanism responsible for directed forgetting is necessarily different than the mechanism of semantic inhibition which serves as a popular account of the RIF effect, described in the previous paradigm. This leads to two possible conclusions. Firstly, it is possible that different types of inhibition operate in these two paradigms. This is a suggestion formulated by Anderson (2005) who argues for a flexible inhibitory mechanism operating at various levels of the cognitive system. This proposal could account for the fact that many results are different between directed forgetting and retrieval practice paradigms, including the issue of results obtained with recognition tests, implicit tests and false memories. However, it needs to be pointed out that this account is far from parsimonious as it simply postulates multiple inhibitory mechanisms. Secondly, it is possible that the same mechanism of inhibition operating in episodic memory is responsible for the phenomena of interest in both the retrieval practice and directed forgetting paradigms. The issue of links between inhibitory processes working in these paradigms is revisited after the empirical part is presented.

Since directed forgetting does not appear to stem from semantic inhibition, the retrieval inhibition account needs to postulate that some type of episodic

information is affected by instructions to forget. Indeed, the theorists of inhibitory mechanisms argue that directed forgetting results in inhibition of episodic information (Bjork, 1989; Bjork & Bjork, 1996). However, this formulation needs additional specification of what type of episodic information is inhibited. Bjork and Bjork argued for inhibition of the whole episode of studying a to-be-forgotten list. However, as pointed out by Racsmány and Conway (2006), such a formulation suggests that participants should have trouble recalling the fact that they even studied a to-be-forgotten list. This, of course, never actually occurs as participants in the Forget condition are fully aware that they studied two lists and are capable of recalling some of the items presented within a to-be-forgotten list. Racsmány and Conway proposed an alternative formulation of inhibition in which it is not the episode that becomes inhibited but the contents of this episode. In other words, participants do not forget that they studied a to-be-forgotten list but they do forget the elements of the study episode which are presentations of individual items. To distinguish this formulation from the one proposed by Bjork and his colleagues, Racsmány and Conway proposed a novel term of episodic inhibition to be used to describe their approach. However, in the present work the episodic inhibition and retrieval inhibition accounts will be treated as one (and referred to as retrieval inhibition) because it is not entirely clear if these two approaches do in fact differ significantly. The point is that the original formulation of the retrieval inhibition account was not well-specified and it was not apparent how the notion of inhibiting the whole list should be understood. In the present work it will be assumed that episodic inhibition constitutes a better specification of the original idea of retrieval inhibition and thus only the latter, traditional term will be used, although it will be defined as inhibition of contents of an episode, as proposed by Racsmány and Conway.

An alternative formulation of an inhibitory mechanism was recently proposed by Anderson (2005). Anderson noted that the instructions provided in directed forgetting ask participants to forget the whole list of items but not individual items presented within this list. This suggests that inhibition may occur at the level of the whole list. However, this does not mean that the episode of



studying a to-be-forgotten list is inhibited, as the original retrieval inhibition formulation would suggest, but rather that the features that distinguish this episode from all other episodes stored in memory become inhibited. The features that distinguish between different episodes in memory are usually referred to as context features. Context in this formulation is the complex of thoughts and feelings with elements which change gradually in time and which accompany all cognitive activity (Howard & Kahana, 2002). When items are presented for study they become associatively linked to this gradually changing complex of contextual features. Due to these gradual changes, context helps to differentiate the episodes in memory. By retrieving the specific thoughts accompanying a certain episode, this episode may be placed differently in time relative to other episodes. According to Anderson's formulation of the inhibitory mechanism operating in directed forgetting, an instruction to forget serves to suppress these context features that accompany the episode of studying a to-be-forgotten list. In a number of memory models, the context features are used to cue memory for the contents of a given episode (e.g. Raaijmakers & Shiffrin, 1981). Thus recall of a to-be-forgotten list presumably starts by cueing with the context features to retrieve the items presented within this list. However, if the features of context are inhibited, they are themselves difficult to retrieve and thus contextual cueing becomes less efficient, resulting in reduced retrieval of items from a to-be-forgotten list. Anderson formulated this version of the inhibitory account of directed forgetting to address the growing body of evidence supporting the context change account, described in the next section of the present chapter. However, at present there is no empirical support for this formulation, except for all the results that are deemed supportive of the context change account. In other words, it is not clear how to separate these two different accounts at this time.

Having defined the locus of inhibitory effects in directed forgetting, it is important to describe empirical findings that can be used to support this account. Several of such findings have been already mentioned. It seems that directed forgetting costs are usually absent from recognition tests (Basden et al., 1993), which suggests that the directed forgetting mechanism operates at retrieval and

not at encoding. Retrieval inhibition is described as a mechanism that serves to preclude retrieval of to-be-forgotten items from memory but not to change the strength of memory traces as assessed by a recognition test and thus results from recognition testing are sometimes cited as support for the retrieval inhibition account. However, this line of reasoning is troubled by the problem of circularity. The null findings in recognition serve at the same time to define how retrieval inhibition should be understood and to prove that retrieval inhibition is actually involved in the process of directed forgetting.

The other already described piece of evidence used to support the retrieval inhibition account comes from the results obtained by Geiselman et al. (1983). These results suggest that instructions to forget affect both intentionally and incidentally encoded items and thus that directed forgetting works on the whole contents of a to-be-forgotten episode. As described previously, these results are inconsistent with the differential rehearsal hypothesis. However, it is less clear if these results provide independent support for the retrieval inhibition account. Again, these findings simultaneously define what retrieval inhibition is and support this view which is a clear case of circularity in argument. There is nothing in the idea of inhibition that would clearly indicate that it needs to affect all contents of the episode targeted by inhibition in the same way. Indeed, in the case of RIF it is argued that inhibition works at the level of individual items. Anderson (2005) argues for a flexible inhibitory mechanism that can operate either at the level of items or at the level of context of a whole episode but this idea provides the way to account for any possible result in respect to specificity of forgetting. It is also worth noting that in research on directed forgetting there are findings that suggest that an instruction to forget can exert its influence specifically on the to-be-forgotten part of an episode. Delaney, Nghiem, and Waldum (2009) conducted an experiment in which participants were presented with sentences describing the actions of three individuals, Tom, Alex, and Joe. The sentences concerning Tom and Alex were presented within list 1 and sentences concerning Joe were presented in list 2 of the directed forgetting paradigm. Importantly, participants in the Forget condition were asked to forget only sentences about Tom to facilitate memory for sentences about

Alex. The results revealed selective directed forgetting effect because participants remembered fewer sentences about Tom when asked to forget them without any impairment to sentences concerning Alex which were included in the same study list. This is a novel result and it is not clear yet if it is replicable (see Koppel, Wilson, Jobbe, & Storm, 2011, for a failed replication) but the main issue here is that this result can also be mentioned in support of the retrieval inhibition account (Delaney, 2011), mostly because it is clearly inconsistent with the predictions of the context change account of directed forgetting, as described later. Thus, the retrieval inhibition account seems to be supported both in the cases in which instructions to forget affect all contents of the episode preceding instructions to forget and in the cases in which instructions to forget affect only specific parts of the episode preceding instructions to forget. The fact that such divergent findings can be used to support the same account suggests that this account is not well specified and in fact cannot be falsified using this type of evidence.

Another empirical finding that has been used in support of the inhibitory account of directed forgetting is one of release from inhibition. Bjork (1989) stressed the adaptive nature of retrieval inhibition and argued that in order to secure maximum functionality of a memory system inhibition should temporarily limit accessibility of irrelevant information but this inhibited information should be easily restored when it becomes relevant again. In other words, a mechanism of release from inhibition should exist which would allow for access to once inhibited information. There are several empirical findings that support the notion of a release from inhibition. Firstly, Basden et al. (1993) demonstrated that if a recall test is preceded with a recognition test for both lists, then directed forgetting effects do not emerge in free recall. These researchers suggested that presentation of to-be-forgotten items within a recognition test releases inhibition for these items. Secondly, Bjork and Bjork (1996) contrasted the role of the format of testing in the phenomenon of release from inhibition. In their design the final recall test was preceded either by a recognition test (in the two-alternative forced choice or the old/new format) in which some of the items from a to-be-forgotten list served as foils or by an implicit test of word-fragment completion. The dependent measure

here was recall of list 2 items so the benefits and not the costs of directed forgetting were assessed. Bjork and Bjork found that presentation only of a subset of words from a to-be-forgotten list in the context of a recognition test removes the benefits of directed forgetting completely whereas these benefits are not affected by an implicit test of word-fragment completion. This finding was again taken to suggest that inhibition is released by access to an episodic representation of to-be-forgotten items. Thirdly, Basden et al. (2003) conducted a set of experiments similar to the one presented by Bjork and Bjork and found release from inhibition when the majority of words from a to-be-forgotten list (75%) were presented either within the implicit test of word-fragment completion or a pleasantness judgment task.

Although the results described above seem to suggest that a release from inhibition genuinely occurs in the directed forgetting task, a word of caution is warranted here. It is important to note that all presented studies looked at the directed forgetting effect to a certain extent through the perspective of benefits and not the costs. In the study by Bjork and Bjork only benefits were assessed. The experiments conducted by Basden et al. (1993) and Basden et al. (2003) were conducted in a within-participants design in which only an instruction to forget is provided and performance for list 1 is compared with performance for list 2. However, this particular design mixes the costs and benefits together so that it is impossible to tell if a given manipulation affects the former or the latter. Thus, even though a release from inhibition concerns the items from a to-be-forgotten list and thus the costs of directed forgetting, the studies on this issue actually concentrated on the benefits of directed forgetting. This is understandable from the perspective of the inhibitory hypothesis, which looks at costs as a precondition for obtaining benefits, but nevertheless it again creates the problem of circularity. In this case the findings concerning benefits serve to formulate conclusions about the costs which are valid only when the theoretical framework of inhibition, the very one these findings are taken to support, is valid in the first place. If, however, benefits are not a consequence of costs, then this reasoning may be incorrect.

The link between costs and benefits of directed forgetting has not only served as a premise for theoretical considerations but also as a source of testable predictions for the inhibitory account of directed forgetting. The retrieval inhibition account strongly argues that the costs and benefits of directed forgetting are closely linked as inhibiting the contents of a to-be-forgotten list, a process which produces the costs, occurs to facilitate retrieval of the contents of a to-be-remembered list. In other words, forgetting is adaptive in this paradigm and thus should occur only when it serves the purpose of producing benefits. The simplest way to preclude the benefits of directed forgetting is to provide only a to-be-forgotten list. Gelfand and Bjork (1985, as described in Bjork, 1989; see also Pastötter & Bäuml, 2007) conducted an experiment in which instructions to forget were not followed by subsequent learning. In this condition the costs of directed forgetting failed to emerge which was interpreted as support for the retrieval inhibition account. Also, Pastötter and Bäuml (2010) reported that the amount of forgetting for the items from a to-be-forgotten list depends crucially on the number of items that are included in the to-be-remembered list that follows the instructions to forget.

The other way to preclude the adaptive function of directed forgetting is to create a situation in which a to-be-forgotten list serves to facilitate rather than impede learning and retrieval of a to-be-remembered list. Conway et al. (2000) presented experiments which aimed at creating such conditions. In this study the elements from a to-be-remembered list were strongly related to items from a to-be-forgotten list. In the case of strongly related items interference from a to-be-forgotten list should not occur because retrieved to-be-forgotten items could actually serve as retrieval cues for strongly related to-be-remembered items. Indeed, Conway et al. found no costs of directed forgetting for strongly related lists.

Although the results described above suggest that costs and benefits of directed forgetting are linked as the retrieval inhibition account would suggest, a recent set of results seems to question this contention. Sahakyan and Delaney (2003) were the first researchers to propose a dual-factor account of directed forgetting in which costs and benefits result from operations of two different

mechanisms (see also Pastötter & Bäuml, 2010, for a similar formulation). In their study Sahakyan and Delaney controlled the encoding strategies which were implemented for to-be-forgotten and to-be-remembered lists by instructing participants to perform either shallow or deep processing of presented items. In two experiments they found that imposing specified encoding strategies had no effect on the costs of directed forgetting but abolished the benefits of directed forgetting. This finding is problematic for the retrieval inhibition account because it is not clear why an inhibitory mechanism should be triggered to produce costs if it does not lead to any benefits. Sahakyan and Delaney argued that a better account of this result is provided by a hypothesis that benefits of directed forgetting stem from changes in encoding strategies due to provision of the instruction to forget. The argument is here that participants given instructions to forget reflect on their memory for to-be-forgotten items and realize that this memory is poor due to relatively simple rote rehearsal strategies employed to encode a single list of words. This metacognitive judgment leads participants to change their approach to the task and to switch to a more effective encoding strategy for a subsequent list of to-be-remembered items. This switch in strategy does not occur in the Remember condition in which participants do not reflect on their performance. Imposing specified strategies for encoding list 2 abolishes the benefits of directed forgetting because it leaves no space for self-chosen strategies in either of the conditions.

Further support for the dual-factor account of costs and benefits of directed forgetting comes from a study by Sahakyan, Delaney, and Kelley (2004) and also some studies on directed forgetting in recognition. Firstly, in the study by Sahakyan et al. participants in the Remember condition were forced to evaluate their performance for items from the first list, either by performing an explicit recall test or making an aggregate metacognitive judgment about the level of learning of these items. These manipulations led to comparable recall rates for items from list 2 between Forget and Remember conditions, suggesting that also participants in the Remember condition changed encoding strategies for list 2 after appraisal of their learning of list 1. Secondly, the studies employing recognition testing sometimes report benefits of directed forgetting without accompanying costs. As

was mentioned earlier, the lack of directed forgetting effects in recognition is commonly taken to suggest that these effects arise at retrieval and not encoding. However, the two-factor account proposed by Sahakyan and Delaney (2003) suggests that the benefits do actually arise from the encoding mechanism of a strategy switch. Thus, according to this account the benefits of directed forgetting should be detectable in recognition. Two different studies have documented such effects when long to-be-remembered lists were presented for study (Sahakyan & Delaney, 2005; Benjamin, 2006). In these studies the benefits of directed forgetting emerged in recognition without the costs which again questions the existence of a strong link between the two effects which is postulated by the retrieval inhibition account.

Directed forgetting has also been examined from a perspective of individual differences. As in the case of RIF, it has been argued that the retrieval inhibition account specifically predicts that people with reduced executive functions should be less able to recruit inhibitory processes thus showing diminished costs of directed forgetting. At least four different sets of results concerning individual differences can be interpreted as supporting this prediction. Firstly, an influential study by Zacks et al. (1996) documented reduced ability to intentionally forget in older adults. This finding was in line with a model of cognitive aging developed by Hasher and Zacks (1988) which assigns cognitive decline in older age to deficits in inhibitory functions. Secondly, studies have also documented deficient directed forgetting in young children who are assumed to have underdeveloped executive functions (Harnishefeger & Pope, 1996; Wilson & Kipp, 1998). Thirdly, a recent study by Delaney and Sahakyan (2007; see also Aslan, Zellner, & Bäuml, 2010) revealed that directed forgetting costs are more pronounced for participants with higher working memory capacity, which parallels the findings obtained by Aslan and Bäuml (2011) in the retrieval practice paradigm. Fourthly, a study involving clinical patients with frontal lobe lesions documented reduced directed forgetting costs compared to a control group (Conway & Fthenaki, 2003). Finally, the last piece of evidence in favour of the executive function hypothesis comes from results obtained by Conway et al. (2000). In this study this problem was addressed with an

experimental manipulation rather than from the individual differences perspective. Conway et al. manipulated the cognitive load during acquisition of to-be-remembered items, under the assumption that additional load should reduce the involvement of executive functions in directed forgetting. Indeed, they found that with cognitive load the directed forgetting effects are abolished, which again parallels the findings obtained for the RIF effect (Róman et al., 2009).

Although the results described here are in line with the predictions of the retrieval inhibition account of directed forgetting, there are also studies revealing a strikingly different pattern of results. Concerning the older adult population, recent developments in the literature suggest that directed forgetting may be intact in this group. Two studies have recently failed to find any differences in the magnitude of directed forgetting between younger and older adults (Sego, Golding, & Gottlob, 2006; Zellner & Bäuml, 2006). A detailed examination of these results performed by Sahakyan, Delaney, and Goodman (2008) tries to account for these discrepancies with a metacognitive mechanism. These authors suggested that older adults may fail to engage in the strategies leading to directed forgetting because they perceive their memory for to-be-forgotten items as so poor that it does not require additional operations in order to reduce it further. In their study Sahakyan et al. found reduced forgetting effects with older adults when a standard instruction to forget was given but they found intact directed forgetting in this group with a modified instruction to forget that stressed the importance of forgetting. A similar idea has been recently developed for studies concerning children. Several studies have documented intact directed forgetting costs in children (Howe, 2005; Knott et al., 2011). Aslan, Staudigl, Samenieh, and Bäuml (2010) have again proposed that the presence or absence of directed forgetting in children may not depend on the inherent effectiveness of executive control in different groups tested in different studies but rather on the willingness of children to engage in the strategies that lead to directed forgetting. Again, using the standard instructions to forget Aslan et al. found no directed forgetting costs in the youngest group of children tested in this study (first graders) but they found reliable directed forgetting costs in this group with a modified instruction.



The results described above suggest that it is important to distinguish between the process of initiation of cognitive operations that lead to directed forgetting and the effectiveness of these operations. The retrieval inhibition account suggests that the effectiveness of inhibitory operations should be reduced in some populations, leading to impoverished directed forgetting. However, the studies reviewed above suggest that the cognitive processes which lead to directed forgetting are equally efficient in at least some of the groups to which the predictions of the retrieval inhibition account pertain (older adults and children) but the chances of initiation of these cognitive processes are different across groups (for a discussion see Delaney & Sahakyan, 2007). These findings suggest that cognitive operations which result in directed forgetting may not necessarily be inhibitory in nature.

The last part of evidence concerning the inhibitory account of directed forgetting deals with the dual-process account of recognition (Yonelinas, 2002) and the effects of directed forgetting on recollection and familiarity. The retrieval inhibition account assumes that inhibition works to limit the accessibility of memory traces but not their availability. If the dual-process perspective is adopted, then it could be argued that directed forgetting should not affect familiarity of individual items which depends on the availability of information stored in memory but should affect recollection that is retrieval of associative information encoded during study and cued by probes presented in a recognition test. Several different methods have been adopted to investigate these predictions and they do seem to support it. The early evidence concerning this issue is present in the already described work by Geiselman et al. (1983). In this research it was found that instructions to forget affect not only recall of items from a to-be-forgotten list but also retrieval of associative information concerning recalled items. Specifically, Geiselman et al. found that list membership judgments were affected by instructions to forget. This suggests that directed forgetting impaired retrieval of contextual associations which indicate in which list a given item was presented. It is important, however, to stress that in this case the affected judgment was made after the recall task and hence it was dependent on the products of recall. It is

possible that directed forgetting affected only recall and through this recall effect it exerted influence on the post-recall judgments of list membership. It seems plausible that retrieval of contextual information would be impaired if fewer items were recalled, reducing the effectiveness of cueing for contextual features.

The issue of the effects of directed forgetting on familiarity and recollection has also been addressed directly with recognition procedures. The already mentioned study by Bjork and Bjork (2003) documented impairment in recollection in the false fame paradigm (Jacoby et al., 1989). Participants studied lists of non-famous (list 1) and famous names (list 2) in the directed forgetting procedure and were then asked to provide the fame judgments for the studied names. It was found that directed forgetting enhances the false fame effect for the non-famous names from list 1. These names in the Forget condition were called famous more often than the same names in the Remember condition. This result suggests that directed forgetting impairs recollection for presented probes, the process which would help participants to assign the probe to a list of non-famous names, but leaves the process of familiarity responsible for calling a non-famous name famous intact. In this study Bjork and Bjork found that participants in the Forget condition revealed reduced ability to assign the non-famous names to list 1 and also reduced ability to recognize that to-be-forgotten words were presented at all during the experiment. This former finding is consistent with Geiselman et al.'s (1983) observation of the effect of directed forgetting on the list membership judgments. This latter finding shows that directed forgetting effects can under certain circumstances emerge in recognition.

Sahakyan, Waldum, Benjamin, and Bickett (2009) investigated the conditions under which directed forgetting effects can emerge in recognition. In one of their experiments they found that the costs of providing instructions to forget occur when discrimination of studied items is made more difficult. Specifically, they investigated directed forgetting in the plurals paradigm (Hintzmann, Curran, & Oppy, 1992) in which participants are presented with nouns for study which are either in singular or in plural form and are later asked to discriminate between studied items and foils created from the same items by

changing the form from singular to plural or in the opposite direction. This task is commonly used to investigate recollection because it is assumed that targets and foils in this paradigm are so similar that the familiarity signal is equal for them and participants need to engage in a recollective process in order to discriminate between them. Sahakyan et al. found directed forgetting costs in this task, which is again consistent with the idea that directed forgetting affects recollection.

Several additional findings provide further support for the hypothesis of impairment in recollection in directed forgetting. Firstly, the already described study by Lehman and Malmberg (2009) found that the costs of directed forgetting in recognition are larger in the exclusion task, in which participants are required to retrieve the list membership of presented items, than in the inclusion task in which such associative retrieval is not required. Secondly, the study Gottlob and Golding (2007) documented directed forgetting effects in the list discrimination task but also in the tasks that required retrieval of information peripheral to the meaning of the studied items, like the case or colour of presented words. Thirdly, the investigation of Racsmany et al. (2008) demonstrated the effects of instructions to forget in recognition memory constrained to items given a remember judgment, which is commonly assumed to reflect recollection (but see Conway et al., 2000, for a contrasting result). Altogether, these findings support the notion that directed forgetting affects recollection and thus they remain consistent with the inhibitory mechanism of this effect. However, as will be argued in the next section, the inhibitory account is not the only account of directed forgetting that predicts the effects of instructions to forget on recollection but not familiarity. Thus, it seems that these results do not provide unique support for the inhibitory account.

### 3.2.3 Context change

Recently, a new proposal concerning the mechanism of directed forgetting has been formulated by Sahakyan and Kelley (2002). According to the context change account of directed forgetting, participants given instructions to forget engage in divertive thoughts which result in a change in the mental context. The newly established context accompanies learning of list 2 and it is subsequently used

to cue memory for both to-be-forgotten and to-be-remembered lists. However, this newly established context is a good match only to the context encoded for the to-be-remembered list and not for the to-be-forgotten list which was studied before the instruction to forget was given and thus was associated with different context features. Because the match between context used as a cue and context encoded during study determines the efficacy of cueing (Tulving & Thomson, 1973), to-be-forgotten items are harmed by this contextual mismatch. Importantly, it is assumed that in the Remember condition no context change occurs and hence there is no mismatch between context used as a cue and context encoded with the to-be-forgotten list. This better match in context features results in better retrieval of items from list 1 in the Remember condition as compared with the Forget condition.

The mechanism proposed by Sahakyan and Kelley (2002) bears some resemblance to the early idea of set differentiation proposed by Bjork (1970) to account for directed forgetting effects. This idea stated that instructions to forget serve to differentiate all studied items into two sets from which one is later subjected to selective rehearsal. The context change account describes a mechanism of such set differentiation which is accomplished by differentiating context features between the two sets (see Sahakyan & Delaney, 2010 for evidence of differentiation from inter-list intrusions). This idea is also related to the already mentioned proposal of Basden and Basden (1998) who suggested that directed forgetting costs occur due to strategy disruption caused by instructions to forget. As long as cueing with the context accompanying study of to-be-forgotten items is defined as a strategy, this account is consistent with the context change hypothesis.

Sahakyan and Kelley (2002) tested the context change account of directed forgetting in two ways. Firstly, they tried to emulate the process of divergent thinking without the instructions to forget to examine if this process can also lead to directed forgetting effects. In two experiments they asked participants in the Remember condition to engage in divertive thoughts by either asking them to imagine what they could do if they were invisible or imagining their parents' house. With these instructions Sahakyan and Kelley found the same pattern of directed

forgetting effects as when the standard instruction to forget was provided. Since this study a number of similar manipulations involving imagination were implemented and they consistently revealed the usual pattern of directed forgetting (e.g. Sahakyan et al., 2008). Moreover, several studies have found that also other manipulations targeting the context features can produce directed forgetting costs. For example, Mulji and Bodner (2010) found that the cost for performance on list 1 is found when participants are asked to wipe a computer screen and their own hands with a wet towel or to engage in a short conversation with an experimenter. These results suggest that there is nothing special about the instruction to forget and the same pattern of results can be obtained with a great variety of contextual manipulations. Secondly, Sahakyan and Kelley investigated if a procedure of context reinstatement affects the pattern of directed forgetting. Participants were given instructions to forget, instructions to remember, or instructions to imagine between the two studied lists and then half of participants just before the final test were guided towards recalling the mental context that accompanied their arrival in a laboratory. It was found that this context reinstatement procedure led to reduction in directed forgetting costs for both participants instructed to forget and participants who engaged in the imagination task. These parallel effects suggest that the same mechanism, one of context change, is responsible for the costs to memory performance caused by intentional forgetting and engagement in an imagination task.

Yet another example of forgetting due to guided imagery was presented by Aslan and Bäuml (2008). These researchers looked at the consequences of guided imagery in children and they found that this manipulation produces a pattern of costs resembling the one obtained with instructions to forget, although no benefits emerged in this study. This dissociation was taken to support the already described dual-factor account by which costs and benefits arise due to different mechanisms, a retrieval one for the costs and an encoding one for the benefits. This dual-factor account is problematic for the retrieval inhibition account which posits that costs and benefits are tightly linked but it is much less problematic for the context change account which focuses exclusively on the costs of directed forgetting. The

context change account predicts that mismatching context reduces the effectiveness of cueing retrieval of items presented prior to the guided imagery episode but makes no clear predictions about the benefits. Although originally this account was proposed to account for both costs and benefits (Sahakyan & Kelley, 2002) by arguing that the novel context established in the Forget condition for to-be-remembered items is associated with fewer items than the context used in the Remember condition which results in reduction interference and enhancement in performance in the former condition, this feature of the model is not a crucial one. It could be argued that the effects of reduced interference are minor and thus the majority of benefits may be caused a different mechanism, consistently with the dual-factor proposal.

Since the finding that guided imagination can cause the same pattern of results as instructions to forget, studies have been conducted to examine if the effects that were taken to support the retrieval inhibition account are also present when forgetting is elicited by context change. Pastötter and Bäuml (2007) examined if both intentional forgetting and forgetting caused by an imagination task occur only when list 1 that precedes the instructional manipulation is followed by new learning of list 2. This result was reported first by Gelfand and Bjork (1985, as described in Bjork, 1989) in reference to directed forgetting to argue that retrieval inhibition requires additional learning because without it there would no competition and hence no need to trigger an inhibitory mechanism. Pastötter and Bäuml replicated this finding for a directed forgetting condition but they obtained exactly the same pattern of results for a condition in which the instruction to forget was substituted with an imagination task. The already described study by Delaney and Sahakyan (2007) that revealed the positive correlation between working memory capacity and the magnitude of directed forgetting costs included also a manipulation of guided imagery for which the same type of correlation was observed. The authors concluded that both the effects of directed forgetting and guided imagery stem from a context change which is executed more effectively for participants with more effective executive functions.

Although not every effect considered supportive of the retrieval inhibition account has been replicated with the context change manipulation, it is worth considering if context change can account for these findings. Following the arguments presented in the previous section, the usual null effects obtained in standard recognition tests served to define inhibition in terms of impoverished accessibility. The consistency of recognition data with the context change account depends on the theoretical perspective. If recognition performance is considered to be driven by a single process of matching the contents of a memory probe to contents of memory, then recognition should be affected by context change to the extent to which the probe contains context features. Indeed, Lehman and Malmberg (2009) argued that the context change account predicts costs in recognition tests and, quite surprisingly given numerous null results in this area (e.g. Basden et al., 1993; Benjamin, 2006), they demonstrated such costs. On the other hand, if the dual-process perspective is adopted, then the context change account predicts effects only to the extent to which performance in this task depends on an associative process of recollection because familiarity is assumed to be a context-free process (see Macken, 2002). Thus, all results that indicate that directed forgetting effects are contained to recollection are consistent with both the retrieval inhibition and context change accounts.

The other two findings that are commonly cited in support of the retrieval inhibition account include the observation that inhibition seems to affect the whole to-be-forgotten episode, as evidenced by results obtained by Geiselman et al. (1983) and the results suggesting the existence of the release from inhibition phenomenon. Regarding the generality of the effects of a forget instruction, the context change account predicts that changing the mental context should affect all episodic information encoded in the context preceding the change elicited by instructions to forget. Thus, this account makes the same prediction concerning the procedure of Geiselman et al. in which to-be-forgotten intentionally studied words were interwoven with incidentally studied words. Moreover, this account makes a stronger prediction that the effects of instructions to forget should not be limited only to the to-be-forgotten episode. Sahakyan (2004) introduced a three-list

learning paradigm in which two lists preceded the instruction to forget only one of these lists. If it is assumed that both studied lists were accompanied by the same mental context, then an instruction to forget one of these lists should actually affect both lists. This was indeed the result obtained by Sahakyan. It is worth pointing out here, however, that the same prediction is made by the context change account for the selective directed forgetting procedure introduced by Delaney et al. (2009). Delaney et al. demonstrated that participants are able to selectively forget part of the study episode which is inconsistent with predictions of the context change account. Turning now to the release from inhibition phenomenon, the context change hypothesis can provide an explanation for it if a reasonable assumption is made that representing some of the to-be-forgotten items within an episodic memory task has the effect of reinstating the context in which they were encoded. As described earlier, context reinstatement has been shown to abolish the costs of directed forgetting (Sahakyan & Kelley, 2002).

To date, no dissociation of directed forgetting and context change manipulations has been observed. In each study in which context change manipulation was used it produced the same results as the directed forgetting manipulation. However, the fact that two manipulations produce equivalent results is not sufficient to conclude that the same mechanism is responsible for these effects. Thus, it is important to consider results that uniquely support the context change account of directed forgetting. One such result is the already described effect of context reinstatement which was found to reduce directed forgetting effects (Sahakyan & Kelley, 2002). On the other hand, it has to be noted that if the context reinstatement mechanism can account for the results thought to support the release from inhibition hypothesis, then it is likely that the release from inhibition mechanism could account for the results thought to support the role of context reinstatement. It could be argued that reinstatement of context features serves to release at least some items from a to-be-forgotten list from inhibition. The retrieval inhibition account makes a prediction that providing sufficiently specific cues may induce release from inhibition. It is thus unclear whether context reinstatement is specifically due to providing context information that is lost and



not automatically accessible (as the context change account stipulates) or due simply to providing additional information which enhances cueing and which does not have to be necessarily contextual in nature.

To date, at least four different studies have been conducted specifically to test the contrasting predictions of the context change and retrieval inhibition accounts. Sahakyan, Delaney, and Waldum (2008) investigated the role of encoding in producing directed forgetting costs. They contrasted the conditions in which encoding of to-be-forgotten items was strengthened by means of additional presentations, longer presentation times or performing a deep orienting task on these items during study. The retrieval inhibition account would predict that stronger and thus more interfering items should be subjected to stronger inhibitory effects. The context change account, on the other hand, makes a prediction that the magnitude of directed forgetting should depend on the amount of context features stored during study. According to the influential framework of context storage developed by Malmberg and Shiffrin (2005), a constant amount of context features are stored automatically with each presentation of an item during study, independently of the study episode duration or the nature of an orienting task. Based on this framework of context storage and the assumption of the context change account of directed forgetting, Sahakyan et al. formulated a specific prediction that the magnitude of directed forgetting costs should increase when strengthening of to-be-forgotten items occurs by means of additional presentations but not by longer presentations or deeper encoding operations. Indeed, this was the pattern of results observed in this study, supporting the context change account. It is interesting to note that the null results obtained by Sahakyan et al. resemble the results obtained by Jakab and Raaijmakers (2009) within the retrieval practice paradigm in which manipulating the strength of encoding of Rp- items by varying their study position within a category or by varying the number of presentations had no effect on the size of the RIF effect. The inhibitory framework can account for these results if they assume that some means of strengthening of to-be-forgotten items (or Rp- items) do not lead to increased interference that would have to be resolved by an inhibitory mechanism. However, nothing in this

framework specifies under which conditions interference is to be expected and thus all accounts of the findings of the type presented here are necessarily *post hoc* explanations.

Sahakyan and Goodmon (2010) presented another set of experiments that build on the already established knowledge on the context effects to provide converging evidence that directed forgetting is an effect that depends on context storage and retrieval as the context change account postulates. In their study Sahakyan and Goodmon built on the conceptual framework of implicit memory developed by Nelson and his colleagues (Nelson, McKinney, Gee, & Janczura, 1998) to account for the findings of recall cued with extra-list associates. In this framework memory is dependent on the operations of two different systems, an implicit one and an explicit one. The implicit system, which is the focus of attention here, works on the contents of an associative network in which studied items are embedded. When an item is presented for study, its conceptual representation together with representations of its semantic associates become activated. Later, when an extra-list semantic associate is presented as a cue for a studied item, this pattern of study activation may be reinstated leading to retrieval of an appropriate target. Importantly, the effects present in implicit memory are dependent on the context match between the study and test episodes. As documented in numerous studies of Nelson and his colleagues (Nelson, McEvoy, Janczura, & Xu, 1993; Nelson & Goodmon, 2002; Nelson, Goodmon, & Akirmak, 2007), the effects of variables describing the associative network and thus affecting retrieval from implicit memory are stronger when the context of study matches the context of the test. Sahakyan and Goodmon used the context-dependent effects present in implicit memory to provide converging evidence for the context change account of directed forgetting. In the first two experiments employing the directed forgetting paradigm they manipulated the amount of activation received by studied items' semantic representations by varying their associative networks (specifically, the number of backward connections from associates to a target, a feature called *resonance*, and the number of connection between associates of a target, called *connectivity*). They found that their experimental variables tied to implicit memory exerted stronger

effects in the Remember than in the Forget condition which is consistent with the context change account which assumes that a contextual match between study and test for list 1 is stronger in the Remember than in the Forget condition. However, these results could be accounted for by the retrieval inhibition hypothesis if it assumed that items that receive more activation during study have a greater potential of interference and thus need to be inhibited to a greater extent. To address this issue, in a further three experiments Sahakyan and Goodmon manipulated the extra-list cues used at retrieval rather than the targets used at study. By varying another three factors tied to implicit memory (specifically, the number of associates of a cue, called *set size*, the strength of a target-to-cue connection and the number of indirect connections between a cue and a target) and again found stronger effects of these variables in the Remember than in the Forget conditions. These findings are particularly problematic for the retrieval inhibition account which would seem to make a prediction that the manipulations strengthening the effectiveness of a cue should actually exert more influence in the Forget condition. This is because this account proposes the mechanism of release from inhibition which is triggered by better, more specific cues and which should operate exclusively in the Forget condition.

Another recent study that can be used to contrast the context change account with the retrieval inhibition account was conducted by Spillers and Unsworth (2011b). In order to examine the effects of instructions to forget these researchers focused on latencies of recall. Some models of memory assume that recall progresses in two steps (Raaijmakers & Shiffrin, 1981; Wixted & Roher, 1993). In the sampling stage a set of traces that match the information present in a cue is localized and each trace sampled in turn. When a memory trace is sampled, a second step of the process begins and an attempted recovery of the trace takes place. When recall is analyzed in detail it is commonly assumed that the latencies of recall reflect the sampling process, with shorter latencies for smaller sets of sampled traces, whereas the proportion of recalled items reflects the joint effects of sampling and recovery. Spillers and Unsworth conducted a single directed forgetting experiment and discovered that the instruction to forget had a strong

effect on both the proportion of recalled items and the mean latencies of recall of items from a to-be-forgotten list. This, according to the researchers, indicates that directed forgetting affects the sampling stage of memory retrieval. Considering the mechanism of directed forgetting, this finding seems consistent with the context change account of directed forgetting, which postulates that retrieval items from a to-be-forgotten list is cued with context that is actually a good match to a to-be-remembered list. Spillers and Unsworth suggested that the sampling stage of retrieval is disrupted in directed forgetting because participants attempting to retrieve the to-be-forgotten list activate the whole set of studied items, including items from a to-be-remembered list, which prolongs the sampling process. On the other hand, this data seems inconsistent with the inhibitory mechanism of directed forgetting which postulates that retrieval inhibition affects the episodic representations encoded during study and not the effectiveness of certain cues in constraining recall to a particular subset of items. In consequence, the retrieval inhibition account predicts that recovery of inhibited items should be impaired and not the sampling process by intentional forgetting. Indeed, this argument has been put straightforwardly in the literature concerning RIF in which Bäuml, Zeller, and Vilimek (2005) conducted an analyses of response latencies and discovered the impairment in recovery of Rp- items, concluding that this finding supports the inhibitory mechanism of RIF (see Tomlinson, Huber, Rieth, & Davelaar, 2009, for an interference-based model that accounts for these findings). However, the data obtained by Spillers and Unsworth in the directed forgetting paradigm are inconsistent with the predictions of the inhibitory account.

Finally, the study contrasting the context change account with the inhibitory account that is most relevant to the empirical part of the present thesis was conducted by Sahakyan et al. (2009). In this already mentioned study researchers looked at directed forgetting in recognition reliant on recollective processes. As described earlier, one of their experiments revealed directed forgetting costs in the plurals paradigm. The other two experiments focused on the recognition of non-words. Sahakyan et al. argued that the lack of directed forgetting costs usually obtained in recognition may reflect the fact that simple recognition tests are not

dependent on contextual information. The reason for it may be that other types of associations overshadow the contextual associations at study which leads to their impoverished encoding and thus minimal role during memory testing. Sahakyan et al. hypothesized that the associations between different studied words may play such an overshadowing role and thus elimination of these associations would cause enhanced encoding of contextual associations, their greater role in memory retrieval and emergence of directed forgetting costs in recognition. In two experiments Sahakyan et al. used non-words as study materials, under the assumption that participants would not relate items that lack semantic information. In these experiments the costs of directed forgetting emerged in recognition. This result suggests that directed forgetting costs are present in recognition when it is dependent on contextual associations, a result not predicted by the retrieval inhibition account. On the other hand, it could be argued that the choice of materials in these experiments induced more reliance on recollection, independently of the type of associations, contextual or inter-item, used by this process. In this case retrieval inhibition would predict the costs because recollection is assumed to be disrupted by retrieval inhibition (Bjork & Bjork, 2003). This issue is a target of scrutiny of the studies presented later.

### **3.3 Summary**

To summarize the considerations on directed forgetting, three mechanisms have been postulated to be responsible for the costs of providing instructions to forget. One of these mechanisms, differential rehearsal affecting the encoding of to-be-forgotten and to-be-remembered lists is rarely considered to be a valid account, although some variant of this encoding mechanism seems to play role in producing directed forgetting benefits. The other two mechanisms are retrieval inhibition and context change. These two mechanisms often lead to similar predictions which makes them difficult to disentangle. Moreover, the mechanism of retrieval inhibition is not well specified as it is unclear even what supposedly becomes inhibited due to the workings of this mechanism. This feature of the retrieval inhibition account makes it difficult to falsify. Although several lines of evidence cited in support of this account have been described here, it is unclear if

the predictions formulated within the described studies follow clearly from the assumption about the tested mechanism. In fact, the arguments concerning retrieval inhibition are quite often circular because the same observations serve to describe the mechanism of retrieval inhibition and support the hypothesis that this mechanism is responsible for directed costs.

In contrast, the context change account makes a quite straightforward prediction that directed forgetting costs in any memory test will be detectable to the extent to which context features are encoded and used during a memory test. Several lines of evidence suggest that this prediction is supported by the data. Most prominently, Sahakyan et al. (2008) documented modulation of directed forgetting costs due to multiple presentations of studied items, a manipulation thought to affect context storage, but not due to other ways of strengthening to-be-forgotten words. Sahakyan and Goodmon (2010) documented the modulating role of directed forgetting instructions on the strength of effects of several variables that are known to produce context-dependent effects. Thus, there is good reason to suspect that directed forgetting is a phenomenon that is tied to contextual associations, in line with the assumption of the context change account.

On the other hand, the retrieval inhibition account seems to postulate a broader mechanism of forgetting. In the present chapter a definition of retrieval inhibition was adopted by which this mechanism serves to inhibit the contents of to-be-forgotten episode of studying lists preceding instructions to forget (Racsmány & Conway, 2006). This perspective can account for at least some of the results supporting the context change account by assuming that context associations are created during study episode and thus they are subjected to inhibition. This proposal resembles the approach proposed by Anderson (2005) who argued for inhibition of context. However, if inhibition affects all contents of a study episode, then its effects should be detectable for other types of associations that are not contextual in nature. The study conducted by Sahakyan et al. (2009) suggests that this may not be the case because in this study directed forgetting was present only when the role of inter-item associations was minimized by the use of non-words rather than words. If inhibition works on all contents of to-be-forgotten episode,

then it should disrupt inter-item associations just as it disrupts contextual associations. However, this argument stands solely on the assumption that the use of non-words does minimize encoding of inter-item associations and maximizes the encoding of contextual associations.

The empirical part concerning directed forgetting focuses on the scope of effects of instructions to forget. It assesses the prediction of the context-dependence of forgetting, which follows from adopting the context change account, with the alternative prediction of a general disruption in episodic associations created during the to-be-forgotten episode of studying list 1, which follows from adopting the retrieval inhibition account. If impairment is limited to contextual associations, then this is consistent with the context change account and although not necessarily inconsistent with some formulations of the retrieval inhibition account (see Anderson, 2005), it puts strong limits on how inhibition could be understood. In fact, in this case it would virtually equate the context change and retrieval inhibition accounts. In contrast, if impairment is general and is not limited to contextual associations, then the context change account makes a wrong prediction in this case and the retrieval inhibition account is favoured.

## 4. Experiments on RIF

### 4.1 Introduction

The empirical approach adopted in the experiments presented here is to examine what part of a memory representation is affected by an inhibitory mechanism in the situation of retrieval from episodic memory. If inhibition truly serves to resolve interference, then it needs to accomplish this by changing the structure of a memory trace of interfering information. However, the representations of such interfering items are complex, consisting of their core semantic features and episodic links between interfering items and other concepts present during encoding, which are either provided by the experimenter or self-generated by participants. For example, if the encoded item “apple” interferes with the retrieval of “pear”, the memory representation of “apple” can be described as consisting of semantic features of the concept of “apple” (round, red, fruit, etc.) and also of episodic links that are established for this concept at study. Such episodic links may consist of associations explicitly presented to participants (e.g. an episodic link between the original cue FRUIT and “apple”) as well as a variety of other links, idiosyncratic for each participant, which can be described as contextual. For instance, when a person thinks of the concept “caterpillar” while studying the pair “FRUIT – apple”, an episodic link may be established between the concepts of “caterpillar” and “apple”. The question that can be posed within inhibitory frameworks is which part of such a complex memory representation is subjected to inhibition. According to some models inhibition operates at the level of semantic features and according to other models it affects episodic links between different concepts. This issue will be examined in the studies presented here.

In the present chapter an assumption will be adopted that inhibition is indeed responsible for forgetting in the retrieval practice paradigm and only the locus of the inhibitory mechanism will be pursued. Thus, the present empirical endeavor can be described as an attempt to specify the inhibitory mechanism. However, it should not be ignored that inhibition is in fact not the sole candidate for a mechanism of RIF, as discussed in the theoretical overview of the research in



this field. As argued earlier, the interference-based model remains a viable alternative to various inhibitory frameworks. With regard to the locus of RIF, the interference-based approach differs from the class of inhibitory models because it clearly specifies such a locus. It places the mechanism of RIF at the level of associations between cues used at retrieval practice and Rp- items. Thus, the present studies should also inform the debate between proponents of the inhibitory and interference-based frameworks of RIF. If it could be shown that the locus of RIF is not at the level of the original cue-to-Rp- item associations, then this would serve not only to specify the inhibitory mechanism responsible for this effect but also it would refute the interference-based accounts of RIF. This issue will be revisited in the discussion of the present findings.

The empirical section concerning RIF is focused on the problem of cue-independence of this effect. As was described in the theoretical overview of research on RIF, the finding of RIF with independent cues is deemed to be one of the most important pieces of evidence supporting the inhibitory mechanism of this effect (Anderson & Spellman, 1995; Anderson, 2003). This finding is commonly used to argue that inhibition operating at the level of semantic features is necessary to account for the RIF effect (e.g. Anderson, Green et al., 2000). Alternatively, the theoretical framework of Norman et al. (2007) tries to account for cue-independence in terms of inhibition affecting episodic links. The present studies will examine the cue-independence of RIF with the aim of establishing the locus of the mechanism responsible for this effect.

Various ways of assessing cue-independence were proposed, which include the examination of cross-category forgetting, by which retrieval of a subset of elements from one category impairs memory access to elements that semantically belong to the same category but are studied and tested as members of a different category (e.g. Anderson & Spellman, 1995, Experiment 1), and examination of second-order forgetting, by which retrieval of a subset of elements from one category impairs memory access to elements that share a semantic relationship with other, non-retrieved elements of this semantic category (e.g. Anderson & Spellman, 1995, Experiments 2 and 4). However, in the present work the cue-

independence of RIF will be examined exclusively in relation to a subset of non-retrieved elements of a practiced category, referred to as Rp- items. This approach is prevalent in the literature on RIF, most likely due to the methodological complexity of examining the RIF effect in multiple categories, and some concerns about the reliability of the cross-category and second-order findings (Williams & Zacks, 2001; Perfect et al., 2004).

Anderson and Spellman (1995) proposed that RIF is cue-independent because the inhibitory mechanism recruited to resolve interference during retrieval practice of Rp+ items serves to suppress the features from which the semantic representation of competing Rp- items is built (the pattern-suppression model). If parts of the semantic representations of these items are suppressed, then it follows that the memory impairment observable for these items should generalize to any possible cues that tap into these semantic representations. In the present work this prediction is tested with two different sets of materials and four different sets of cues. In Experiments 1 and 2 a subset of slightly revised categories used in the study by Anderson, Green et al. (2000) was employed. In these materials study items belong to two different categories, one that is presented during study and used as a cue for Rp+ items during retrieval practice, and one that is used only at test to serve as an independent cue for Rp- and Nrp items. Using these kinds of materials, Anderson et al. documented reliable RIF, confirming that RIF can be detected with independent cues. To preview, in the current experiments this effect is not replicated and RIF is absent from a test employing category independent cues in both Experiment 1 and Experiment 2.

An important feature of the methodology used by Anderson, Green et al. (2000) is that the independent cues employed in a final test relate to many elements in the set of studied items. This can have important consequences as discussed by Perfect et al. (2004) and as suggested by the framework developed by Norman et al. (2007). In such a methodology it is possible that participants are able to identify the independent cues during the study phase. This covert identification can lead to at least two different effects that can be responsible for the apparent

cue-independence of RIF, even if inhibition does not really operate at the level of semantic features.

Firstly, identified independent cues may become linked with category labels used at study and retrieval practice. Later, in a final test with independent cues such an episodic association between different types of cues may lead to covert retrieval of the original cues which are in turn used to access memory instead of the independent cues provided to participants by an experimenter. If this mechanism of covert cueing is responsible for RIF with independent cues, then the effect is not due to the suppression of semantic features but either due to the simple process of interference or due to some inhibitory mechanism operating in episodic memory. Focusing on this second possibility, it could be argued that inhibition serves to disrupt an episodic link between a cue used at retrieval practice and items not retrieved in this phase but competing for access.

Secondly, identified independent cues may become linked to their appropriate targets, rather than to original cues. In this case an episodic link between an independent cue and its target is established during the study phase. According to the model developed by Norman et al. (2007), such episodic links may become disrupted due to operations of an inhibitory mechanism working in episodic memory. In this case attempted retrieval of Rp+ items activates the semantic representation of Rp- items which in turn activates episodic links created during study which tie this semantic representation to different concepts, such as the concept representing an independent cue. This activation is regulated by an inhibitory mechanism to facilitate retrieval of Rp+ items. This regulation takes the form of unlearning of the episodic connection between the competing Rp- item and its independent cue. Thus, in this framework inhibition has general consequences in the form of changes to the stored network of episodic links that extends beyond the links between the original cues and Rp- items.

Figure 1 graphically summarizes the three different theoretical approaches to inhibition in the retrieval practice paradigm. As presented, they differ in the locus of postulated effects of an inhibitory mechanism. The pattern-suppression

model (Anderson & Spellman, 1995) assumes that inhibition occurs at the level of semantic features. In contrast, two other inhibitory models assume that inhibition operates on episodic links between semantic representations. The model developed by Norman et al. (2007) describes an inhibitory mechanism of a vast scope that affects all episodic links referring to the semantic representations of Rp-items. The constrained episodic model predicts that only links that directly underlie interference during retrieval practice become affected by inhibition. The studies presented here assess all three approaches.

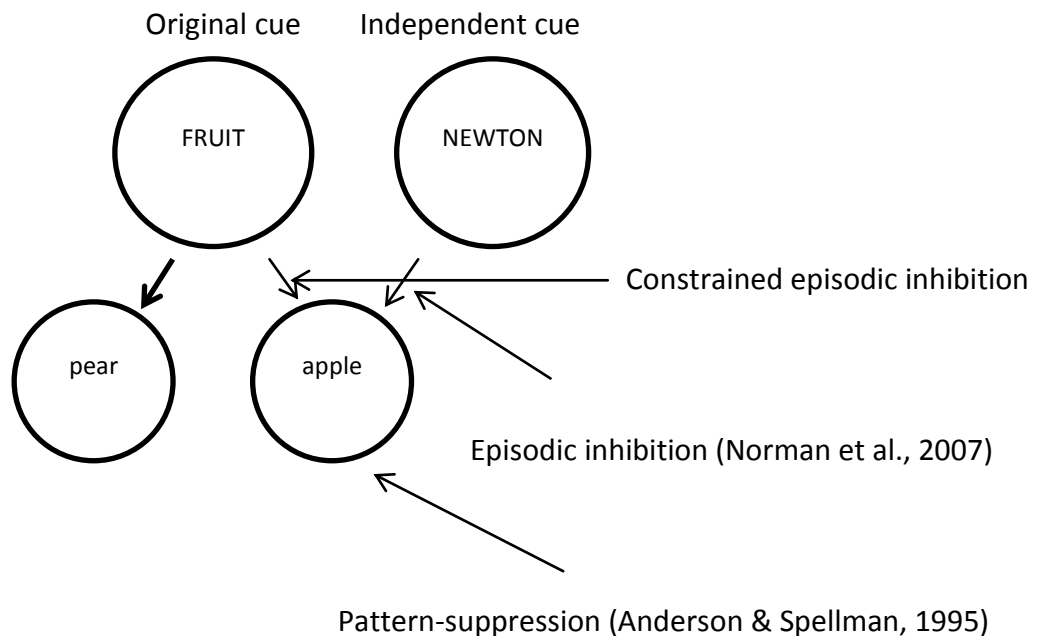


Figure 1. Possible loci of inhibitory processes. The link between FRUIT and *pear* becomes strengthened during retrieval practice. The inhibitory mechanism may become recruited to resolve interference. This mechanism may affect the semantic representation of *apple* (the pattern suppression model), all episodic links that contain the representation of *apple* (episodic inhibition) or only an episodic link that is directly responsible for interference during the retrieval of *pear* (constrained episodic inhibition).

Given that Experiments 1 and 2 produced no evidence for the cue-independence of RIF, directly contradicting predictions from the model of inhibition defined as suppression of semantic features, the next experiments aimed at

assessing the hypotheses of covert cueing and episodic inhibition model by Norman et al. (2007). Both of these approaches stress the role of identification of independent cues during study, a process that is not under experimenter's control with materials developed by Anderson, Green et al. (2000). To provide better control over identification and the process of establishing the episodic links between independent cues and their targets or original cues for these targets, the materials for the rest of the experiments described here were changed to a novel set in which item-specific independent cues were employed. As described in the theoretical overview, there are published studies indicating that RIF is absent with such item-specific independent cues (Camp et al., 2007; Perfect et al., 2004), possibly because such cues are highly unlikely to be identified during the study phase. In the present set of experiments this identification and creating of the aforementioned episodic links was enabled by direct presentations of independent cues with either their appropriate targets (Experiment 4 and 7) or the original cues related to these targets (Experiment 8). In this way the processes that are thought to occur with category independent cues as used by Anderson, Green et al. (2000) were directly imposed with a different set of materials containing item-specific independent cues. If either covert cueing or episodic inhibition are responsible for the cue-independence of RIF, then one of these experiments should reveal this effect with item-specific independent cues. However, to preview, no evidence for the cue-independence of RIF was obtained in any of the experiments reported here, contradicting not only the predictions derived from the pattern-suppression model but also the predictions from covert cueing and episodic inhibition models.

#### **4.2 Experiment 1**

Experiment 1 was conducted for the purpose of examining the cue-independence of RIF with category independent cues. To this aim, the standard retrieval practice was employed and memory for Rp- and Nrp items was assessed with both the original cues present at study and retrieval practice and category independent cues present only at test. Previous studies have found evidence for cue-independence with this type of category independent cues (e.g. Anderson, Green et al., 2000; Anderson & Spellman, 1995; Camp et al., 2005). The predictions,

formulated on the basis of the pattern-suppression model of RIF, developed by Anderson and Spellman, were that RIF would be present with both original and category independent cues.

### *Participants*

Thirty eight participants were tested in this experiment. They were recruited from the University of Hull subject pool and received credits for their participation.

### *Materials and design*

Four categories were created with eight exemplars each (see Appendix for the complete list). All categories (WOOD, FLY, SHARP, RED) were chosen from the materials used by Anderson, Green et al. (2000). Most of the exemplars were also taken from the materials provided by Anderson et al., although some were replaced to allow for a better choice of item-specific independent cues that were used in Experiment 2. The words in each category were divided into two sets of four words. The words from one set were used as practiced (Rp+) items in the retrieval practice phase and the words from the other set were used as unpracticed (Rp-) or control (Nrp) items. All words that served as Rp- and Nrp items belonged also to covert categories (FURNITURE for WOOD, ANIMAL for FLY, WEAPON for SHARP, FOOD for RED) that were used as category independent cues at test. One additional filler category (SOFT) with four exemplars was chosen to be used as a source of fillers in the study and retrieval practice phases.

Four experimental categories were presented to each of the participants in the study phase. Out of four studied categories, two were chosen to serve as practiced categories. The four exemplars from these practiced categories were cued for retrieval in the retrieval practice phase, resulting in eight Rp+ items. The rest of the words from practiced categories served as eight Rp- items. The words with double categorization from the two categories that were not practiced in the retrieval practice phase served as eight Nrp items. The assignment of categories for practice was counterbalanced across participants.

There were two tests for all Rp- and Nrp items. The Rp+ items were never tested. In the first test an original cue that was used in the study and retrieval practice was used. In the second test category independent cues were used to test the same items. The order of the tests was fixed. The experiment conformed to a 2 (item type: Rp- vs. Nrp) x 2 (test type: original cue vs. category independent cue) design with both factors manipulated within participants.

### *Procedure*

Participants were tested individually or in pairs. The procedure of the experiment conformed to the scheme of a retrieval practice paradigm. There were four separate phases.

*Study phase:* In the study phase of the experiment participants were presented with the pairs of category label and category instance (e.g. SHARP – sword). Two filler pairs were presented at the beginning and two at the end of the study phase to control for primacy and recency effects. The presentation of experimental pairs was block-randomized with eight blocks of four pairs, each from four different experimental categories. Every pair was presented for five seconds with no inter-stimulus interval (ISI) and participants were asked to study the pair for a future test. On every trial a label was presented in capital letters and an exemplar was presented in lower-case font below a label.

*Retrieval practice phase:* In this phase, retrieval of eight words from two of the studied categories was practiced. Additionally, retrieval of four words from the filler category was also practiced. The retrieval practice was block-randomized with each of four blocks containing cues for three words, each from a different category. Each trial commenced in three steps. A category label was presented for two seconds, followed by a blank 1-second interval. Finally, the category label was again presented, this time with the first two letters of a target that participants were asked to recall and type within 10 seconds. This type of cueing, shaped after the procedure used by Bajo et al. (2006), was implemented to maximize competition in the retrieval practice phase. The whole cycle of retrieval was repeated three times resulting in 36 retrieval trials.

*Filler phase:* In this phase participants were required to solve algebra problems for five minutes.

*Final test:* In this phase participants were required to retrieve words from the study phase. Only Rp- and Nrp words were tested. In the first test, retrieval was cued by presenting a category label used at study together with the first letter of a target. The time for retrieval was limited to 10 seconds. Presentation of cues was block-randomized with four blocks, each containing four cues, two for Nrp and two for Rp- items, from four different categories. In the second test retrieval of the same words was cued by presenting a category independent cue together with the first letter of a target. The time for retrieval was again limited to 10 seconds and the presentation of cues was block-randomized. The two tests were separated by a 1-minuted interval filled with algebra.

### *Results*

The descriptive statistics for the final test results in all experiments presented here are included in Table 1. The proportion of correctly recalled items during retrieval practice was .72 ( $SD = .14$ ). The results of the final tests were analyzed separately for original cue and category independent cue tests. For the original cue test a t test comparing performance for Rp- and Nrp items showed a significant difference,  $t(37) = 2.06$ ,  $SE = 0.23$ ,  $p < .05$ . Performance for Rp- items was worse than performance for Nrp items and thus RIF was obtained in the original cue test. The same analysis of results for the category independent cue test showed no significant difference,  $t < 1$ . Performance in this test was therefore comparable for Rp- and Nrp items.



	Rp+	Rp-	Nrp	Ns
Experiment 1				
Original cues	-	.40 (.22)	.48 (.20)	-
Category independent cues	-	.48 (.21)	.51 (.21)	-
Experiment 2				
ISIC group				
Independent cues	-	.39 (.22)	.38 (.18)	-
Original cues	-	.53 (.20)	.53 (.19)	-
CIP group				
Independent cues	-	.40 (.23)	.44 (.20)	-
Original cues	-	.49 (.21)	.55 (.20)	-
Experiment 3	.59 (.18)	.41 (.19)	.49 (.14)	-
Experiment 4	.61 (.12)	.75 (.12)	.75 (.16)	-
Experiment 5	.53 (.16)	.45 (.17)	.44 (.15)	-
Experiment 6	.58 (.15)	.38 (.16)	.46 (.17)	-
Experiment 7	.54 (.20)	.36 (.26)	.34 (.21)	-
Experiment 8				
Associated cues	.64 (.24)	.55 (.24)	.52 (.21)	.40 (.21)
Unassociated cues	.58 (.25)	.45 (.19)	.46 (.19)	.28 (.15)

Table 1. Recall performance in Experiments 1-8. Rp+ refers to practiced items from practiced categories, Rp- items refer to unpracticed items from practiced categories, Nrp refers to items from unpracticed categories and Ns refers to not studied items. Standard deviations are given in parentheses.

## *Discussion*

The present experiment produced two noteworthy results. First, replicating numerous previous studies, RIF was observed when the same category labels used at study were used as cues in the retrieval practice and test phases of the procedure. It is important also that RIF was obtained when in the final test with original cues every target word was cued with its first letter. In the retrieval practice paradigm it is quite common to assess memory for Rp- items and Nrp items by providing only category labels as cues (e.g. Jakab & Raaijmakers, 2009; see Storm, 2010, for a discussion). However, under these conditions it is unclear whether impaired access to Rp- items is caused directly by attempted retrieval of Rp+ items during retrieval practice or if it is a by-product of preferential access and early output positions of Rp+ items during a test. In the present experiment such confounds were eliminated because each combination of a label and the first letter was unique and specifically cued only one of the Rp- or Nrp items. The Rp+ items were never cued and thus could not have been output before Rp- and Nrp items, suggesting that the RIF effect documented in this experiment stemmed directly from the dynamics of retrieval practice, as intended in this paradigm.

Interestingly, Butler et al. (2001) failed to show RIF with cues that uniquely specified one of the studied items. The present experiment documents RIF under such specific cueing conditions which converges with other studies in which RIF was detected with this kind of cueing at test (e.g. Anderson, Green et al., 2000; Camp et al. 2007). Anderson (2003) hypothesized that a failure to obtain RIF when word stems are provided with original cues may be caused by the use of lexical representations on such tests rather than the conceptual ones. It is worth noting that Butler et al. used two-letter stems and in the current experiment only the first letter was provided. Two letter-stems may induce more reliance on lexical representations than one-letter stems.

The second, crucial result of the present experiment was that RIF was not obtained when category independent cues were used at test. This null finding contrasts with the significant effect obtained with the original cues and it

constitutes a failure to replicate previous results indicative of the cue-independence of RIF (e.g. Anderson & Spellman, 1995; Anderson, Green et al., 2000). One factor that could underlie this null result obtained with the category independent cue test was the fixed order of tests used in the present experiment. In the current procedure the test employing original cues always preceded the test employing independent cues, and this could have produced conditions under which inhibition was released in the test with the original cues and thus it was not detectable in the subsequently provided independent cue test. As described in the overview of the directed forgetting paradigm, in the theorizing about inhibition the concept of a release from inhibition plays a prominent role (e.g. Bjork, 1989). It has been argued that inhibition serves its function only if it limits memorial access temporarily so that this information becomes again accessible when it is relevant to the current processing. Importantly, also some findings from the RIF literature seem to suggest that a release from inhibition may sometimes be present in the retrieval practice paradigm. Specifically, Storm, Bjork, and Bjork (2008) demonstrated that Rp- items suffering from limited accessibility can actually benefit more from relearning than items that were not subjected to RIF. It could be hypothesized that such accelerated relearning stems from releasing Rp- items from inhibition. It is unclear if release from inhibition resulting from retrieval practice can occur also with testing rather than an additional study session but drawing an analogy to directed forgetting studies, in which release from inhibition is argued to occur with testing of only a subset of to-be-forgotten items (Bjork & Bjork, 1996), it can be argued that such a possibility should not be excluded. Thus, to avoid the criticism of the current results drawing from the release from inhibition hypothesis and to properly assess cue-independence of RIF a test employing independent cues could be given before a test employing original cues. This approach was adopted in Experiment 2.

### **4.3 Experiment 2**

Experiment 2 served two aims. Firstly, it was designed to test the cue-independence of RIF under conditions that would preclude any contaminating effects of the original cue test. For this purpose the order of the tests from

Experiment 1 was reversed and the independent cue test always preceded the original cue test. Secondly, Experiment 2 sought to generalize the findings obtained with category independent cues to item-specific independent cues. The pattern-suppression model of Anderson and Spellman (1995), which is tested here, makes the same prediction for both of these types of independent cues. Because it postulates a general cue-independence of RIF, it predicts reliable RIF with both category and item-specific independent cues. However, the findings reported in the literature do not seem to be consistent with this prediction. Although RIF with category independent cues was reported numerous times (e.g. Anderson, Green et al., 2000; Camp et al., 2005), RIF with item-specific independent cues is more elusive with some studies finding such an effect (Anderson & Bell, 2001) but some studies finding no RIF under these testing conditions (Camp et al., 2007; Perfect et al., 2004). In the present study semantic associates were used as item-specific independent cues, similarly to the procedure developed by Camp et al. in which no evidence for cue-independence of RIF emerged. Thus, the pattern suppression model predicts RIF with item-specific independent cues but the results obtained by Camp et al. suggest that this effect may not be obtained in this condition.

### *Participants*

One hundred and fourteen participants were tested in this experiment. They were recruited from the University of Hull subject pool and received credits for their participation. 57 participants were assigned to the item-specific independent cue test condition and 57 were assigned to the category independent cue test condition.

### *Materials and design*

The materials used for the present experiment were taken from Experiment 1. A semantic associate was chosen for each item from experimental sets of words to be used as an item-specific independent cue in one of the final tests (see Appendix 1 for the complete list of stimuli). The associates were taken from the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 1998) with a mean cue-target strength of .11 (SD = .13).

The design of the study replicated Experiment 1 with two changes. Firstly, the order of the tests was reversed with the independent cue test given first and the original cue test given second. Secondly, the condition employing item-specific independent cues was added. The experiment conformed then to a 2 (type of item: Rp- vs. Nrp) x 2 (type of test: independent vs. original cue) x 2 (type of independent cue: item-specific vs. category) design with the first two factors manipulated within participants and the last one manipulated between participants.

### *Procedure*

The procedure of the present experiment replicated the procedure of Experiment 1, except for the changes in the order of the tests and the nature of cues provided in the item-specific independent cue condition.

### *Results*

The proportion of correctly recalled items during retrieval practice was .71 ( $SD = .16$ ) for the group tested later with category independent cues and .70 ( $SD = .17$ ) for the group tested later with item-specific independent cues.

The results of the final tests were analyzed separately for the independent cue test and the original cue test. For the independent cue test a 2 (type of independent cue) x 2 (type of item) mixed ANOVA produced no significant results,  $F(1,112) = 1.22$ ,  $MSE = 0.048$ ,  $p = .27$  for the main effect of type of cue,  $F < 1$  for the main effect of type of item and  $F(1,112) = 1.05$ ,  $MSE = 0.041$ ,  $p = .31$  for the interaction of these two factors. Despite the non-significant interaction planned comparisons were conducted separately for type of test conditions to ensure that the pattern of non-significant differences is consistent across these conditions. Separate t tests revealed no RIF with item-specific independent cues,  $t < 1$ , and category independent cues,  $t(56) = 1.43$ ,  $SE = 0.25$ ,  $p = .16$ .

For the original cue test, a 2(type of cue) x 2(type of item) mixed ANOVA produced no significant results,  $F < 1$  for the main effect of type of cue,  $F(1,112) = 2.16$ ,  $MSE = 0.029$ ,  $p = .14$  for the main effect of type of item and  $F(1,112) = 1.96$ ,  $MSE = 0.029$ ,  $p = .16$  for the interaction. Despite the non-significant interaction

planned comparisons were again conducted separately for the different type of independent cue test conditions. Separate t tests revealed no difference between Rp- and Nrp items when the original cue test was preceded by the item-specific independent cue test,  $t < 1$ , and a difference approaching significance when original cue test was preceded by the category independent cue test,  $t(56) = 1.93$ ,  $SE = 0.25$ ,  $p = .058$ .

### *Discussion*

The present experiment was designed to assess the cue-independence of RIF by using at test two types of cues that were not used in the study or retrieval practice phases of the experimental procedure. RIF failed to emerge with either category independent cues that related to four items in the set or item-specific independent cues that related to only a single item in the set. The lack of RIF with item-specific independent cues is congruent with the results of the study by Camp et al. (2007) which used the same type of cues. However, the lack of RIF with category independent cues goes against the results obtained in previous studies (e.g. Anderson & Spellman, 1995; Anderson, Green et al., 2000). Finally, the results from the additional original cue test were mixed. There was a marginally significant difference between Rp- and Nrp items when the original cue test was preceded by the category independent cue test but there was no such difference when it was preceded with the item-specific independent cue test. These results should, however, be treated with caution as the interaction was not significant. It is possible that the preceding test affects the likelihood of obtaining RIF, possibly due to some mechanism akin to release from inhibition, but additional research would be required to allow for any clear conclusion on this matter.

Although the null result obtained with item-specific independent cues could have been predicted based on the published literature (Camp et al., 2007), the null result obtained with category independent cues is inconsistent with the results previously reported, most notably with the results of a study by Anderson, Green et al. (2000) from which the current methodology and materials were derived. The most obvious reason for this inconsistency may lie in the lack of power to detect

the effect. In both Experiment 1 and Experiment 2 the difference between Rp- and Nrp items was in the direction indicative of the RIF effect. To gain more statistical power, data from Experiment 1 and the category independent cue condition of Experiment 2 which differed only in the order of tests were combined resulting in a sample of 95 participants. The 2 (item type: Rp- vs. Nrp) x 2 (Experiment: 1 vs. 2) ANOVA with repeated measures on the first factor and with the dependent measure of the proportion recalled in the category independent cue test was conducted. The power to detect a medium size effect of partial  $\eta^2 = .05$  was .97 in this analysis. However, the analysis produced only the main effect of the factor of the experiment,  $F(1,93) = 4.34$ ,  $MSE = .061$ ,  $p < .05$ , showing that participants were better in Experiment 1 when the category independent cue test was preceded by the original cue test ( $M = .50$ ,  $SD = .17$ ) than in Experiment 2 when the category independent cue test was given first ( $M = .42$ ;  $SD = .18$ ). The RIF effect still failed to emerge as the main effect of type of item was not significant,  $F(1,93) = 2.32$ ,  $MSE = .032$ ,  $p = .13$ , and neither was the interaction,  $F < 1$ . This analysis suggests that the null effect with category independent cues is unlikely to stem from insufficient statistical power.

The fact that RIF was consistently absent when memory was tested with independent cues in both Experiment 1 and in the present Experiment 2 with two types of independent cues directly contradicts the predictions derived from the pattern-suppression model developed by Anderson and Spellman (1995). The model accounts for RIF by assuming that inhibition operates at the level of semantic features and thus predicts that if RIF is present with original cues, as it was in Experiment 1 and also in one of the conditions of Experiment 2, RIF should also be present with all types of cues that require access to suppressed semantic features. Both category and item-specific independent cues used in the present experiments were semantically related to their targets and thus required access to semantic representations to support performance in the final test. However, RIF did not occur for these cues which leads to the conclusion that RIF is unlikely to stem from inhibition occurring at the level of semantic features.

Although both Experiment 1 and Experiment 2 provide evidence against the pattern-suppression model, they do not rule out all inhibitory models which may account for the cue-independence of RIF. For example, the model developed by Norman et al. (2007) accounts for the results obtained with independent cues without postulating that the main locus of the inhibitory effect is placed at the level of semantic features. This model explains RIF obtained with independent cues in terms of disruption of episodic links established during study by assuming that competition from semantic representations of Rp- items during retrieval practice of Rp+ items activates all episodic links that contain these competing semantic representations and leads to unlearning of these activated episodic links. In order for this model to predict RIF with independent cues it needs to assume that independent cues become identified during the study phase and that they are episodically linked to their appropriate targets. Considering the present results in the perspective of this model, it could be argued that the present procedure worked against the identification of independent cues during the study. It is intuitively obvious that item-specific independent cues cannot be identified during the study phase as they relate to only one item in the set. These cues can be implicitly activated, as all associates of studied items are (Nelson et al., 1998), but this implicit activation is different than creating an episodic link that supports explicit access during the test. On the other hand, category independent cues may become identified during study because they relate to many items from the studied set. This could have occurred in the procedure used by Anderson, Green et al. (2000) in which all items were presented for study in two cycles, one encouraging creating associations between cues and targets and one encouraging creation of associations between different targets. This methodology was used by Anderson et al. to investigate the effects of integration in producing RIF. However, the present study was not designed to investigate the effects of integration and thus the methodology used here diverged from the one employed by Anderson et al. In the present experiments all items were presented once only which could have precluded identification of category independent cues and consequently establishing episodic links between these cues and targets.



A yet different variant of an inhibitory model operating in episodic memory could postulate that RIF stems exclusively from disruption of episodic links that are directly responsible for interference during retrieval practice (original cue-to-Rp-items links). This can be described as a constrained version of the model proposed by Norman et al. (2007) in which the semantic representation of competing items does not activate any episodic links, most likely because its activation is curtailed by an inhibitory mechanism limiting activation by disrupting an episodic link between a cue used at retrieval practice and the competing item. Racsomány and Conway (2006) proposed that inhibition works specifically on the episodic links that create interference during retrieval practice (see also Racsomány, Conway, Keresztes, & Krajcsi, 2012). Their proposal does not necessitate adopting the assumption of broad effects of recruiting an inhibitory mechanism in episodic memory. On the other hand, this model by itself cannot account for findings of RIF with independent cues. In fact, the independent cue methodology was designed specifically to rule out simple associative accounts of RIF in which the effect stems solely from the changes in the effectiveness of the original cue-to-Rp-item episodic links in supporting memory performance. However, this account can use the idea of covert cueing to account for some of the results obtained with independent cues. As described earlier, it is possible that independent cues identified during study become episodically linked to original cues which are later retrieved and are then used to access memory. Because according to this constrained inhibitory model such episodic links are disrupted for Rp-items, the covert cueing may lead to RIF even with independent cues.

Both of the explanations presented here underscore the importance of the identification of independent cues and their inclusion in the network of episodic links created during study. The rest of the present chapter will be devoted to testing these accounts. Although the discussion presented above focused on inconsistent findings concerning category independent cues and the probability of their identification in different study procedures, the rest of the experiments will employ item-specific independent cues. The use of this type of independent cues allows for control over the encoding of episodic links containing these cues.

#### **4.4 Experiment 3**

The present experiment serves as a control experiment for the rest of the experiments presented in this chapter. In this experiment a novel set of materials was used within the standard retrieval practice paradigm. Memory in the present experiment was tested with the original cues used at study and retrieval practice to establish the basic pattern of RIF that is compared with the experiments in which independent cues were employed at test.

##### *Participants*

Thirty three participants were tested in this experiment. They were recruited from the University of Hull subject pool and received credits for their participation.

##### *Materials and design*

Eight lists of words were created (see Appendix 2 for the complete lists). Each list was composed of a single “theme” word (e.g. BLACK) and six semantic associates of this theme word (e.g. night, sheep, etc.). The theme words and associates were taken either from a set of the lists normed for the DRM paradigm (Stadler, Roediger, & McDermott, 1999) or from the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 1998). Each associate within a list started with a different letter which allowed for control over the testing position. Two additional filler lists were created by choosing two theme words together with two associates each.

Six lists of theme word – associate pairs were presented to every participant in the study phase. Two lists were not presented, being a source of not studied (Ns) items. Ns items were not used in the current procedure but they were employed in one of the subsequent experiments and therefore they were included in the current counterbalancing scheme. Out of six studied lists, four were chosen to serve as practiced lists in the retrieval practice phase. Retrieval of half of associates from those four lists was practiced. As a result the entire set of 48 associates was divided into 12 practiced items (Rp+), 12 unpracticed items from practiced lists (Rp-), 12

control items (Nrp) from unpracticed lists and 12 not studied items (Ns). Recall of Rp+, Rp-, and Nrp items was tested and a proportion of correctly recalled items served as the dependent variable.

For the purpose of counterbalancing, the eight lists of words used in this experiment were divided into four sets with two lists each. For each participant, lists from two sets served as a source of Rp+ and Rp- items, lists from one set served as a source of Nrp items and lists from one set served as a source of Ns items. The assignment of sets to participants was counterbalanced according to the latin-square design, resulting in four counterbalancing conditions. Since there were four practiced lists for every participant and only two control and not studied lists, every list served as a practiced list in two different counterbalancing conditions.

Every list was divided into two halves. If for a given counterbalancing condition a list was practiced in the retrieval practice phase, then half of the associates served as Rp+ items and the other half served as Rp- items. Since every list was practiced in two different counterbalancing conditions, assignment of items to Rp+ and Rp- conditions was also counterbalanced. As a result of this counterbalancing design every item served equally often as Rp+, Rp-, Nrp, and Ns items across participants.

### *Procedure*

The participants were tested in small groups of up to 5 people. The procedure of the experiment conformed to a scheme of the retrieval practice paradigm. There were four separate phases.

*Study phase:* In the study phase of the experiment participants were presented with 40 associates together with their appropriate theme words. Every pair was presented for 4 seconds without ISI and participants were asked to spend this time relating words in each pair. The presentation was block-randomized with blocks of six pairs, each from six different studied lists. Additionally two filler pairs were presented at the beginning and at the end of a study presentation. On every trial a

theme word was presented in capital letters and an associate was presented in normal font below a label.

*Retrieval practice phase:* In this phase retrieval of 12 items from four of the studied lists was practiced. Retrieval was cued by presenting a theme word together with the first letter of a target (e.g. BLACK n\_\_\_\_\_). Participants were required to type the appropriate associate within a 10 second interval. Participants were instructed to move to the next trial if they could not recall a word. Retrieval practice was block-randomized with each of three blocks containing four theme words, each from a different practiced list. The whole cycle of retrieval was repeated three times resulting in 36 retrieval trials.

*Filler phase:* In this phase participants were required to solve algebra problems for 5 minutes.

*Final test:* In this phase participants were required to retrieve all studied associates. Retrieval was again cued by presenting a theme word used at study together with the first letter of a target and the time for retrieval was limited to 10 seconds. Presentation of cues was block-randomized with six blocks, each containing six items from six different lists.

### *Results*

The proportion of correctly recalled items during retrieval practice was 0.61 ( $SD = 0.19$ ). Planned comparisons were conducted to compare the recall level for Rp+ items and Rp- items with the level of recall of Nrp items. Rp+ items were recalled better than Nrp items and this difference was significant,  $t(32) = 2.82$ ,  $SE = 0.36$ ,  $p < 0.01$ , showing a beneficial effect of retrieval practice. In contrast, recall of Rp- items was impaired compared to Nrp items,  $t(32) = 2.20$ ,  $SE = 0.36$ ,  $p < 0.05$ , showing the RIF effect.

### *Discussion*

In the present experiment employing the standard retrieval practice paradigm and lists of associate words, RIF was obtained. The fact that RIF was

obtained with a list of associates rather than the commonly employed lists of categorized words replicates the findings by other researchers (e.g. Bäuml & Kuhbandner, 2003; Starns & Hicks, 2004), who also obtained RIF in this type of materials. Two issues concerning the present results are worthy of notice. First, RIF was again obtained when cues in a final test were constructed from the original cues and the first letters of targets, replicating the results of Experiment 1. Second, RIF was obtained under conditions of relatively low recall in the retrieval practice phase, supposedly caused by the use of lists of associates rather than semantic categories and the procedure of cueing with only one letter of a target in the retrieval practice phase. Whereas in Experiments 1 and 2 recall performance during retrieval practice exceeded 70%, in this experiment it was only 61%. However, that did not prevent RIF from occurring, which remains consistent with the results obtained by Storm, Bjork, Bjork, & Nestojko (2006) who showed that retrieval success is not a necessary precondition for obtaining RIF.

#### **4.5 Experiment 4**

The present experiment was designed as the first test of an episodic unlearning hypothesis formulated by Norman et al. (2007). As described earlier, Norman et al. argued that the cue-independence of RIF arises due to the disruption of episodic links established between independent cues and their targets, a process that can occur for category independent cues but is unlikely to occur for item-specific independent cues. In the present experiment conditions were created for which this process could operate also for item-specific independent cues. To this end, item-specific independent cues were used in the present experiment and creation of episodic links between these cues and their targets was enabled by presentations of the cue-target pairs within the study phase, along with the standard presentation of original cue – target pairs. If the account proposed by Norman et al. is correct, creation of these independent cue – target episodic associations should lead to their activation during the retrieval practice of Rp+ items, resulting in their disruption and eventually the RIF effect when these cues are provided in a final test.

### *Participants*

Thirty three participants were tested in this experiment. They were recruited from the University of Hull subject pool and received credits for their participation.

### *Materials and design*

The materials used in the present experiment were taken from Experiment 3. Six lists that produced the highest indices of RIF (the mean difference between recall of Nrp and Rp- items) were chosen out of eight used in the previous experiment (the lists used were RUBBER, WINDOW, LION, BREAD, MUSIC, and CAR). For each associate an item-specific independent cue was chosen from the University of South Florida Free Association Norm (Nelson, McEvoy, & Schreiber, 1998). The mean cue-to-target strength was  $M = .078$  ( $SD = .059$ ). These cues were related to only one studied item and also unrelated to any of the theme words (see appendix 2).

The design of the experiment was the same as Experiment 3 with a single independent factor of type of item (Rp+, Rp-, and Nrp), except for the changes in the counterbalancing scheme, which were introduced because in the present experiment all six categories were used at study for all participants (there were no non-studied categories).

### *Procedure*

The procedure of Experiment 4 followed the procedure of Experiment 3, except for three changes. Firstly, item-specific independent cues were used at test. Secondly, the study phase was modified to include additional presentations of associates together with their independent cues. Each associate assigned to the Rp- or Nrp condition was presented two times, once with the theme word and once with an independent cue. For example, the associate *door* was presented once in the pair “WINDOW – door” and once in the pair “TRAP – door”. Rp+ items were presented only with their appropriate theme words and thus they were not repeated within the study phase. This feature of the procedure was shaped after

the procedure used by Jakab and Raaijmakers (2009) and was implemented to preclude integration of Rp- and Rp+ items, which has been shown to increase with repeated study presentations of all items and to reduce the magnitude of the RIF effect (Anderson & McCulloch, 1999). Thus, in the study phase participants were presented with 60 trials altogether. Thirty six were presentations of theme word – associate pairs, as in Experiment 3. An additional 24 presentations were composed of 12 Rp- and 12 Nrp items presented together with their item-specific independent cues. The presentation was block-randomized with six blocks composed of 10 pairs, six of them being words with their theme words (one from each studied lists) and four of them being additional presentations of independent cue – associate pairs. Thirdly, cues provided in the retrieval practice phase consisted of theme words and the first two letters of a target (only one letter was used in Experiment 3).

### *Results*

The proportion of correctly recalled items during the retrieval practice was .76 ( $SD = .12$ ). Although in the present experiment Rp+ were tested (as in Experiment 3 but not as in Experiments 1 and 2), the results for them were not analyzed because of the lack of an appropriate baseline. Rp+ items were presented once only whereas Nrp items to which they are usually compared were presented two times, precluding a sensible analysis. A single t test was used to compare performance for Rp- and Nrp items, for which the number and format of presentations during study were equated. No significant difference was obtained,  $t < 1$ . The performance was exactly the same for Rp- items ( $M = .75$ ) and Nrp items ( $M = .75$ ).

### *Discussion*

In the present experiment RIF was again tested with item-specific independent cues. Consistently with the results of Experiment 2, RIF was not present with such cues. This result is again inconsistent with the prediction derived from the pattern-suppression model developed by Anderson and Spellman (1995) which predicts a general cue-independence of RIF. The present experiment adds to the generality of this null finding because it used a different set of materials than

the one used in Experiment 2, with a novel set of item-specific independent cues. Even more importantly, this result is also inconsistent with the prediction derived from the model of RIF developed by Norman et al. (2007). Based on this model, it was predicted that creating episodic links between item-specific independent cues and their targets in the study phase would lead to RIF in the final test. This should occur because the presentation of independent cue – target pairs in the study phase served to establish an episodic link between these two items that would later support retrieval in the test employing independent cues. Such episodic links for Rp- items should be disrupted during the retrieval practice of Rp+ items, resulting in RIF in the final test, an effect that was not observed.

However, at least two reservations can be formulated towards the present result. Firstly, although the present experiment used the methodology of Experiment 3, in which RIF was obtained with original cues that were employed both at retrieval practice and in the final test, the change of cues was not the only difference between Experiments 3 and 4. The creation of episodic links between independent cues and their targets necessitated additional presentations of Rp- and Nrp items during the study phase. Thus, whereas in Experiment 3 all associates were presented once, in Experiment 4 some of the associates were presented twice. It is unclear, therefore, if the fact that RIF was obtained in Experiment 3 but not in Experiment 4 stems from the change in cues employed at test or the change in encoding conditions. This latter factor could play a significant role if it assumed that various schedules of encoding lead to a changeable amount of competition during retrieval practice. According to the inhibitory accounts of RIF, the amount of competition exerted by Rp- items during retrieval of Rp+ items is crucial for obtaining RIF (e.g. Anderson et al., 1994). Usually the relationship between the amount of competition and the magnitude of RIF is presented as a monotonic one with more competition from Rp- items leading to greater memory impairment for these items. If this is the correct representation of this relationship, then the procedure used in the present experiment should actually lead to increased RIF because the Rp- items presented twice in Experiment 4 should compete for access more than Rp- items presented once in Experiment 3. However, Norman et al.



(2007) suggested that the relationship between competition and the magnitude of RIF can be non-monotonic and that at very high levels of competition from Rp-items the inhibitory mechanism loses its functionality and it is unable to resolve interference by unlearning episodic associations containing the semantic representations of Rp- items. Thus, it could be argued that the change in encoding conditions in the present study led to exacerbated competition and resulted in the abolishing of the RIF effect.

Secondly, the framework of Norman et al. (2007) predicts the RIF effect with independent cues to the extent to which performance in the final test depends on the disrupted episodic associations between these independent cues and their targets. However, the use of semantic associates in the present experiment could have allowed participants to circumvent the use of such episodic links during retrieval altogether. Although the mean initial strength of independent cue-to-target associations was relatively low, as indicated by the association norms from which the cues were chosen ( $M = .078$ ), this strength could have been temporarily increased by the presentation in the study phase. During retrieval participants could have relied at least to a certain extent on their semantic memory to produce associates to the item-specific independent cues, resulting in a diminished capacity for revealing RIF in the present procedure.

To address these two issues further experiments were conducted. In these experiments episodic rather semantic associates were used as independent cues. The memory performance for such cues can be based solely on episodic memory and thus the issue of circumventing episodic retrieval with semantic memory is not germane in this case. In this choice of episodic associates as independent cues these further experiments followed the procedure used by Perfect et al. (2004, Experiment 3). Although this work indicates that RIF does not occur when memory is cued with episodic associates, Norman et al. (2007) argued that the test presented by Perfect et al. is not conclusive for their model. These considerations and the differences between the current procedure and the one employed by Perfect et al. will be described in detail in the introduction to Experiment 7 in which episodic item-specific independent cues were used to cue memory at test. Before

that, however, it is important to create conditions under which episodic links between cues and their targets are established and the RIF effect occurs with original cues. This was the purpose of Experiments 5 and 6.

#### **4.6 Experiment 5**

The present experiment aimed at creating a procedure in which Rp- and Nrp items become episodically associated with their independent cues and the RIF is present when memory is tested with original cues. Such a procedure could then be used as a suitable control with equated encoding conditions for assessing RIF with an independent cue test. In other words, the present experiment aims at developing the procedure in which multiple presentations of Rp- and Nrp items, necessary for associating them with their independent cues, lead to the amount of competition during retrieval practice of Rp+ items that allows for an inhibitory mechanism to operate in service of resolving interference and, consequently, allows for the detection of RIF.

##### *Participants*

Thirty six participants were tested in this experiment. They were recruited from the University of Hull subject pool and received credits for their participation.

##### *Materials and design*

The materials used in the present experiment were taken from Experiment 4. Instead of semantic item-specific independent cues, a set of random, non-related words were chosen from the MRC linguistic database to serve as episodic item-specific independent cues for the studied associates. The list of 36 words was composed and each of these words was randomly paired with one of the associates used as studied items.

The design of the present experiment was the same as the design of Experiment 4.

##### *Procedure*

The procedure of the present experiment was the same of the procedure of Experiment 4, except for three changes. Firstly, the item-specific independent cues presented at study were changed from semantic associates of Rp- and Nrp items to unrelated, episodic associates. Secondly, the number of presentations of independent cue – associate pairs was increased from one to two. This was done to ensure an appropriate level of encoding of these semantically unrelated pairs that would support memory retrieval in subsequent experiments. Thirdly, memory in the final test was assessed with the theme words present in both study and retrieval practice rather than independent cues present only at study.

### *Results*

The proportion of correctly recalled items during retrieval practice was .56 ( $SD = .15$ ). As in Experiment 4 the Rp+ items were tested but the results for them were not analyzed because of the lack of an appropriate baseline. Rp+ items were presented once only whereas Nrp items to which they are usually compared were presented two times, precluding a sensible analysis. A single t test was used to compare performance for Rp- and Nrp items, for which the number and format of presentations during study were equated. No significant difference was obtained,  $t < 1$ . The performance was almost the same for Rp- items ( $M = .45$ ) and Nrp items ( $M = .44$ ).

### *Discussion*

The null result obtained in the present experiment is best viewed against the reliable RIF effect obtained in Experiment 3. Both of these experiments employed original cues used at retrieval practice to cue memory for Rp- and Nrp items in a final test. They differed, however, in the encoding phase. The study session of Experiment 3 was a commonly used variant in which participants are simply presented with original cue – associate pairs for study. The study session in Experiment 5 was modified to include independent cues. Although these cues were not used later to actually cue memory (which was the aim for the next experiment), they were included in the study phase to create episodic associations between these independent cues and their targets. Surprisingly, this change of encoding

conditions abolished RIF which was present in Experiment 3 but absent in Experiment 5. This null finding also sheds light on the null effect obtained in Experiment 4 in which independent cues in the shape of semantic independent cues were both included in the study phase, as were episodic cues in Experiment 5, and used in the final test to cue memory for Rp- and Nrp items. Although this null result obtained in Experiment 4 was interpreted to suggest that RIF does not occur with item-specific independent cues, the present null finding does indicate that the modification introduced in the study phase could have actually underlain this failure to obtain RIF.

Why then was RIF absent when item-specific independent cues were included in the study phase? At least two possible explanations exist and both of them are built on the common observation that the magnitude of RIF depends upon the amount of competition from Rp- items (Anderson et al., 1994). Norman et al. (2007) argued that the relationship between competition and RIF is curvilinear so that RIF is present at a moderate level of competition but does not occur when competition is too weak to trigger an inhibitory mechanism or is too strong and an inhibitory mechanism becomes unable to resolve the interference. In the present experiment Rp- and Nrp items were repeated three times, once with their theme words and twice with their independent cues, whereas Rp+ items were presented once with their theme words. This difference in the number of presentations created a situation in which memory performance for Rp+ items ( $M = .53$ ) was barely above the mean performance for Rp- items ( $M = .45$ ). It is also worth mentioning that performance in the retrieval practice phase in the present experiment was particularly low ( $M = .56$ ). These observations suggest that the procedure of the present experiment created conditions of excessive competition from Rp- during retrieval practice of Rp+ items which could not have been resolved by inhibition.

An alternative view posits that presentation of Rp- items together with their item-specific independent cues at study created conditions of insufficient competition. Anderson and Bjork (1994) have argued that some cognitive operations may temporarily change the meaning of a certain concept. They used

this idea as one of the possible explanations of RIF by which the retrieval practice of a subset of exemplars from a category (e.g. FRUIT – orange, FRUIT – lemon) changes the meaning associated with the cue (e.g. FRUIT becomes related to the concept of citrus) so that this cue no longer matches other exemplars (e.g. apple). The same logic can in principle be applied to a situation in which associates are presented in pairs with other, semantically unrelated words, as in the present experiment. Such presentations may temporarily change the meaning of these associates so that they no longer match a theme word for which they were chosen. Such a mismatch may in turn reduce competition from Rp- items during retrieval practice of Rp+ items which is cued by the theme words. As documented in some studies, the reduced competition from Rp- items may abolish the RIF effect (Anderson et al., 1994; Storm et al., 2007). The next experiment was designed to test between these two opposite accounts of the null effect obtained in the present experiment.

#### **4.7 Experiment 6**

The previous experiment found no RIF when studied associates were linked with unrelated words during study. Two explanations of this null result have been proposed, according to which additional presentations of Rp- items in the context of unrelated words either lead to excessive competition during the retrieval practice of Rp+ items or lead to reduced competition by virtue of changing the meaning of Rp- items. To test between these two different accounts, the present experiment implemented a change designed to reduce competition during retrieval practice. This was done by including additional repetitions of Rp+ items in the study phase in the context of their own episodic item-specific independent cues. Thus, the present experiment used exactly the same materials and procedures as Experiment 5, but this time all items (Rp+, Rp-, Nrp) were presented three times during the study.

Although previous studies published in the literature looked at competition only by manipulating the encoding of Rp- items, Norman et al. (2007) noticed that competition is a relative concept that links Rp- and Rp+ items. According to this idea

competition may be reduced either by decreasing the encoding strength of Rp- items or by enhancing the encoding strength of Rp+ items. This idea has recently gained support from a study on RIF in the area of numerical cognition (Campbell & Phenix, 2009). In the present experiment it was assumed that repeated presentations of Rp+ items will reduce competition from Rp- items compared to the conditions created in Experiment 5. If excessive competition was responsible for the null effect obtained in the previous experiment, then reduction of competition in the present experiment should create more favourable conditions for obtaining RIF. In contrast, if insufficient competition was responsible for this null effect, then reducing competition even further should not reinstate RIF.

### *Participants*

Thirty three participants were tested in this experiment. They were recruited from the University of Hull subject pool and received credits for their participation.

### *Materials, design and procedure*

The materials and design used in the present experiment were the same as the ones used in Experiment 5. The only change in the procedure was that all associates were presented three times, once with the appropriate theme word and twice with an episodic item-specific independent cue. Memory in the final test was again assessed with the theme words serving as cues.

### *Results*

The average rate of retrieval during three cycles of retrieval practice was .60 ( $SD = .19$ ). Retrieval practice for Rp+ items benefitted memory for these items in a subsequent test as evidenced by higher performance for Rp+ items compared to the baseline performance for Nrp items,  $t(32) = 3.40$ ,  $SE = .04$ ,  $p < .01$ . More importantly, retrieval practice of Rp+ items impaired memory for Rp- items, as evidenced by a lower performance for Rp- items compared to the baseline performance for Nrp items,  $t(32) = 2.23$ ,  $SE = .03$ ,  $p < .05$ .

## *Discussion*

In the present experiment RIF was obtained when memory was tested with original cues. This finding is best viewed against the null result obtained in Experiment 5. These two experiments differed only in the encoding conditions for Rp+ items. Whereas in Experiment 5 the Rp+ items were presented once with their theme words, in the present experiment they were presented three times, once with their theme words and twice with their episodic item-specific independent cues. This difference in results obtained in Experiments 5 and 6 suggests that RIF is sensitive to the amount of competition from Rp- items present during the retrieval of Rp+ items. It also suggests that the null result obtained in Experiment 5 was due to excessive competition from Rp- items which were selectively strengthened over Rp+ items by additional study presentations. When study presentations for Rp- and Rp+ items were equated in the present study, presumably leading to reduction in competition, the RIF effect emerged in the final test.

The combined results of Experiments 5 and 6 seem to be consistent with the predictions of inhibitory frameworks which postulate that RIF results from recruiting inhibition to resolve interference from Rp- items during retrieval of Rp+ items. They give support to the hypothesis developed by Norman et al. (2007) that inhibition may become disrupted at high levels of competition from Rp- items and thus the best chances of detecting RIF are created at a moderate level of competition. However, at least two words of caution are in place here before this result is taken to support inhibitory frameworks. Firstly, from a methodological point of view, the cross-experimental comparisons may be suggestive of certain effects but should not be taken as conclusive and thus additional studies would be required to support the dissociation in findings between Experiments 5 and 6. Secondly, the way inhibitory frameworks account for the present result makes this theory overly flexible. By assuming that the relationship between competition and RIF is non-monotonic these frameworks can account for virtually any pattern of results stemming from encoding manipulations. Indeed, a contrasting prediction for Experiment 6 was also based on the predictions of inhibitory frameworks and had RIF not been obtained in this experiment, the results would still be consistent with

an inhibitory approach. The strength of evidence supporting a certain theoretical framework is a function of the specificity with which predictions of this framework are formulated. Because the inhibitory frameworks' predictions concerning the role of competition are far from being specific, the evidence reported here does not provide strong support for these frameworks.

#### **4.8 Experiment 7**

Having obtained in Experiment 6 reliable RIF with original cues, under conditions in which episodic item-specific independent cues became linked to studied associates, the present experiment was conducted to once again assess if RIF generalizes to tests employing independent cues. Thus, the present experiment was an exact copy of Experiment 6 in which RIF was obtained, but with one important change by which episodic item-specific independent cues rather than original cues were used to assess memory in the final test. The predictions formulated within the pattern-suppression model are again clear. If RIF is due to inhibition operating at the level of semantic features, then any type of cues, including the independent cues used in the present experiment, should reveal reliable RIF.

The predictions formulated within the model developed by Norman et al. (2007) require a longer introduction. This model predicts that inhibition should operate to disrupt episodic associations referring to semantic representations of Rp- items. However, some results in the literature indicate that this may not occur. Specifically, Perfect et al. (2004, Experiment 3) used the procedure in which Rp+, Rp- and Nrp items were episodically linked to their independent cues in a separate phase of the experiment, preceding the main study phase of the retrieval practice paradigm. Later, memory for all studied items was assessed with either these independent cues or original cues used at study and retrieval practice. Perfect et al. found reliable RIF with original cues but no RIF with episodic item-specific independent cues. At first look, these findings seem inconsistent with the predictions formulated within the model of Norman et al. After all, the associations created between targets and their independent cues were purely episodic in nature



and they certainly referred to semantic representations of studied items so a subset of these associations linking Rp- item with their independent cues should be disrupted during the retrieval practice of Rp+ items, resulting in impaired access to Rp- items during the independent cue test. However, Norman et al. suggested that one feature of the methodology developed by Perfect et al. renders this experiment a sub-optimal test of the discussed model. Specifically, Norman et al. argued that cueing during retrieval practice utilizes both the original cue provided to participants and the contextual cue developed by the participants themselves. In other words, during retrieval practice participants attempt to constrain their retrieval to the study phase alone by evoking mental context which accompanied this study episode. According to Norman et al., such contextually constrained retrieval reduces the activation of episodic links created outside the study phase context. Because in this model, as in every inhibitory model of RIF, long-term representations containing Rp- items are impaired during retrieval practice only to the extent to which these representations becomes activated during the retrieval practice of Rp+ items, reduced activation of episodic links due to contextually constrained retrieval shields these links from inhibition.

Norman et al. (2007) formulated an explicit prediction that their model would predict reliable RIF with independent cues if the episodic links between these cues and their targets were created within the main study phase of the retrieval practice paradigm. In this way such links referring to Rp- items would become activated by contextual cueing during the retrieval practice of Rp+ items which would make them sensitive to inhibition. The present experiment tests this explicit prediction. It differs from the experiment conducted by Perfect et al. (2004, Experiment 3) in that the presentation of pairs of episodic item-specific independent cues and their targets was embedded in the main study phase. If the model developed by Norman et al. (2007) allows for a correct prediction in respect to RIF with independent cues, the RIF effect should be obtained in the present experiment.

### *Participants*

Thirty one participants were tested in this experiment. They were recruited from the University of Hull subject pool and received credits for their participation.

### *Materials, design and procedure*

The materials and the design used in the present experiment were the same as the ones used in Experiment 6. The only change in the procedure was that episodic item-specific independent cues were used to assess memory in the final test.

### *Results*

The average rate of retrieval during three cycles of retrieval practice was .66 ( $SD = .16$ ). Retrieval practice for Rp+ items benefitted memory for these items in a subsequent test as evidenced by a higher performance for Rp+ items compared to the baseline performance for Nrp items,  $t(30) = 6.94$ ,  $SE = .03$ ,  $p < .01$ . However, and more importantly, retrieval practice of Rp+ had no effect on the subsequent performance for Rp- items. Indeed, the performance for Rp- items in this experiment ( $M = .36$ ) was not significantly different than the performance for Nrp items ( $M = .34$ ),  $t(30) = .44$ ,  $SE = .03$ ,  $p > .60$ , and, if anything, the means were in the opposite direction to the predictions of the model developed by Norman et al. (2007).

### *Discussion*

The present experiment tested if RIF would be present with episodic item-specific independent cues associated with their targets during the main study phase. It employed the procedure of Experiment 6 in which reliable RIF was obtained when memory was tested with original cues used during retrieval practice. However, in the present experiment RIF was absent, demonstrating that this does not generalize to all types of independent cues. In this, the results of the present experiment are consistent with the results of Experiments 2 and 4, in which RIF was also not obtained with semantic item-specific independent cues, and also with the results obtained by Perfect et al. (2004).

The null finding of the present experiment is inconsistent with the prediction of the pattern-suppression model (Anderson & Spellman, 1995). Once again the change of cues to the ones that were not used during retrieval practice abolished the RIF effect, clearly showing that RIF is not cue-independent, as the pattern-suppression model would predict.

More importantly, the present null result directly contradicts the prediction derived from the model developed by Norman et al. (2007). This model describes the broad effect of the inhibitory mechanism on episodic associations referring to the semantic representation of Rp- items. The fact that in the present experiment RIF was not obtained suggests that the retrieval practice of Rp+ items had no effect on the strength of associations between Rp- items and their episodic item-specific independent cues. Importantly, the contextual cueing mechanism, evoked by Norman et al. to explain a similar result obtained in the study by Perfect et al., cannot account for the failure to obtain RIF in the present experiment. Unlike the procedure used by Perfect et al., the procedure used here associated item-specific independent cues with their Rp- targets within the same study phase in which Rp+ items were presented. Accordingly, the context used as a cue during retrieval practice of Rp+ items was a good match to context stored during the encoding of Rp- items and their independent cues which, according to the discussed model, should lead to activation of independent cue-to-Rp- item links during retrieval of Rp+ items and therefore to their disruption by an inhibitory mechanism. The fact that such disruption did not occur contradicts the specific prediction of the model by Norman et al. that the authors explicitly formulated themselves.

#### **4.9 Experiment 8**

The experiments conducted thus far are inconsistent with two hypotheses concerning the locus of operations of an inhibitory mechanism. The lack of evidence for the cue-independence of RIF is inconsistent with the predictions of the pattern-suppression model (Anderson & Spellman, 1995) by which inhibition occurs at the level of semantic features. The results of Experiments 4 and 7 are inconsistent with the predictions of the model developed by Norman et al. (2007) by which inhibition

works on the broad network of episodic associations referring to semantic representations of Rp- items. The remaining hypothesis states that inhibition disrupts only an episodic association that links an Rp- item with a cue that is used during retrieval practice to access Rp+ items. However, this hypothesis is inconsistent with the results reported in the literature by which RIF sometimes is obtained with independent cues. As discussed by Anderson and Bjork (1994), the evidence of RIF with independent cues directly contradicts the idea that RIF is due to some change to this original cue-to-Rp- items link.

The hypothesis of constrained episodic inhibition can account for the RIF effect if it is assumed that RIF obtained with independent cues stems from a mechanism of covert cueing by which independent cues cease to be independent. If independent cues become identified during study and linked to original cues, then such episodic links can support later retrieval of original cues during the test. The covertly retrieved original cues may be in turn used to access Rp- items and Nrp items and if inhibition does work to disrupt the links between these cues and Rp- items, then the pattern of RIF should be predicted.

Research conducted by Camp, Pecher, Schmidt, and Zeelenberg (2009) showed that the mechanism of covert cueing is more than just a convenient hypothesis evoked to support any mechanism that does not predict the cue-independence of RIF. In their study Camp et al. presented their participants with cue – target pairs for study. Importantly, for some pairs they included additional presentations of a cue that preceded the main study phase. In the test phase the independent cue methodology was used and participants were provided with semantic item-specific independent cues related to targets they were asked to retrieve. The results indicated that memory for targets was better if their original cues were strengthened by repetitions, even though the original cues were never presented at test. Presumably, participants attempted to retrieve the original cues during the test, a process more effective when these cues were strengthened by repetition, and subsequently used the retrieved cues to aid their recall of associated targets.

Although the study by Camp et al. (2009) suggests that independent cues are not always independent, it does not address the issue of whether the process of covert cueing occurs in the retrieval practice paradigm and whether it can lead to RIF with independent cues. Some doubts are in place here because if participants routinely attempted the retrieval of original cues which would lead to RIF, then RIF would be expected on all tests employing independent cues, including the ones presented in the present work. The current null results as well as other null results reported in the literature (Perfect et al., 2004; Camp et al., 2007) suggest that either participants do not always retrieve original cues to augment their performance in the independent cue test or that such retrieval does not result in RIF. Thus, although the results obtained by Camp et al. suggest how RIF can be obtained with independent cues, the necessary link to RIF studies needs to be established. This was the purpose of the present experiment.

In the present experiment the mechanism of covert cueing and its links to RIF was investigated in the retrieval practice paradigm. A standard retrieval practice paradigm was employed with the semantic item-specific independent cues used at test. The novel feature of the procedure was that the main study phase was preceded with an additional pre-training phase in which half of the item-specific independent cues were episodically associated with the original cues that referred to the same target (*the associated cue condition*). These links were created to emulate the postulated process of associating original cues with category independent cues that may be responsible for the RIF effect reported in the literature (e.g. Anderson, Green et al., 2000; Anderson & Spellman, 1995). It was predicted that creating such links would lead to covert retrieval of original cues at test employing independent cues only which would manifest in increased performance in the associated cue condition compared to a standard independent cue condition. This was predicted because it was assumed that retrieved original cues would aid memory performance. Furthermore, it was predicted that using original cues to access Rp- items in the associated cue condition would be less effective than using original cues to access Nrp items, resulting in the RIF effect in this condition. This was predicted based on the assumption that retrieval practice

of Rp+ items recruits the inhibitory mechanism disrupting the link between the original cue and the Rp- item.

### *Participants*

Thirty two participants were tested in this experiment. They were recruited from the University of Hull subject pool and received credits for their participation.

### *Materials and design*

The material for the study was the same as in Experiment 3. All eight lists were used. An item-specific independent cue was chosen for each target from the University of South Florida Free Association Norm (Nelson, McEvoy, & Schreiber, 1998). The mean cue-to-target strength was  $M = .086$  ( $SD = .063$ ).

The design of the experiment followed the design of Experiment 3 except for the following changes. Firstly, item-specific independent cues were employed at test. Secondly, the design of the study was modified to allow for a creation of the episodic links between original and independent cues. For this purpose, the procedure was supplemented with an additional pre-training phase in which item-specific independent cues linked to half of the studied items were presented together with appropriate original cues. The cues that were presented in this phase constituted an associated cue condition. Third, in the test phase not studied items were included to assess the level of learning in the other condition against guessing from semantically related cues. The experiment conformed then to a 4 (type of item: Rp+, Rp-, Nrp, and Ns) x 2 (type of cue: unassociated vs. associated) within participants design.

### *Procedure*

The procedure for Experiment 8 was the same as procedure for Experiment 3 except for several changes. First, a pre-training phase was added to the procedure. In this phase participants were presented with pairs of item-specific independent cue and appropriate original cue for 4 seconds with a 1 second ISI. Participants were instructed to rate the relatedness of the words within a pair on

the scale 1-6. There were 24 trials in this phase composed of 6 blocks, each containing four items, each from a different condition (Rp+, Rp-, Nrp, and Ns). In the final test participants were instructed that some of the cues would not be related to any studied items and were asked to write down any word associated to a cue if they could recall an appropriate word from the study phase. A practice test with feedback was given that included four fillers and two new words to familiarize participants with the testing procedure.

### *Results*

The average rate of retrieval during three cycles of retrieval practice was .59 ( $SD = .17$ ). The results from the final test were analyzed with a 4 (type of item) x 2 (type of cue) within-participants ANOVA. The analysis yielded a main effect of type of cue,  $F(1,31) = 12.50$ ,  $MSE = .037$ ,  $p < .01$ , and a main effect of type of item,  $F(3,93) = 16.36$ ,  $MSE = .047$ ,  $p < .001$ , but no interaction,  $F < 1$ . The main effect of type of cue reflected better performance for associated ( $M = .53$ ;  $SD = .12$ ) than for unassociated cues ( $M = .44$ ;  $SD = .11$ ). To analyze the main effect of type of item Tukey post-hoc tests were conducted which showed the best performance for Rp+ items ( $M = .61$ ;  $SD = .19$ ), followed by performance for Rp- ( $M = .50$ ;  $SD = .17$ ) and Nrp items ( $M = .49$ ;  $SD = .14$ ) that did not differ. Performance for Ns items was worse than performance for the other three types of items ( $M = .34$ ;  $SD = .14$ ).

### *Discussion*

Experiment 8 produced two noteworthy results. Firstly, associating item-specific independent cues with original cues led to improvement in recall of all targets when independent cues were employed at test. This result is conceptually similar to the results obtained by Camp et al. (2009) and is indicative of the use of covert cueing in the final test. In the test participants were presented only with independent cues but the pre-trained association of those cues and original cues probably led to retrieval of the latter. With two cues at their disposal, retrieval of targets was more effective, compared to the unassociated condition where only independent cues were utilized.

The second result indicates that covert cueing is not enough to produce RIF. Despite evidence suggesting that participants employed covert cueing strategies in the associated cue condition, RIF was not obtained in this condition, just as it was not obtained in the standard unassociated cue condition. Again, these null results are inconsistent with the predictions of inhibitory frameworks that postulate that inhibition works at the level of semantic features and thus predict a general cue-independence of RIF (Anderson & Spellman, 1995). More importantly, the null result from the associated cue condition seems inconsistent even with the most constrained inhibitory model which assumes that inhibition operates only to disrupt episodic links that are the source of interference during retrieval of Rp+ items. If episodic associations between original cues and Rp- items were disrupted by an inhibitory mechanism, then the tests in which performance is at least partially supported by original cue-to-target associations should reveal RIF. The benefit of using associated cues over item-specific independent cues suggests that episodic original cue-to-target associations were indeed used in the present experiment to support performance in the final test and the lack of RIF in the associated cue condition is thus inconsistent with the predictions of the constrained episodic inhibition account.

The covert cueing hypothesis tested here is commonly mentioned in the literature concerning RIF in the context of the interference-based account of this effect (e.g. Perfect et al., 2004). In such work it is argued that when original cues are retrieved during independent cue testing and used to access memory for Rp- items, this use of cues related to Rp+ items reinstates interference from the strengthened items leading to the RIF effect. This line of reasoning is used to present how RIF can be obtained with independent cues, even though it is caused by interference which should not result in cue-independence of RIF. From this perspective, it is important to consider if the present results are not only inconsistent with the constrained episodic account of RIF but also whether they contradict predictions of the interference-based account. The most commonly described interference-based account of RIF, by which impairment of memory to Rp- items occurs as a result of blockage caused by covert retrieval of strengthened



Rp+ items, assumes that RIF should be present to the extent to which cues in a final test are a good match to Rp+ items. If due to the covert cueing strategy original cues are used instead of independent cues, such a good match obviously occurs as Rp+ items are strongly related to original cues. However, if covertly retrieved original cues are used to supplement rather than to substitute independent cues, then the compound cue consisting of both the independent and original cue is still a poor match to the Rp+ item. In this scenario covert cueing should not lead to preferential retrieval of Rp+ items over Rp- items and hence no RIF should occur. The present results indicate that covert cueing occurred but they do not allow for conclusions as to whether original cues were used to supplement or substitute the independent cues provided to participants. It could be argued, then, that the present results are not inconsistent with the interference-based account if it is assumed that in the associated cue condition, original cues were used only to supplement independent cues and thus the mechanism of covert cueing did not lead to interference from Rp+ items in a final test.

Finally, a caveat of the present experiment needs to be mentioned. In the procedure used in this experiment item-specific independent cues were associated with original cues during the pre-training phase. However, the use of semantic independent cues created a situation in which independent cues and original cues were in fact related by virtue of a common semantic associate, a target for which both served as semantically-related cues. Presenting the pairs of original and independent cues in the pre-training phase could have thus led to a covert generation of targets, associates on which semantic information in the cues converged. If targets were covertly generated in the pre-training phase, then the benefits obtained for them in the final test may have been caused simply by enhanced encoding rather than more effective cueing arising from the covert cueing mechanism. Thus, the possibility that no covert cueing occurred in the present experiment cannot be dismissed on the basis of these findings alone. Importantly, if covert cueing did not occur and participants did not use original cues in the final test, then the constrained episodic inhibition framework would not predict the RIF effect. Further studies should assess this possibility by imposing a

covert cueing strategy under conditions in which participants would not be able to generate targets. If under these conditions evidence for covert cueing are obtained and RIF does not occur, then the conclusion that inhibition does not appear to disrupt original cue-to-Rp- item associations would be strengthened.

#### **4.10 Discussion of the RIF experiments**

The broad implications of the present findings for the inhibitory models will be described in the conclusions section, after presenting experiments concerning directed forgetting. Here the specific discussion concerning the RIF effect only is presented. Three different inhibitory accounts of RIF were assessed in order to establish the locus of inhibitory effects in long-term memory. However, this locus has not been established as none of the tested models gained empirical support. The most consistently refuted model is the pattern-suppression model developed by Anderson and Spellman (1995). According to this model, inhibition works to suppress features that belong to semantic representation of Rp- items. This account predicts that when such suppression occurs, it should be detectable with all types of cues that require access to conceptual representations of Rp- items. This prediction was consistently falsified in the present set of experiments. In Experiments 1 and 2, category independent cues semantically related to multiple studied items were used to cue memory at test and no RIF was found. Experiments 2, 4, 7, and 8 used item-specific independent cues, with experiments 2, 4 and 8 employing cues semantically related to their targets and Experiment 7 employing cues which were only episodically related to their targets. In none of these experiments was RIF obtained. Although some of these null results may stem from factors other than the use of independent cues at test *per se*, as in the case of Experiment 4 in which changes in encoding could have been responsible for abolishing RIF (a similar case could be made for the associated cue condition in Experiment 8), at least some of these null results (Experiments 2, 7 and the unassociated cue condition of Experiment 8) were contrasted directly with reliable RIF obtained under the same encoding conditions with the procedural differences limited to using original rather than independent cues at test.

Altogether, these results indicate that RIF does not occur due to changes in memory representations at the level of semantic features. It is important to add two additional notes to this conclusion. Firstly, the present results cannot be taken to imply that RIF never occurs with independent cues. Numerous experiments reported in the literature suggest that sometimes it does occur when memory is tested with such cues (Anderson, Green et al., 2000; Camp et al., 2005; Aslan et al., 2007). What has to be stressed, however, is that the pattern-suppression model of semantic inhibition predicts not that RIF may be present with independent cues under some conditions, but that this effect is generally cue-independent and this prediction is not supported by the present results. Secondly, these results cannot be taken to imply that inhibition in semantic memory never occurs. Norman et al. (2007) in their model of RIF implemented an inhibitory mechanism that works both in episodic memory and in semantic memory in which inhibition leads to an unbinding of semantic features constituting a single conceptual representation. With the help of one of their simulations Norman et al. (2007) argued that inhibition in semantic memory is necessary to account for the findings from the task that does not require use of episodic memory (Carter, 2004; as described in Norman et al.; see also Johnson & Anderson, 2004). The present series of experiments used only tasks that involved episodic memory and thus these experiments cannot speak to the issue of semantic inhibition in semantic memory tasks. The present studies can only be taken to imply that inhibition at the level of semantic memory does not operate in episodic memory tasks.

If inhibition does not occur at the level of semantic features, then the proponents of this approach need to argue that the mechanism of inhibition operates in episodic memory to disrupt episodic links between different semantic representations. An inhibitory model of RIF developed by Norman et al. (2007) takes such an episodic perspective by describing how the mechanism of unlearning affects episodic links that tie semantic representations of Rp- items to other semantic elements which may later be used as cues to retrieve these Rp- items. Importantly, in order to account for the occasional finding of RIF with independent cues, this model makes an assumption of broad effects of unlearning and describes

how episodic links for Rp- items that are not a direct source of competition during retrieval of Rp+ items become activated and disrupted. The predictions concerning this model were tested in Experiments 4 and 7, in which episodic links were created between independent cues and their targets. The model by Norman et al. predicts that if such episodic links become activated during retrieval practice of Rp+, they should be subjected to the operations of the inhibitory mechanism of unlearning. In Experiments 4 and 7 it was ensured that the activation of these links occurred by designing a procedure in which episodic links between independent cues and their targets were established in the main study phase. In this way context encoded for these associations matched context encoded for associations between original cues and Rp+ items. If participants use contextual cueing during retrieval of Rp+ items, then this cueing should lead to activation of independent cue-to-Rp- item associations, as argued by Norman et al. However, in Experiments 4 and 7 no RIF was obtained. Although, again, the null finding from Experiment 4 could stem from the changes in the encoding session compared to the control Experiment 3, such a criticism does not apply to the findings of Experiment 7 in which the encoding phase was exactly the same as in the control Experiment 6 in which RIF was obtained with original cues. Altogether, these findings indicate that retrieval practice of Rp+ items does not disrupt all episodic links referring to semantic representations of Rp- items.

Finally, the last option for the locus of effects of an inhibitory mechanism is provided by the constrained episodic inhibition approach by which inhibition serves to disrupt an episodic link between an original cue and Rp- item. Although this idea seems to be inconsistent with the occasional findings of RIF with independent cues, it nevertheless has advocates in the published literature (e.g. Racsmany & Conway, 2006; Racsmany et al., 2012). The reason why the findings from independent cues cannot serve to refute this approach is that results obtained with independent cues are often inconsistent and can be criticized on the methodological basis. Specifically, Camp et al. (2009) argued that in the independent cue methodology participants may use the strategy of covert cueing and use covertly retrieved original cues to search memory for Rp- and Nrp items. If inhibition affects episodic

links between original cues and Rp- items, then the mechanism of covert cueing should lead to RIF even when only independent cues are presented at test. In Experiment 8 an attempt was made to test both the covert cueing explanation of findings of RIF with independent cues and the inhibitory hypothesis of disruption to original cue-to-Rp- item associations. Although the results indicated that covert cueing occurred when independent cues became associated with original cues in a separate phase of the experiment, no RIF emerged as a result of covert cueing. These findings have two implications. Firstly, they suggest that covert cueing may not be responsible for occasional reports of RIF with independent cues. What is responsible for such results remains unknown. This problem could not have been effectively addressed with the present procedures because in none of the experiments reported here was RIF with independent cues obtained.

Secondly, and more importantly for the present purpose, these results suggest that inhibition does not affect episodic associations between original cues and Rp- items. If participants used associations between original cues and their targets to retrieve the latter, even though they were provided only with independent cues, and yet no RIF emerged, then it indicates that associations between original cues and Rp- items were as effective for cueing memory as associations between original cues and Nrp items, which contradicts the predictions of the inhibitory account. A word of caution is warranted here, however, as this reasoning is crucially based on the assumption that participants used a covert cueing strategy. This assumption is partially supported by the observation that independent cues associated with original cues produced better memory performance than unassociated independent cues. However, it can be also argued that this difference reflected encoding effects by which participants generated targets when presented with pairs of independent and original cues for study.

To summarize, three types of inhibitory frameworks for RIF were examined and none of them gained support from the present findings. The results concerning the pattern-suppression model and the model developed by Norman et al. (2007) seem quite strong as they directly contradict specific predictions formulated within these frameworks. The evidence concerning the constrained episodic inhibition

model are of limited strength as they come from a single experiment in which the interpretation of results is dependent on the assumptions concerning the strategies employed by participants. However, it has to be stressed that the approach of searching for the locus of inhibitory effects in the retrieval practice paradigm that has been adopted here can be suboptimal for testing this particular inhibitory model. The constrained model suggests that inhibition operates at the level of original cue-to-Rp- item associations. On the other hand, an interference-based model, which constitutes the alternative to inhibitory approaches to RIF, places the locus of the mechanism responsible for RIF also at the level of original cue-to-Rp- item associations. If two competing theories place the locus of RIF at the same level of memory representation of Rp- items, then close scrutiny of this locus is unlikely to provide clear indication as to which of these theories is actually correct.

The idea that inhibition can be supported over interference-based accounts of forgetting in long-term memory by examining the locus of a mechanism responsible for RIF comes from the work of Anderson and his colleagues (Anderson & Bjork, 1994; Anderson & Spellman, 1995). In this work it has been argued that inhibition occurs at the level of semantic representations of suppressed items and thus the independent cue methodology can provide unequivocal evidence supporting inhibitory model. However, the present findings contradict this notion and show that if inhibition occurs in the retrieval practice paradigm, it does not affect semantic representations. Instead, the present findings suggest that if inhibition does occur, then it works at the same level of episodic links as the alternative mechanism of interference. In this scenario, considerations on the locus of inhibitory effect cannot provide strong evidence supporting this mechanism over the alternative model of interference.

If discovering the locus of the effects responsible for RIF is not sufficient to support the inhibitory approach over the interference-based framework, two research strategies may be used to provide further theoretical insights into mechanisms of forgetting in long-term memory. Other research paradigms can be used in which inhibition is contrasted with the alternative mechanisms or other differences between inhibition and interference may be discussed in the context of

the retrieval practice paradigm. Focusing on the latter strategy, it is worth reiterating that multiple differences other than the locus of a mechanism of RIF have been described between inhibition and interference. The one that is relevant to the findings of the experiments reported here concerns the issue of the competitiveness of retrieval practice. As described earlier, the inhibitory framework makes an explicit prediction that the magnitude of RIF should be related to the amount of competition exerted by Rp- items during retrieval of Rp+ items. Only when Rp- items compete for access during retrieval of Rp+ items, an inhibitory mechanism needs to be recruited to resolve interference (Anderson et al., 1994; Anderson, 2003). In the present study the comparison of results of Experiments 5 and 6 brings the issue of competitive retrieval into focus. These experiments, which employed original cues at test, differed only in the conditions of the encoding of Rp+ items. In Experiment 5 these items were presented once with their original cue and in Experiment 6 they were additionally presented twice with their episodic item-specific independent cues. In both experiments Rp- and Nrp items were presented three times, once with original cues and twice with independent cues. The RIF effect was obtained in Experiment 6 but not in Experiment 5. A potential explanation of this unexpected dissociation builds on the concept of competitive retrieval. It could be argued that when encoding of Rp+ items is impoverished relatively to encoding of Rp- items, as in Experiment 5, retrieval practice becomes too competitive and inhibition is no longer able to resolve interference. As described by Norman et al. (2007), in this case to-be-inhibited episodic links become activated even before the relevant cue-to-Rp+ item links, which makes inhibition ineffective in regulating retrieval.

Although the comparison of Experiments 5 and 6 may suggest that competitiveness of retrieval plays an important role in shaping the pattern of RIF, as the inhibitory frameworks would suggest, it is important to note that the results obtained in these experiments are actually in the opposite direction to the straightforward predictions of an inhibitory account. These results suggest that RIF can be eliminated when retrieval competitiveness is increased, not that RIF is a monotonic function of competitiveness. The hypothesis that the relationship

between competitiveness of retrieval practice and the magnitude of RIF is a non-monotonic one is not inconsistent with the inhibitory approach, but it is also not the one that can be formulated within this approach based on fundamental assumptions of this framework. There is nothing in the idea of inhibition that requires an assumption according to which inhibition stops working at a high level of competitiveness. Thus, although the present findings can certainly be considered in terms of an inhibitory framework, they should not necessarily be treated as empirical support for the inhibitory mechanism of RIF.

The other research strategy that can be used to further examine the inhibitory account of forgetting in long-term memory is to provide additional data from a different paradigm. If the inhibitory mechanism can account for the results in the retrieval practice paradigm only by postulating that inhibition works at same level of memory representation that is postulated also to be affected by an alternative account of interference, then it is reasonable to examine a different paradigm in which inhibition is assumed to operate on a different level than the alternative account. The experiments on directed forgetting will be presented next to meet this aim. In directed forgetting studies, inhibition is contrasted not with a mechanism of interference but with the context change account that makes a very specific prediction, different from the predictions of the inhibitory framework, about the locus of the mechanism responsible for forgetting, as will be described next. Thus, the aim of the directed forgetting studies will be similar to the one reported for the retrieval practice paradigm, to examine which part of memory representation becomes affected in forgetting and by this to determine if inhibition can be a mechanism that leads to this impairment.



## 5. Experiments on directed forgetting

### 5.1 Introduction

The studies concerning directed forgetting presented here had the same aim as the studies on RIF described in the previous chapter, which was to examine the locus of potential inhibitory effects. According to the retrieval inhibition account, postulated to account for both directed forgetting costs and benefits, the instructions to forget a list of already presented items serves to inhibit the contents of an episode of studying this list (Bjork & Bjork, 1996; Racsmany & Conway, 2006). The first question is whether these inhibited contents are best understood as information stored in semantic or episodic memory. In the case of directed forgetting it is widely acknowledged that the locus of inhibition is not at the level of semantic features of individual words included in a to-be-forgotten list. The fact that directed forgetting costs are commonly absent from recognition (e.g. Basden et al., 1993; Benjamin, 2006) and conceptual implicit tests (Basden et al., 1993) serves as evidence that inhibition in this case does not operate at the level of semantic features. It follows thus that the postulated inhibitory process needs to affect episodic memory representations.

The question that stands before the inhibitory account of directed forgetting pertains to the generality of the changes in episodic representations. Two types of episodic associations created during study of a to-be-forgotten list can be distinguished. Firstly, there are episodic links that associate studied items with each other, referred to as inter-item associations. Secondly, there are episodic links that associate studied items with a global mental context that accompanies learning. Inhibition can affect either both of these types of episodic associations or only one of these. Without additional specification, the inhibitory account straightforwardly predicts that all contents of a to-be-forgotten episode should be affected by the recruitment of the inhibitory mechanism and thus both inter-item and contextual associations should be sensitive to directed forgetting effects. On the other hand, a recent development in theorizing about inhibition proposed by Anderson (2005) suggests that directed forgetting results in inhibition of context information only.

According to this proposal inhibition affects contextual information that differentiates between to-be-forgotten and to-be-remembered lists. In summary, the inhibitory accounts of directed forgetting may predict either impairment to all associations created during the study of a to-be-forgotten list or, with additional assumptions, impairment confined only to contextual associations. The present experiments aim at examining the generality of impairment of episodic memory in the directed forgetting paradigm.

The predictions of the inhibitory account of directed forgetting should be viewed in the perspective of predictions of the main alternative account of this effect, the context change hypothesis (Sahakyan & Kelley, 2002). The context change account assigns directed forgetting costs to a mismatch in contextual features used at test with the ones that accompanied study of a to-be-forgotten list. This account suggests that instructions to forget do not affect any episodic links but rather they make contextual links less relevant for retrieval due to the use of other context features to cue memory. Both retrieval inhibition and the context change account therefore make a prediction that directed forgetting costs should be present in tasks that utilize contextual cues. Retrieval inhibition makes this prediction because contextual associations should be disrupted by inhibition and the context change account makes this prediction because a change in context features used to cue memory should render contextual associations containing different context features difficult to retrieve. The more theoretically interesting situation is, however, created for inter-item associations. The basic retrieval inhibition account predicts that directed forgetting costs should be present in a task utilizing these associations. On the other hand, the approach developed by Anderson (2005), which will be referred to as the context inhibition account, makes the opposite prediction and suggests that inter-item associations should not be disrupted by inhibition. Finally, the context change account predicts that the tasks utilizing inter-item associations should not be affected by directed forgetting. This prediction stems from an outshining hypothesis by which the role of contextual cueing at retrieval is greatly reduced if other specific cues are available (Smith & Vela, 2001). In the case of retrieval of an inter-item link at least one of the items

from the pair of associated items needs to be present to cue memory for the whole association and this item should outshine contextual cues. If contextual cues are not used to retrieve inter-item associations, then the context change mechanism should not affect performance. Thus, to summarize, defining the loci of the mechanism of directed forgetting can help to settle a dispute between the retrieval inhibition account on the one side and the context inhibition and context change accounts on the other, although it cannot disentangle these latter two accounts.

There are empirical results that suggest that all types of episodic links become disrupted by instructions to forget. Focusing first on contextual associations (links between items and context), such associations are responsible for assessing list membership of presented items. The only thing that differentiates between a to-be-forgotten and a to-be-remembered list in the directed forgetting paradigm is the mental context that accompanies the learning of all materials and which gradually drifts in time, allowing for discriminating between different episodes. The fact that directed forgetting impairs list discrimination performance, as demonstrated by several different studies (e.g. Bjork & Bjork, 2003; Gottlob & Golding, 2007), suggests that the inhibitory process, if it is recruited in this task, does indeed affect contextual associations. Considering other than contextual associations, results reported by Geiselman et al. (1983) seem to suggest that directed forgetting affects also episodic links created between presented items. In this study a correspondence between input and output positions of recalled words was lower for items from a to-be-forgotten list than for items from a to-be-remembered list. This diminished correspondence suggests that inhibition affected links between different studied items, which resulted in an impaired process of cueing between items. On the other hand, it is important to notice that this result for input-output correspondence was obtained in a recall test in which instructions to forget affected also the proportion of recalled words. If a word is not recalled due to decreased capacity for contextual cueing, it also cannot be used to cue other studied items and hence disorganized recall is expected. Thus, it is still possible that instructions to forget affect only contextual associations and the finding of

disorganized retrieval is a mere by-product of reduced accessibility of studied items caused by the effects limited to changes in the strengths of contextual associations.

The study by Geiselman et al. (1983) looked at the effects of directed forgetting on contextual and inter-item associations only indirectly, focusing instead on the issue of the effects of intentional versus incidental learning. The experiments presented here examine directly the issue of the effect of directed forgetting on contextual and inter-item associations. One way in which the problem with confounding of the contextual and inter-item associations present in the study by Geiselman et al. can be circumvented is to use a cued recall procedure. In such a procedure the experimenter controls the cues used for retrieval, which could allow for independent assessment of the effectiveness of contextual and inter-item associations in cueing for studied items. A similar logic was applied in the studies on RIF in which effectiveness of original and independent cues was established by cueing with these two types of cues in the final test. As described in the previous chapter, in the context of RIF, such experiments indicate that the potential inhibitory process seems to affect links between studied items and their original cues but not the links between the same items and their independent cues.

However, there is an important problem with employing similar methodology to assess the effects of directed forgetting on contextual and inter-item associations. Specifically, the experimenter can have no knowledge about the specific contextual features associated with studied items by each participant. Thus, the experimenter cannot provide contextual features to cue specific items and needs to choose a coarser cueing procedure. To provide a test for contextual cues a list-cued recall would have to be used in which participants are asked to recall studied items from a given list, a methodology commonly employed in studies on directed forgetting (e.g. Spillers & Unsworth, 2011). However, when such a cueing procedure is employed, it is again not clear if the impairment in recall of items from a to-be-forgotten list stems from diminished capacity of contextual associations for supporting retrieval from memory. In memory models it is often assumed that during free recall (to which list-cued recall is similar in many respects) participants first use contextual cues to retrieve one item and then they use compound cues of

context and retrieved items to search for the rest of the items in memory (Raaijmakers & Shiffrin, 1981). Thus, when inter-item associations become disrupted, free recall may be reduced even though contextual associations are not affected (see McDaniel, Cahill, Bugg, & Meadow, 2011, for an example of reduction in free recall caused by impairment to inter-item associations).

Given the problems associated with manipulating cues at retrieval for examination of different types of episodic links affected by inhibition, a different approach was adopted here. In the present experiments the cues were held constant and the nature of the task required from participants was varied. Participants were presented with pairs of words for study in the directed forgetting paradigm which deviates from the common procedure of presenting single words. Although encoding of single words allows for creation of inter-item associations across study trials (McDaniel & Bugg, 2008), such associations are largely beyond experimental control. Presenting pairs of words allows for establishing well-defined inter-item associations. Two different memory tasks were employed to assess if contextual and inter-items associations are affected by a directed forgetting manipulation. Firstly, a list discrimination task was employed to examine contextual associations. This kind of test has been already been examined in the directed forgetting paradigm and the results obtained with this task are commonly interpreted as indicating that directed forgetting exerts its effect at the level of contextual associations (Gottlob & Golding, 2007), as both inhibitory accounts and the context change account would predict. Secondly, an associative recognition task was employed to assess the effect of the directed forgetting manipulation on inter-item associations. The associative recognition test requires distinguishing between pairs presented at study and rearranged pairs created from words from different studied pairs. To accomplish this task retrieval of the episodic association between two different items is necessary. If these associations become disrupted due to the provision of instructions to forget, then decreased performance in this task is predicted.

## 5.2 Experiment 9

The first experiment was conducted solely to test the instructions and the experimental design for use in the subsequent two experiments. The test of instructions is important in the light of recent findings that not all instructions to forget produce directed forgetting effects (Mulji & Bodner, 2010; Sahakyan et al., 2008). For example, the study by Mulji and Bodner (2010) demonstrated that instructions to forget result in directed forgetting costs only if they ask participants to focus on the encoding of a subsequent list. The test of experimental design was necessary to establish if directed forgetting costs can be obtained in the within-participants design. Although such a design is sometimes used in studies on directed forgetting (e.g. Zellner & Bäuml, 2006; Racsmany et al., 2008) and the data that has been published by now does not suggest any dissociations between effects obtained with between- and within-participants designs, it remains the case that the vast majority of the directed forgetting paradigm use a between-participants design. Thus, it seemed to be prudent to demonstrate that the particular within-participant design employed in the current experiments is capable of producing the effects of interest.

### *Participants*

Thirty-one undergraduates of the Jagiellonian University were tested in exchange for partial course credit or monetary compensation.

### *Materials and design*

Sixty-four words were chosen and divided into 4 lists of sixteen words. The assignment of lists to the conditions was counterbalanced across participants.

The condition (Remember vs. Forget) and list (1 vs. 2) factors were both manipulated within-participants. All participants studied two lists in the Remember condition, in which an instruction to remember the first list was provided after its presentation, and two lists in the Forget condition, in which an instruction to forget the first list was provided after its presentation. The order of the conditions was

counterbalanced across participants. The memory for the studied words was assessed with recall tests.

### *Procedure*

Participants were first presented with a list of sixteen words with a 5 second per word presentation rate. After the presentation of the first list participants received either a remember instruction that asked them to remember words just presented for a future test, or a forget instruction, stating (translated from Polish):

The list that you have just studied was a practice list. The pairs you have just studied will not be tested. Try to forget those pairs so that the learning of the next list would be easier. Now the list that will be later tested will be presented.

The remember/forget instruction was followed by a 45 second blank interval. The interval was used for comparison to other experiments, not reported here, that required a context change manipulation (see Sahakyan & Kelley, 2002). The interval was followed by the presentation of the second list. After both lists were presented an immediate recall test followed. Participants were to start recall with the words from the first list and only then continue recall with the words from the second list. They were given one minute to recall words from each list. After the recall test was finished a one-minute long interval filled with math followed, after which participants were again presented with two lists with either remember or forget instructions, depending on the counterbalancing condition they were assigned to, and the recall test for those lists.

### *Results and discussion*

The preliminary analyses were conducted to assess if the order of conditions (Remember vs. Forget) affected the pattern of results. Because none of the analyses including the factor of order produced significant effects (lowest  $p$  found for the triple interaction of condition, order, and list,  $F(1,29) = 2.53$ ,  $p = .12$ ), the

data from the two order conditions was collapsed. The recall rates were subjected to a 2 (condition: Remember vs. Forget) x 2 (list: 1 vs. 2) repeated measures ANOVA. The main effects of condition and list were not significant (both  $F_s < 1$ ) but the analysis yielded a significant interaction,  $F(1,30) = 6.86$ ;  $MSE = .029$ ;  $p < .05$ . Separate  $t$ -tests indicated that recall of the words from the first list was worse in the Forget condition ( $M = .44$ ) than in the Remember condition ( $M = .53$ ),  $t(30) = 2.42$ ;  $SE = .04$ ;  $p < .05$ , but there was no difference for the words from the second list ( $M = .55$ , for the Forget condition, and  $M = .48$ , for the Remember condition),  $t(30) = 1.68$ ;  $SE = .04$ ;  $p > .1$ . The present procedure, therefore, allows for detection of the costs of directed forgetting (but not the benefits).

### 5.3 Experiment 10

Experiment 10 was conducted to examine if directed forgetting affects both contextual and inter-item episodic associations created during the study of a to-be-forgotten list. To this end, participants' memory was tested with two tests that utilize different types of episodic associations. Participants studied pairs of unrelated words and were tested with an associative recognition task in which they had to discriminate between intact and rearranged pairs. For pairs identified as intact participants were asked to indicate if that pair was studied within List 1 or List 2. It is assumed here that associative recognition performance relies on retrieval of inter-item associations. Only retrieval of an association linking two words within a pair supports correct answers in this test. On the other hand, performance in a list discrimination task is assumed to utilize contextual associations as context differentiates between the two lists.

In the present experiment steps were taken to ensure the appropriate level of list discrimination performance. It has been suggested in the literature that presenting for study materials that induce encoding of inter-items associations (like pairs of words) may overshadow the contextual associations leading to their impoverished encoding (Smith & Vela, 2001). If this were the case, in the present study a very low level of performance in the list discrimination task could be obtained which would preclude detection of any additional effects of intended



forgetting in this task. To prevent this scenario, participants were explicitly asked to focus on encoding the list membership of presented pairs in hope of maximizing the efficacy of encoding contextual associations and thus enhancing the list discrimination performance.

### *Participants*

Forty undergraduates of the Jagiellonian University were tested in exchange for partial course credit or monetary compensation.

### *Materials and design*

A list of 192 words was prepared. The words were divided into 96 pairs of unrelated words from which four lists of 24 pairs were created. The assignment of lists to the conditions was counterbalanced across participants.

The condition (Remember vs. Forget) and list (1 vs. 2) factors were both manipulated within-participants and the order of the conditions was counterbalanced, as in Experiment 1. The memory for studied pairs was assessed with associative recognition and list discrimination tests. For the associative recognition test half of the studied pairs from each list were presented intact whereas the other half were rearranged. Rearranged pairs always consisted of the words presented within one list.

### *Procedure*

Participants were first informed that they would be presented with lists of pairs of words that they should memorize. The exact instructions provided to participants stated (translated from Polish):

You will be presented with lists of word pairs.  
Try to memorize these pairs.  
Pay attention to the list in which a given pair is presented. The information about the number of the list will always be presented above a

pair. In the final test you will be asked to indicate in which list a pair was presented.

The first list of 24 pairs of words, each presented for 2500 ms with a 500 ms interval, followed. The label “list 1” was displayed above each of the pairs. After the presentation of the first list participants received either a remember instruction that asked them to remember pairs just presented for a future test and prepare for the presentation of the second list, or the same forget instruction that was used in Experiment 1. The remember/forget instruction was followed by a 45 second blank interval after which presentation of the second list of 24 pairs that participants were asked to memorize followed. The label “list 2” was displayed above each of the pairs.

After both lists were presented a test was administered. Participants were first presented with a pair and asked to indicate if it was intact or rearranged. If the participant indicated that the pair was rearranged, the procedure moved to the next pair. If the participant indicated that the pair was intact, the list discrimination question appeared and the participant was asked to indicate if the pair belonged to the first or the second list. The time for decision in both tests was not limited. After the test a one-minute interval filled with math followed, after which participants were presented with another two lists. Depending on the counterbalancing condition the participant was assigned to, the second pair of lists was studied either in the Forget condition, in which the participant was asked to forget the first list and remember the second list, or the Remember condition, in which the participant was asked to remember both lists. The immediate test again followed the presentation of these two lists. After the whole procedure was finished participants were debriefed about the purpose of the experiment.

### *Results*

The performance for associative recognition was calculated as a difference in hit rates to intact pairs and false alarm rates to rearranged pairs (see Table 1). These accuracy scores were subjected to a 2 (condition) x 2 (list) repeated measures ANOVA. The main effect of list was significant,  $F(1,39) = 4.81$ ,  $MSE = .05$ ,  $p < .05$ ,

with better associative recognition performance for pairs from List 2 ( $M = .43$ ) than pairs from List 1 ( $M = .37$ ), but the main effect of condition was not significant,  $F < 1$ . Importantly, the interaction was not significant,  $F(1,39) = 0.04$ ,  $MSE = .05$ . These results indicate that no directed forgetting occurred in the associative recognition test. The performance in the list discrimination task was calculated as a proportion of pairs assigned to a correct list out of all pairs correctly identified as intact (see Table 2). These scores were subjected to a 2 (condition) x 2 (list) repeated measures ANOVA. This analysis yielded a significant effect of list,  $F(1,39) = 5.19$ ,  $MSE = .06$ ,  $p < .05$ , with better list discrimination performance for pairs from List 2 ( $M = .72$ ) than pairs from List 1 ( $M = .64$ ), but no effect of condition,  $F(1,39) = 1.15$ ,  $MSE = .06$ . Crucially, the interaction was significant,  $F(1,39) = 4.86$ ,  $MSE = .06$ ,  $p < .05$ . Separate t tests indicated that more list confusions were present for List 1 pairs in the Forget than Remember condition,  $t(39) = 2.16$ ,  $SE = .05$ ,  $p < .05$ , whereas no difference occurred for List 2 pairs,  $t(39) = 1.2$ ,  $SE = .04$ ,  $p > .2$ . These results indicate that directed forgetting costs occurred in the list discrimination task.

	List 1		List 2	
	Remember	Forget	Remember	Forget
Experiment 10				
HR	.60 (.03)	.53 (.04)	.66 (.03)	.66 (.03)
FAR	.21 (.03)	.19 (.03)	.21 (.03)	.25 (.04)
Acc	.39 (.05)	.34 (.05)	.45 (.05)	.41 (.05)
Experiment 11				
List-oriented group				
HR	.67 (.03)	.66 (.04)	.63 (.03)	.66 (.03)
FAR	.32 (.04)	.31 (.05)	.29 (.04)	.28 (.04)
Acc	.36 (.05)	.35 (.06)	.35 (.05)	.38 (.05)
Pair-oriented group				
HR	.79 (.03)	.74 (.03)	.70 (.05)	.70 (.04)
FAR	.13 (.03)	.16 (.03)	.14 (.02)	.13 (.03)
Acc	.67 (.06)	.58 (.05)	.57 (.06)	.57 (.05)

Table 2. Associative recognition performance in Experiments 10 and 11. Hit rates, false alarm rates and accuracy scores (HR – FAR) in the associative recognition task as a function of list (1 and 2), condition (Remember and Forget) and group (List oriented and Pair-oriented) in Experiments 10 and 11. Standard errors of the means are given in parentheses.

	List 1		List 2	
	Remember	Forget	Remember	Forget
Experiment 10	.70 (.03)	.58 (.04)	.69 (.03)	.74 (.03)
Experiment 11				
List-oriented group				
Intact	.65 (.03)	.57 (.04)	.55 (.03)	.59 (.02)
Rearranged	.57 (.03)	.53 (.03)	.61 (.03)	.62 (.03)
Pair-oriented group				
Intact	.67 (.03)	.57 (.03)	.59 (.03)	.67 (.03)
Rearranged	.53 (.03)	.50 (.03)	.65 (.03)	.70 (.03)

Table 3. List discrimination performance in Experiments 10 and 11. List discrimination performance is presented as a function of list (1 and 2), condition (Remember and Forget), type of pair (intact and rearranged), and group (List-oriented and Pair-oriented). For Experiment, 10 list discrimination performance indices reflect performance for intact pairs correctly identified in the associative recognition task. For Experiment 11, list discrimination performance indices reflect performance for both intact and rearranged pairs, independently of the decision made in the associative recognition task. Standard errors of the means are given in parentheses.

### *Additional analyses*

The present study employed a within-participants design in which the order of conditions was counterbalanced. Previous studies using this kind of design, as well as the results of Experiment 9, failed to document any effects of the order of Remember and Forget conditions on the magnitude of directed forgetting costs (e.g. Bäuml & Kuhbandner, 2009; Bäuml & Samenieh, in press). However, these studies employed a recall test, which differs considerably from the tests employed here. Hence, additional analyses were conducted that included the order of conditions as an independent variable. The focus of these analyses was exclusively on the costs of directed forgetting which was a phenomenon of interest for the present experiment and thus only performance for pairs of words from List 1 was analyzed.

The accuracy scores in the associative recognition task for pairs from List 1 were analysed in a 2 (condition) x 2 (order of conditions: Remember first vs. Forget first) mixed ANOVA. This analysis yielded only a significant interaction,  $F(1,38) = 18.55$ ,  $MSE = .06$ ,  $p < .01$ , which arose because performance in the Forget condition was significantly worse than performance in the Remember condition when the Forget condition was presented first,  $t(19) = 3.23$ ,  $SE = .09$ ,  $p < .01$ , but performance in the Forget condition was significantly better than performance in the Remember condition when the Remember condition was presented first,  $t(19) = 2.90$ ,  $SE = .06$ ,  $p < .01$ . A similar 2 (condition) x 2 (order of conditions) mixed ANOVA on scores in the list discrimination task revealed a significant effect of condition,  $F(1,38) = 5.59$ ,  $MSE = .05$ ,  $p < .05$ , confirming the result of the main analyses of better performance in the Remember than the Forget condition, but also a significant interaction,  $F(1,38) = 8.92$ ,  $MSE = .05$ ,  $p < .01$ . The interaction arose because list discrimination performance from identified intact pairs from List 1 was worse in the Forget than the Remember condition when the Forget condition was presented first,  $t(19) = 3.38$ ,  $SE = .08$ ,  $p < .01$ , but no difference was observed when the Forget condition was presented second,  $t < 1$ .

### *Discussion*

The results of the present experiment indicate that directed forgetting affects contextual associations, as revealed by directed costs in the list discrimination task, but it does not affect inter-item associations, as revealed by preserved memory performance in the associative recognition task when instructions to forget were given. However, two lines of criticism can be formulated in respect to these findings. Firstly, it can be argued that the procedure of Experiment 10 created conditions under which disruption of contextual association was more likely than disruption of inter-item associations. The instructions used to orient participants during the study phase of the present experiment aimed at enhancing memory for list membership which could lead to impoverished encoding of inter-item associations. Because the retrieval inhibition account predicts that impairment to any episodic association is a function of the interference this association may cause during retrieval of a to-be-remembered list, impoverished encoding of inter-item associations in the present experiment could have led to reduced capacity for interference from these associations and consequently to reduced inhibitory control over these associations.

Secondly, the additional analyses indicated that the order of conditions had important consequences for the pattern of directed forgetting costs in the present experiment. This observation may be a result of at least two mechanisms that are not mutually exclusive. Firstly, it is possible that an instruction to forget is effective only when it is given after the first studied list and is not effective when two lists from the Remember condition are studied before the to-be-forgotten list. After all, participants may be reluctant to believe that they will not be tested on the to-be-forgotten test if they are fully aware of the structure of a memory task from their experience derived from the Remember condition. Secondly, it is possible that the observed interactions at least partially stem from the practice effects that are not specific to the forget instruction. Specifically, experience with the tests for the first condition could result in changes in encoding strategies in the second condition, resulting in enhanced performance on the second set of tests. Importantly, whatever the combination of these two factors was that produced the aforementioned effects of order of conditions in the present experiment, it remains

the case that any practice effects could potentially mask the directed forgetting costs in the associative recognition test.

The rest of the discussion of the present results is deferred until the results of Experiment 11 are presented. The aim of the next experiment was to address the potential criticisms of Experiment 10 and provide stronger evidence that the locus of directed forgetting costs lies at the level of contextual associations but not at the level of inter-item associations.

#### **5.4 Experiment 11**

Experiment 10 produced the results that suggest that directed forgetting affects retrieval of contextual associations but not retrieval of inter-item associations. However, this dissociation could have stemmed from relatively impoverished encoding of inter-item associations in this experiment, caused by specific instructions given to participants before study to focus attention on encoding the list membership of the studied pairs. Additionally, the analyses of the order of conditions revealed interactions with remember/forget instructions given to participants in the midst of the study session that could have been at least partially responsible for the null effect of this instructional manipulation observed in the overall analyses of performance in the associative recognition task

To remedy these problems, the design of Experiment 11 included a new group in which participants were specifically asked to focus on inter-item associations in preparation for the associative recognition test (Pair-oriented group). It was predicted that in this group encoding of inter-item associations will be enhanced compared to the group asked to focus on the list membership of studied pairs (List-oriented group). If the lack of directed forgetting costs in associative recognition in Experiment 10 did result from impoverished encoding of inter-item associations, then it should be possible to observe such costs in the present experiment for participants in the Pair-oriented group. Moreover, the Pair-oriented group should allow for assessing the effects of forget instructions for associative recognition performance that is not contaminated by changes in encoding strategies. In this group participants were to focus on inter-item



associations from the start of the first condition and thus they were not expected to modify their encoding strategies after provision of the first associative recognition test. Thus, it was predicted that the practice effects would at least be minimized in this group, allowing for the detection of any possible effects of the forget instruction.

### *Participants*

Seventy undergraduates of the Jagiellonian University were tested in exchange for partial course credit. They were assigned to List-oriented and Pair-oriented groups with 35 participants each.

### *Materials and design*

The materials were the same as in Experiment 10. The design of the experiment was the same as the designs of Experiment 10 except for two changes. Two groups of participants were tested. In the List-oriented group participants were instructed to focus on the list membership of presented pairs in preparation for the list discrimination task and in the Pair-oriented group participants were instructed to focus on the link between two words in a pair in preparation for the associative recognition task. As a result the design was a 2 (instructions: List- vs. Pair-oriented) x 2 (condition: Remember vs. Forget) x 2 (list: 1 vs. 2) mixed factorial with instructions manipulated between participants and condition and list manipulated within participants. Additionally, in the present design the list membership was queried for all pairs, not only for intact pairs as in Experiment 10. This was done to increase statistical power for the analysis of list discrimination performance. It resulted in the additional factor of type of pair (intact vs. rearranged) for the list membership performance analysis.

### *Procedure*

The procedure was the same as in Experiment 10, except for the changes described below. Firstly, the new study instructions were given in the Pair-oriented group. The new instructions stated:

You will be presented with lists of word pairs.  
Try to memorize these pairs.  
Pay attention to the arrangement of the words. In the test you will be asked to distinguish between pairs presented intact and pairs composed of rearranged words. Thus, your task now is to memorize a link between words constituting a given pair. To better remember those links you can try to make a sentence that would contain both of these words or to create an image that would contain both items to which the words refer to.

Secondly, the list membership question always followed a decision in the associative recognition task. Thirdly, an interval of 45 seconds following the forget/remember instructions was dropped. Fourthly, a two-minute interval filled with maths was inserted between study sessions and tests.

### *Results*

The performance for associative recognition was calculated as a difference in hit rates to intact pairs and false alarm rates to rearranged pairs (see Table 1). These accuracy scores were subjected to a 2 (instructions) x 2 (condition) x 2 (list) mixed ANOVA. The only significant effect was the main effect of instructions,  $F(1,68) = 14.46$ ,  $MSE = .27$ ,  $p < .001$ , indicating that associative recognition performance was higher in the Pair-oriented group ( $M = .60$ ) than in the List-oriented group ( $M = .36$ ). This main effect suggests that the instructional manipulation was effective in orienting participants' attention towards or away from inter-item associations. Crucially for the present purpose, the interaction of condition and list was not significant,  $F(1,68) = 1.36$ ,  $MSE = .05$ ,  $p > .2$ , and neither was the triple interaction of instructions, condition, and list,  $F(1,68) = .31$ ,  $MSE =$

.05,  $p > .5$ . These non significant interactions once again show that directed forgetting costs do not emerge in the associative recognition task.

The performance in the list discrimination task was calculated as a proportion of pairs assigned to the correct list (see Table 2). These scores were subjected to a 2 (instructions) x 2 (condition) x 2 (list) x 2 (type of pair: Intact vs. Rearranged) mixed ANOVA. This analysis revealed a significant effect of list,  $F(1,68) = 5.03$ ,  $MSE = .06$ ,  $p < .05$ , with better list discrimination performance for pairs from List 2 ( $M = .62$ ) than pairs from List 1 ( $M = .58$ ). The main effect of type of pair was marginally significant,  $F(1,68) = 3.96$ ,  $MSE = .01$ ,  $p = .05$ , with better list discrimination performance for intact pairs ( $M = .61$ ) than for rearranged pairs ( $M = .59$ ). The interaction of list and type of pair was significant,  $F(1,68) = 14.72$ ,  $MSE = .04$ ,  $p < .001$ . This interaction arose because list discrimination performance was better for rearranged pairs presented in List 2 ( $M = .64$ ) compared to rearranged pairs presented in List 1 ( $M = .53$ ), whereas no difference emerged for intact pairs ( $M = .60$  for intact pairs presented in List 2, and  $M = .62$  for intact pairs presented in List 1). Crucially for the present purpose, the interaction of condition and list was significant,  $F(1,68) = 21.57$ ,  $MSE = .02$ ,  $p < .001$ , suggestive of the directed forgetting effects. Indeed, planned comparisons revealed that list discrimination for pairs from List 1 was better in the Remember condition ( $M = .61$ ) than in the Forget condition ( $M = .54$ ),  $t(69) = 3.23$ ,  $SE = .02$ ,  $p < .01$ , demonstrating the costs of directed forgetting. Additionally, list discrimination for pairs from List 2 was better in the Forget condition ( $M = .65$ ) than in the Remember condition ( $M = .60$ ),  $t(69) = 2.56$ ,  $SE = .02$ ,  $p < .05$ . Importantly for the present purpose, the triple interaction of instructions, condition, and list was not significant,  $F(1,68) = .61$ ,  $MSE = .02$ ,  $p > .4$ , indicating that the instructional manipulation did not modulate the directed forgetting effects. Indeed, none of the analyses involving the factor of instructions produced significant effects, indicating that the manipulation of instructions had no effect on the list discrimination performance. This stands in a direct contrast to the results obtained with associative recognition, which were heavily affected by this manipulation.

#### *Additional analyses*

A series of additional analyses concerning the role of order of conditions for the results obtained for pairs from List 1 was conducted for the present experiment. The scores in the associative recognition test were analysed in a 2 (condition) x 2 (order of conditions) x 2 (instructions: Pair-oriented vs. List-oriented) mixed ANOVA. This analysis yielded a significant main effect of instructions,  $F(1,66) = 15.92$ ,  $MSE = .16$ ,  $p < .001$ , and a significant condition by order of conditions interaction,  $F(1,63) = 4.77$ ,  $MSE = .06$ ,  $p < .05$ . The interaction arose because when the Forget condition was presented first, associative recognition performance was better in the Remember condition than in the Forget condition,  $t(33) = 2.25$ ,  $SE = .06$ ,  $p < .05$ , but when the Remember condition was presented first this difference was not significant,  $t < 1$ . Although this analysis may suggest that directed forgetting costs were present when Forget condition was presented first, it is contaminated by practice effects with the task and changes to the encoding strategies between conditions. Although the triple interaction of condition, order and instructions was not significant,  $F(1,66) = 1.38$ ,  $MSE = .06$ ,  $p > .2$ , the results for both instructional groups were further analysed in separation, under the assumption that changes in encoding strategies should be minimized in the Pair-oriented group. Indeed, two separate 2 (condition) x 2 (order of conditions) mixed ANOVAs revealed a significant interaction for the List-oriented group,  $F(1,33) = 4.73$ ,  $MSE = .07$ ,  $p < .05$ , and no interaction for the Pair-oriented group,  $F < 1$ . These analyses tentatively suggest that the interaction including the order of conditions in the overall analysis likely stemmed from changes in encoding strategies during the course of the experimental procedure and that when these changes were eliminated in the Pair-oriented group, the costs of directed forgetting still failed to emerge in associative recognition.

To address the question of order of conditions in the list discrimination task, a similar overall analysis for List 1 pairs for the list discrimination performance was conducted with an additional factor of status of a pair. A 2 (condition) x 2 (order of conditions) x 2 (instructions) x 2 (status of a pair: intact vs. rearranged) mixed ANOVA yielded only a significant main effect of condition,  $F(1,66) = 10.61$ ,  $MSE = .03$ ,  $p < .01$ , and a significant main effect of status,  $F(1,66) = 18.66$ ,  $MSE = .03$ ,  $p <$

.001. The lack of interaction between condition and order,  $F < 1$ , suggests that the instruction to forget was effective both when it was provided in the first and in the second condition. This again suggests that the effects of order observed for the associative recognition task emerged due to changes in the encoding strategies during the task and not from greater effectiveness of the forget instruction when the Forget condition was presented first.

These results together suggest that the instruction to forget affects list discrimination but not associative recognition performance and that the interaction involving the order of conditions for associative recognition stems from changes in encoding strategies rather than different effectiveness of forget instruction in different order conditions. To provide converging evidence for this suggestion, a final analysis was conducted for pairs from List 1 in which the data from all participants was restricted to the first condition that they performed. In effect, a design was obtained in which condition (Remember vs. Forget) was manipulated between participants and thus all possible order effects were eliminated. For the scores in the associative recognition task a 2 (condition) x 2 (instructions) independent measures ANOVA revealed only the main effect of instructions,  $F(1,66) = 16.73$ ,  $MSE = .10$ ,  $p < .001$ . For the scores in list discrimination task a 2 (condition) x 2 (instructions) x 2 (status) mixed ANOVA revealed a significant effect of status,  $F(1,66) = 8.44$ ,  $MSE = .03$ ,  $p < .01$ , and, more importantly, a significant main effect of condition,  $F(1,66) = 11.68$ ,  $MSE = .05$ ,  $p < .01$ . Thus, even with this restricted analysis the statistical power was sufficient to reveal reliable costs of directed forgetting in the list discrimination task but the parallel effects failed to emerge in the associative recognition task, supporting the main observation from the within-participants analyses.

### *Discussion*

Experiment 11 produced two important findings. Firstly, the pattern of results from Experiment 10 was replicated showing that directed forgetting costs emerge in the list discrimination task but not in the associative recognition task. The costs of directed forgetting in the associative recognition task failed to emerge

even when creation of inter-item associations during encoding was promoted by specific instructions. This finding suggests that relatively poor encoding of these associations, which resulted in poor performance in the associative recognition task in Experiment 10 (and in the List-oriented group of Experiment 11), was not responsible for the null effect of instructions to forget in the associative recognition task. In Experiment 11 specific instructions provided in the Pair-oriented group directed participants' attention towards inter-item associations, resulting in enhanced associative recognition performance, but the costs of directed forgetting still failed to emerge. Also, the additional analyses performed for Experiment 11 suggest that the use of within-participants was not crucial for the obtained results. Together, these results strongly suggest that directed forgetting effects are present at the level of contextual associations but absent at the level of inter-item associations. The implications of these findings for the theories of directed forgetting are discussed in the summary of the directed forgetting experiments.

Secondly, the manipulation of study instructions proved ineffective in modulating performance in the list discrimination task, although it had strong effects on associative recognition performance. In Experiment 10 and in the List-oriented group of Experiment 11 specific instructions were used to promote encoding of contextual associations to ensure appropriate levels of list discrimination performance. This procedure was based on the insights from the overshadowing hypothesis (Smith & Vela, 2001), which would seem to predict that the creation of contextual and inter-item associations should be subjected to a trade-off and thus when participants focus on inter-items associations the encoding of contextual associations supporting list discrimination should suffer. However, the results of Experiment 11 are inconsistent with this trade-off hypothesis because clear instructional effects in associative recognition were not mirrored in list discrimination performance. Why, then, did the discussed trade-off fail to emerge?

Two hypotheses may be formulated to account for this result. First, it could be argued that performance in the list discrimination task did not depend on contextual association and thus, even though overshadowing of contextual associations by inter-item associations did occur, it played no role in shaping list

discrimination performance. If list discrimination did not depend on contextual associations then the other source of memorial information had to be used to sustain performance in this task, which was clearly above the chance level. The obvious candidate for such memorial information is the relative familiarity of pairs from different lists (e.g. Curran & Friedman, 2003). In the two-list paradigms, such as list-method directed forgetting, items presented in the first list are presented earlier than items from the second list and, thus, may be less familiar. This difference in familiarity between items taken from different lists may serve as the basis for list membership judgments. However, this hypothesis seems to be inconsistent with the results of directed forgetting manipulation. If list membership performance was entirely driven by differences in relative familiarity, then the effects of “forget” instructions on list membership performance should also be accounted for by some changes to a familiarity signal. However, studies on directed forgetting costs in recognition are quite consistent in showing that familiarity is not affected by instructions to forget (Bjork & Bjork, 2003; Kimball & Bjork, 2002; Benjamin, 2006). It seems, then, that list discrimination performance in both Experiments 10 and 11 was at least partially supported by retrieval of contextual associations, a process affected by directed forgetting, although relative familiarity could also contribute to it.

The second hypothesis that could account for the lack of a trade-off between associative recognition and list discrimination performance states that contextual associations are encoded automatically and thus their encoding cannot be aided by explicit instructions, nor it can be overshadowed by more effective encoding of inter-item associations. The idea that contextual associations are encoded automatically is not novel and has been discussed in some models of context storage (Malmberg & Shiffrin, 2005). Although the hypothesis of automatic storage of contextual associations accounts well for the current findings, it needs to be stressed that automatic encoding of certain types of contextual associations should not be generalized to all types of contextual associations. Several studies have documented the effects of instruction-induced changes in encoding strategies on context-driven performance (Franco-Watkins & Dougherty, 2006; Skinner &

Fernandes, 2009; Hockley, 2008). However, it is also worth pointing out that these studies used well-defined local contexts, like pictures or words. It stands to reason that people can consciously aid encoding of context features when those features are well-defined and distinctive. In contrast, encoding of vague context of a mental rather than perceptual nature that distinguishes between pairs from List 1 and pairs from List 2 may be immune to instructional manipulations.

### **5.5 Discussion of the directed forgetting experiments**

The results of Experiments 10 and 11 reveal the dissociation in the effects of directed forgetting on contextual and inter-item associations. Consistently with the previous studies (e.g. Gottlob & Golding, 2007; Bjork & Bjork, 2003), directed forgetting costs were obtained in the list discrimination task, which indicates that directed forgetting affected retrieval of contextual associations. This means that either inhibition operates to disrupt such contextual associations, as the retrieval inhibition and context inhibition accounts would stipulate, or that more mismatching context features were used to cue memory in the Forget condition than in the Remember condition in which case original contextual associations created in the Forget condition were less effectively retrieved, as the context change account would hold.

At the same time, no costs of directed forgetting occurred in the associative recognition task, which indicates that the retrieval of inter-item associations was not affected by the directed forgetting manipulation. This result suggests that either inhibition operating in the directed forgetting paradigm is of limited scope and affects only contextual associations, as the context inhibition account would stipulate, or that no inhibition occurs in this task, as suggested by the context change account. Independently of which of these two accounts is true, the present results are inconsistent with the predictions derived from the retrieval inhibition account. If inhibition served to disrupt or temporarily suppress all episodic links created during the study of a to-be-forgotten list, then it should pertain also to inter-item associations supporting performance in the associative recognition task.



The null results obtained with the associative recognition task is interesting when considered against the background of previous studies assessing the effects of instructions to forget on recognition tests that rely heavily on recollection. The vast majority of such studies documented reliable effects of the instruction to forget on recollective-driven recognition tests. For example, Sahakyan et al. (2009) found reliable RIF in the plurals paradigm in which reliance on recollection was imposed by using foils that were very similar (and thus almost equated in familiarity) to studied items. Racsomány et al. (2008) obtained results according to which directed forgetting affects recognition accompanied with recollective experience as measured by remember responses (but see Conway et al., 2000). In this context it is important to note that associative recognition is one of the most commonly used recognition procedures that serve to measure recollective-driven performance (see Malmberg, 2008, for a recent discussion). Although some suggestions have been formulated that discrimination between intact and rearranged pairs can also involve a familiarity signal for unitized pairs of words (Quamme, Yonelinas, & Norman, 2007), such units are assumed to be created only with repeated presentations of intact pairs (Kilb & Naveh-Benjamin, 2011), a methodology different than the one employed in the present experiment, in which pairs were presented once only. Why, then, should results from the present recollective-driven test of associative recognition contrast with the results reported in the literature?

The argument presented throughout this chapter is that it is important to differentiate between different types of episodic associations that support recollective experience in various recognition tests. Such an argument is, however, rarely considered in respect to various methodologies examining recollection. In the literature recollection is commonly considered as a unitary construct that is contrasted with familiarity and the focus is rarely on the information that is actually recollected (see Bodner & Lindsay, 2003; Parks, 2007, Gruppuso, Lindsay, & Kelley, 1997, for exceptions and Hintzman, 2011, for a recent discussion). The point raised here is that it is important to consider if recollection pertains to an association between two studied items (for example, retrieval of a mediator created during

study) or an association between studied items and the overall context of the learning episode. Certain manipulations may affect only some types of associations. The directed forgetting manipulation seems to affect retrieval of information that specifies list membership of presented pairs but does not affect retrieval of information specifying whether the presented pair is intact or rearranged. It is worth noticing that other measures of recollection, like the already mentioned performance in plurals paradigm or proportion of recognized items accompanied with the remember response, do not allow for specifying the type of information that is recollected. It seems likely that these measures reflect retrieval of contextual associations because the materials used in such tasks consist of single words and thus provide a limited space for creating inter-item associations. The conclusion is, therefore, that the present results are not necessarily inconsistent with the results of previous studies concerning recollection in the directed forgetting paradigm. These results suggest that some types of recollective processes are affected by the directed forgetting manipulation, as the previous studies indicate, but they also suggest that previously employed methods examined only a limited subset of information that can be recollected and thus they produced results that should not be generalized to all types of recollective processes.

Finally, for the purpose of the present work it is important to discuss in more detail the implications of the present findings for the inhibitory account of directed forgetting. As discussed above, the present findings are consistent with the context inhibition account of Anderson (2005) but do not seem to be consistent with a traditional formulation of retrieval inhibition in which inhibition serves to suppress the whole to-be-forgotten episode (Bjork & Bjork, 1996) or, in a slightly different formulation, the contents of this episode (Racsmany & Conway, 2006). In other words, the present findings can be used to constrain the theories of inhibition in directed forgetting by indicating the locus of inhibitory effects, which in this case lies in contextual associations. In some ways this observation is not surprising. If inhibition serves to limit interference from a to-be-forgotten episode that it makes sense that this mechanism affects episodic associations that are directly responsible for interference. As discussed several times throughout the present work,

interference stems from associating several items to the same cue. The more items are associated to the same cue (the bigger the associative fan is), the greater interference accompanies retrieval of any of these items. In the directed forgetting paradigm both lists become associated to the same context features (assuming that the context change does not occur) that are later used to retrieve items from these lists. The inhibitory account of directed forgetting suggests that in order to minimize interference, some of the contextual associations become disrupted so that the fan of contextual cues would be reduced. The inhibitory account does not need to postulate that all episodic links created during study are disrupted because in order to resolve interference from a to-be-forgotten list only contextual associations need to be affected. Therefore, the context inhibition account of directed forgetting is consistent with the main assumptions of all inhibitory accounts, that inhibition is recruited to resolve interference by modifying representations stored in long-term memory, while remaining consistent with the empirical results obtained in the directed forgetting paradigm.

However, the success of the context inhibition account is not without its costs. Specifically, the context change account achieves consistency with empirical results by placing the locus of inhibitory effects in a way that makes this theory almost indistinguishable from the context change account. Both of these accounts assume that the directed forgetting manipulation impairs retrieval of contextual associations. The context change account assumes that such retrieval is impaired because directed forgetting manipulation changes the context features used to cue memory and the context inhibition account suggests that the contextual links become disrupted. If inhibition does not work beyond contextual associations, then the predictions of this account would probably always mimic the predictions of the context change account, which also postulates impairment of retrieval of the same associations. Possibly, the only difference between these two accounts lies in the issue of overcoming impairment from directed forgetting. If this impairment stems from changes to context features, then reinstating old context features at retrieval should eliminate the directed forgetting effects. This has been shown to be true in the study by Sahakyan and Kelley (2002). However, the context inhibition account

could try to account even for these findings with the help of the release from inhibition idea by which reinstating context and thus providing more specific cues serves to reinstate the contextual associations that were subjected to inhibition. The issue of similarity of context change inhibition and context change accounts will be revisited in the conclusions section.

## 6. Conclusions

The experiments presented in the dissertation concerned the inhibitory mechanism operating in long-term memory. For the purpose of these experiments, it was assumed that in the face of interference in a memory system, an inhibitory mechanism is recruited that resolves this interference by affecting long-term memory representations of interfering items. The question that was asked was which part of the memory representations of the interfering items is changed due to operations of an inhibitory mechanism. This question was addressed with two different paradigms in which interference has been postulated to operate and forgetting, assumed to reflect long-term changes to memory representations, has been observed.

Experiments 1-8 examined forgetting observed in the retrieval practice paradigm (Anderson et al., 1994). In this paradigm inhibition is commonly assumed to resolve interference during competitive retrieval. Items associated with one cue are studied and then retrieval of some of these items is practiced. The inhibitory account is assumed to regulate activation of related but not practiced items in order to facilitate retrieval of the practiced items. The inhibitory mechanism postulated in this paradigm is contrasted with the interference-based account, which postulates that forgetting occurs as a mere by-product of strengthening of the associative links between practiced items and the common cue. The interference-based account makes a specific assumption that effects of retrieval practice concerning non-practiced items are due to changes in the effectiveness of the links between the common cue and the non-practiced items in supporting retrieval of the latter. In contrast, the inhibitory account in its most basic formulation is mute on the issue of which part of memory representation containing non-practiced items is affected by the retrieval of the practiced items. Thus, if it could be shown that forgetting in the retrieval practice paradigm is caused by changes to memory representations that extend beyond the cue-to-non-practiced items associations, then this observation would uniquely support the inhibitory account.

The results of Experiments 1-8 indicate, however, that if inhibition is implicated in the forgetting observed in the retrieval practice paradigm, then this inhibitory process affects only cue-to-non-practiced items associations. The results reported here indicate that inhibition does not occur at the level of semantic features and it does not affect other episodic links referring to non-practiced items. In essence, then, the results suggest that inhibitory accounts of RIF cannot be distinguished from the interference-based accounts of this effect based on the locus of the mechanism responsible for this effect.

Experiment 9-11 examined the directed forgetting paradigm in which the inhibitory process may also be implicated. In this paradigm participants are explicitly asked to forget a list of already encoded items that could interfere with encoding or retrieval of a subsequent, to-be-remembered list. The inhibitory account postulates that the inhibitory mechanism is recruited to lower accessibility of a to-be-forgotten list, which results in worse memory performance for items from this list and better performance for items from a to-be-remembered list. The inhibitory account of directed forgetting is contrasted with the context change account (Sahakyan & Kelley, 2002) which postulates that forgetting in this paradigm stems from the change in mental context which accompanies learning of to-be-forgotten and to-be-remembered lists, evoked by diversionary thoughts that participants engage in after receiving instructions to forget already stored information. The context change account makes a specific prediction that the locus of directed forgetting effects lies exclusively at the level of associations between studied items and the context features that accompanied their encoding. In contrast, the inhibitory account in its most basic formulation is mute on the issue of the scope of changes that inhibition makes to representations containing interfering items. Thus again, if it could be shown that forgetting in the directed forgetting paradigm is caused by changes to memory representations that extend beyond the contextual associations, then this observation would uniquely support the inhibitory account.

The results concerning directed forgetting indicate, however, that if inhibition is implicated in the forgetting observed in the directed forgetting

paradigm, then this inhibitory process affects only contextual associations. The hypothesis that inhibition occurs at the level of semantic features was not tested here because previously published results unequivocally indicate that such semantic inhibition does not take place in this paradigm (e.g. Bjork & Bjork, 1996; Basden et al., 1993). Instead, the hypothesis was assessed that the locus of the mechanism responsible for directed forgetting extends to inter-item associations but this hypothesis was not supported. In essence, then, the results suggest that inhibitory accounts of directed forgetting cannot be distinguished from the context change account based on the locus of a mechanism responsible for this effect.

In summary, the current studies failed to provide evidence that would uniquely support inhibitory accounts of forgetting information stored in long-term memory. Although the present results can help to specify what part of the memory representation of interfering information is affected by inhibition, it does not provide independent support for the assumption that inhibition is actually involved in these paradigms. It was hypothesized that examining the locus of mechanisms responsible for forgetting in two different paradigms in which inhibitory processes have been postulated may provide decisive argument in support of the inhibitory hypothesis. However, in both the retrieval practice paradigm and the directed forgetting paradigm the locus of the effects was constrained in such a way that it remained consistent with alternative, non-inhibitory accounts of these effects. The main conclusion of the current experiments is, then, that inhibitory accounts of forgetting are unlikely to be disentangled from non-inhibitory accounts on the basis of the locus of the effects caused by the postulated inhibitory processes.

It is important, however, to stress that the results of the current experiments do not indicate that inhibition does not operate in long-term memory. Indeed, both the experiments on RIF and directed forgetting are consistent with what seems to be the most straightforward formulation of the inhibitory account. Inhibition is assumed to be recruited in the face of interference from information stored in long-term memory. Such interference arises due to the fact that interfering information is associated to the same cue to which more relevant information is associated. It seems intuitive, then, that the inhibitory mechanism

that would serve to limit the access to interfering information should work to disrupt or temporarily deactivate the associative links that underlie interference.

In the retrieval practice paradigm an associative link that underlies interference leads from a cue used for practiced items to related but non-practiced items. The results of experiments on RIF suggest that some change to the effectiveness with which this association supports retrieval underlies the RIF effect. With the possible exception of Experiment 8 (as discussed in the summary of the RIF experiments), whenever this associative link was necessary for retrieval of non-practiced items, an impairment occurred and whenever this link was not necessary for retrieval (due to cueing that enabled the use of alternative links), an impairment did not occur. An important note needs to be made here, however, about the nature of the retrieval practice paradigm implemented in the current experiments. These experiments employed a standard version of this paradigm in which both episodic and semantic relations are of importance because participants study (an episodic component) pairs of category labels and an exemplar of this category (a semantic component). In such a design, interference could in theory stem both from episodic links between cues and encoded targets and semantic relations. If semantic relations underlay interference during retrieval practice, it would make sense that semantic information would be inhibited. This indeed, was the premise of the original proposal of the pattern-suppression model of Anderson and Spellman (1995). However, the lack of evidence for semantic inhibition presented in the current work suggests that the inhibitory account would need to postulate that the bulk of interference occurring in such a mixed episodic-semantic paradigm arises from the episodic component which is therefore affected by an inhibitory mechanism. This observation does not deny the possibility that under conditions in which the study phase is eliminated and thus the role of the episodic component is minimized, the role of semantically-driven interference may increase, leading to semantic inhibition (e.g. Johnson & Anderson, 2004).

The results obtained with the directed forgetting paradigm are conceptually similar to the results obtained with the retrieval practice paradigm. As already discussed in the summary of the directed forgetting experiments, the interference



from a to-be-forgotten list in this paradigm stems from its association to the context features that are also associated with a to-be-remembered list. In order to minimize interference from items coming from the to-be-forgotten list, the inhibitory mechanism should be recruited against such contextual associations. The results of experiments conducted on directed forgetting seems consistent with this formulation by showing that in this paradigm contextual associations are affected by instructions to forget but other episodic associations created during study of a to-be-forgotten list, that should not interfere with learning and retrieval of to-be-remembered items, are not affected by these instructions.

Despite the fact that the current experiments do not deny the possibility that inhibitory mechanisms operate in long-term memory to resolve interference, the work presented here is nevertheless problematic for the theories of inhibition. This stems from the fact that the main argument concerning the importance of including inhibitory mechanisms of forgetting to the current memory models comes from the assumption that these mechanisms produce vast changes in memory representations. The recent surge in studies on inhibition has been initiated by the theoretical work by Anderson and his colleagues (Anderson & Spellman, 1995; Anderson, Green et al., 2000; Anderson, 2003) in which it has been argued that inhibition can be differentiated from alternative accounts of forgetting because it leads to more pronounced changes to the memory representations for interfering items. Anderson argued that inhibition should be described as a mechanism operating at the level of semantic features, affecting a broad spectrum of tests that require access to the semantic representations of competing items. Support for this hypothesis came from studies on RIF that employed independent cues which are still cited as the main piece of evidence for contributions of inhibition (e.g. Hulbert, Shivde, & Anderson, 2012). However, both the results obtained in the current experiment and some of the previous studies examining RIF with independent cues (Camp et al., 2007; Perfect et al., 2004) suggest that this formulation of inhibition is not accurate, at least in reference to the paradigms that involve an episodic component.

A similar situation can be seen in the theorizing about directed forgetting in which empirical evidence that has been used to support the inhibitory framework of directed forgetting indicated that instructions to forget affect the broad spectrum of retrieval processes, as investigated both in recall and recognition (e.g. Bjork, 1989; Bjork & Bjork, 2003). The assumption about the broad effects of such instructions are reflected even in the term given to the postulated inhibitory process. The term “retrieval inhibition” commonly used in the directed forgetting literature seems to suggest that all retrieval processes are disrupted by this inhibitory process. However, the current experiments indicate that this formulation is too general and only some types of retrieval are affected by instructions to forget.

If the locus of inhibitory effects does not extend beyond associative links responsible for interference and thus the locus of the mechanism causing forgetting cannot be used in support of inhibitory frameworks, then these frameworks need to propose different predictions that would be specific to inhibitory processes and thus would uniquely support the inhibitory hypothesis. The main candidate area for looking for such predictions involves the idea of interference resolution. As argued throughout the present work, the idea that the mechanism of inhibition is recruited to resolve interference lies at the core of the concept of inhibition and it is probably more important even than the question of what part of memory representation is actually changed by a postulated inhibitory process (see Storm, 2010, for a discussion). However, quite surprisingly, the inhibitory frameworks do not examine this issue extensively. In the context of the retrieval practice paradigm this issue has been examined in only a few studies, described in section 2.3.4. As discussed there, these studies do not provide a consistent description of the effects of manipulating the competitiveness of retrieval practice. Although, the initial evidence provided by Anderson et al. (1994) suggested that forgetting in this paradigm is a function of competitiveness of retrieval practice, these conclusions were not supported in the studies by Williams and Zacks (2001) and Jakab and Raaijmakers (2009). Interestingly, the hypothesis of the interference-dependence of inhibition has not been tested in the context of the directed forgetting paradigm at all. Although the

inhibitory account of this assumes that inhibition is recruited to suppress interfering items from a to-be-forgotten list, to my knowledge no study using the directed forgetting paradigm has been conducted in which the level of interference would be directly manipulated.

The question that is pertinent here is whether the lack of tests of the interference-dependence of inhibition stems from some problems with formulating clear predictions that would be based on this hypothesis. This seems likely due to a particular feature of the inhibitory frameworks. Specifically, it is common in the literature on inhibition to assume that the relationship between interference and impairment of memory for interfering information is non-monotonic (Norman et al., 2007; Anderson & Levy, 2010). It is assumed that there needs to be some interference in order to trigger an inhibitory mechanism to resolve this interference but at the same time this interference cannot be excessive. The problem with this formulation is that it allows any pattern of empirical results to be predicted. This can be observed, for example, in the case of studies employing the retrieval practice paradigm to investigate the effects of emotionality of competing items. The items characterized by increased emotional arousal are usually remembered better than items with lower values of arousal (e.g. Talmi & McGarry, 2012) and thus it stands to reason that such items should compete more during retrieval practice of other, related items. Following the straightforward predictions of the inhibitory account, it would seem that such items should be subjected to stronger inhibitory effects. However, the results of at least two studies suggest that such items are less susceptible to forgetting in the retrieval practice paradigm (Dehli & Brennen, 2009; Kuhbandner, Bäuml, & Stiedl, 2009). Could these observations be treated as evidence against the inhibitory framework? Not according to the authors of these studies, who argue that emotional items are difficult to inhibit just because they are remembered better which makes them resistant to inhibition. A similar argument has been made in the context of the directed forgetting paradigm. Some studies conducted in this area also suggest that forgetting is less effective for presumably more interfering emotional items (Payne & Corrigan, 2007; Minnema & Knowlton, 2007) and again these findings are deemed consistent with the inhibitory

framework. It seems, therefore, that despite straightforward formulation of the inhibitory framework by which more interference should lead to more forgetting, the framework can actually be interpreted in a way that allows accommodation of any possible findings by declaring that some items are simply resistant to inhibition.

In the current work the issue of the interference-dependence of inhibition was discussed in relation to Experiments 5 and 6, conducted within the retrieval practice paradigm, which produced results that can be considered in the perspective of the interference-dependence assumption. However, as already discussed, these findings go against the simplest version of the inhibitory prediction by which more interference should lead to more forgetting, and instead can be interpreted as showing that more interference makes interfering items more resistant to inhibition. This discussion is thus an example of how inhibition frameworks produce predictions that cannot be falsified by empirical data.

It is worth pointing out that this problem of inhibitory frameworks seems to be ubiquitous. As already discussed, the findings that inhibition does not affect information at the level of semantic features or the broad spectrum of episodic links cannot falsify the theories because the modified versions of inhibitory accounts can place the locus of the inhibitory effects elsewhere. The findings that indicate that inhibition is not dependent on the amount of interference cannot falsify these theories because it can be argued that the baseline level of interference was placed at a value that did not allow for finding the predicted result. Yet another mechanism that gives these types of account excessive flexibility, and which is frequently mentioned in reference to the inhibitory mechanisms of directed forgetting, is the mechanism of release from inhibition. As described in chapter 3, some of the results within the inhibitory framework are discussed as reflecting release from inhibition by which presenting presumably inhibited items leads to their return to the state of full accessibility (Bjork & Bjork, 1996). However, there is nothing in the inhibitory accounts *per se* that would suggest when exactly such release should occur. In effect, the idea of release from inhibition can be used to account for any pattern of results by using a circular reasoning by which when forgetting is detected the conditions apparently do not

lead to release from inhibition and when such forgetting is not detected, release from inhibition is implicated.

The findings of Experiments 10-11 speak to the issue of release from inhibition. In these experiments clear directed forgetting costs were observed for list membership judgments of presented pairs of words. Importantly, in the current paradigm list membership was queried for intact pairs taken directly from the study phase and presented within the same test trials in the context of a recognition task. Bjork and Bjork (1996) argued that their findings indicated that recognition testing of studied items leads to a release from inhibition. Yet the current results suggest that such release did not occur. These results are indeed congruent with numerous studies showing that directed forgetting effects are present in recognition whenever recognition performance relies on recollective processes (e.g. Bjork & Bjork, 2003; Sahakyan et al., 2009; Gottlob & Golding, 2007). Thus, it seems that the presentation of to-be-forgotten items within a recognition task does not lead to a release from inhibition. It follows, then, that even based on empirical results (and a not well-specified theory), predicting when release from inhibition should occur is not possible. In effect, the mechanism of release from inhibition is not a hypothesis that can be falsified but rather an *ad hoc* idea that can be used to label rather than explain null findings in the cases in which the inhibitory accounts would actually predict forgetting.

The last problem with the inhibitory frameworks that needs to be discussed here is the problem of the diversity of the ways in which the notion of inhibition is interpreted. Chapter 1 of the current dissertation described various interpretations of the term inhibition. It was concluded that the term “inhibition” should refer to a particular mechanism (as opposed to the pattern of empirical data or a set of functions) that has an established locus of operations. The approach adopted here was to examine the possible locus of such an inhibitory mechanism in long-term memory. The results suggest that if inhibition does operate in episodic memory tasks, it seems to affect episodic links that are directly responsible for some type of interference that inhibition is recruited to resolve. The question arises as to whether in this formulation inhibition can be considered a unitary concept that

enriches our understanding of memory functioning. On the one hand, it seems to be the case that a single definition of inhibition can be formulated which makes this concept consistent with the current results. On the other hand, such a formulation leads to the conclusion that the manifestations of the inhibitory mechanism will differ between different paradigms because different episodic links are responsible for interference in different procedures. This observation then leads to the conclusion that the effects obtained in one paradigm could not be used to formulate predictions about the effects obtained in a different paradigm in which interference stems from a different source.

This disparity between predictions concerning different paradigms constitutes a serious challenge to the inhibitory framework. Again, much of the appeal of an inhibitory framework stems from its claims that the findings obtained in one paradigm can be used to predict similar effects in other memory paradigms. For example, the observation that RIF is obtained with independent cues gave rise to similar observations for the newly established paradigms, like the think/no-think task (Anderson & Green, 2001) as well as already developed paradigms in which the role of inhibitory processes has been implicated, like the part-set cueing paradigm (Aslan et al., 2007). However, if inhibition manifests itself differently in each paradigm, then there is not much gained by postulating this mechanism. This means that every time an inhibitory mechanism is postulated to play a role in a certain paradigm, the consequences of recruiting such an inhibitory process need to be established anew. It also means that no standard can be set for establishing the contribution of inhibition to various effects. If inhibition affects different parts of memory representations in different paradigms, then a standard similar to cue-independence proposed by Anderson and Spellman (1995) that, if met, would unequivocally establish the contribution of inhibition, cannot be developed.

To summarize all present considerations, the current results make it possible to formulate a constrained definition of inhibition operating in an episodic memory task by which inhibition is a mechanism recruited to resolve interference by modifying episodic associations that are responsible for interference. However, in this formulation inhibition becomes a mechanism that manifests itself in various

ways in different paradigms in which interference is caused by different parts of representations stored in long-term memory. This variety of manifestations of inhibition strips this account from its explanatory power. Moreover, this power is further constrained by various additions to inhibitory theories, like a postulated non-monotonic relationship between interference and inhibition and the mechanism of release from inhibition, that further limit the ability of the inhibitory framework to produce testable predictions. In effect, the inhibitory framework does not bring new understanding into the already examined effects, does not stimulate discoveries of new empirical patterns and as such does not provide novel insights into the functioning of the memory system.

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APPENDIX 1

Materials used in Experiments 1 and 2

Original cue	Exemplar	Category independent cue	Item-specific independent cue
WOOD	Fence		
WOOD	Paper		
WOOD	Mast		
WOOD	Hanger		
WOOD	Desk	FURNITURE	Clerk
WOOD	Bench	FURNITURE	Park
WOOD	Chair	FURNITURE	Throne
WOOD	Table	FURNITURE	Pool
FLY	Rocket		
FLY	Frisbee		
FLY	Glider		
FLY	Kite		
FLY	Eagle	ANIMAL	Legal
FLY	Bat	ANIMAL	Vampire
FLY	Wasp	ANIMAL	Sting
FLY	Mosquito	ANIMAL	Malaria
SHARP	Thorn		
SHARP	Needle		
SHARP	Chisel		
SHARP	Tack		
SHARP	Blade	WEAPON	Runner
SHARP	Knife	WEAPON	Fork
SHARP	Sword	WEAPON	Dragon
SHARP	Dagger	WEAPON	Cloak
RED	Brick		
RED	Heart		
RED	Fire		
RED	Lipstick		
RED	Tomato	FOOD	Paste
RED	Apple	FOOD	Newton
RED	Cherry	FOOD	Pit
RED	Strawberry	FOOD	Field

APPENDIX 2

Materials used in Experiments 3-8

Original cue	Exemplar	Item-specific independent cue (Experiments 4 & 8)
BLACK	Night	Dusk
BLACK	Sheep	Wool
BLACK	Coal	Mine
BLACK	Grief	Sympathy
BLACK	Death	Fate
BLACK	White	Dove
DOCTOR	Nurse	Uniform
DOCTOR	Medicine	Remedy
DOCTOR	Sick	Vomit
DOCTOR	Health	Condition
DOCTOR	Lawyer	Contract
DOCTOR	Office	Secretary
RUBBER	Glove	Baseball
RUBBER	Duck	Pond
RUBBER	Flexible	Gymnast
RUBBER	Eraser	Chalkboard
RUBBER	Plastic	Metal
RUBBER	Band	Wrist
WINDOW	Door	Trap
WINDOW	Curtain	Shower
WINDOW	House	Guest
WINDOW	Frame	Painting
WINDOW	View	Opinion
WINDOW	Mirror	Looks
LION	Tiger	Stripe
LION	King	Castle
LION	Pride	Honour
LION	Circus	Clown
LION	Africa	Tribe
LION	Jungle	Wilderness
BREAD	Jelly	Mint
BREAD	Food	Portion
BREAD	Milk	Breast
BREAD	Rye	Catcher
BREAD	Sandwich	Mayonnaise
BREAD	Wine	Whisky
CAR	Speed	Full
CAR	Fast	Brisk
CAR	Race	Winner
CAR	Travel	Luggage
CAR	Boat	Captain
CAR	Engine	Fire
MUSIC	Piano	Lesson
MUSIC	Concert	Ticket
MUSIC	Sound	Alarm
MUSIC	Horn	Bull
MUSIC	Radio	Wire
MUSIC	Dance	Aerobics