SUMMARY[1]

Many people incorrectly assume that human memory works like a video camera, which records, stores, and later replays fixed memories. In fact, memory is a more complex, dynamic system. Memory retrieval, in particular, is not a simple replay process. Instead, each retrieval can change the content and accessibility of memories.

For learners, it is particularly interesting that **memory retrieval can be practiced:** When learners retrieve information from memory, it becomes easier to later retrieve that information again. This is of great interest for anyone who needs to remember large amounts of information, such as language learners who memorize hundreds of words when mastering a new language. For them, retrieval practice is a promising technique to enhance their ability to later recall the practiced words. Retrieval practice is also more effective than other learning techniques during which the complete information is presented, for example, repeatedly reading words with translations. The benefits of *retrieval practice* compared to other forms of *restudying* are known in the literature as the **testing effect.**

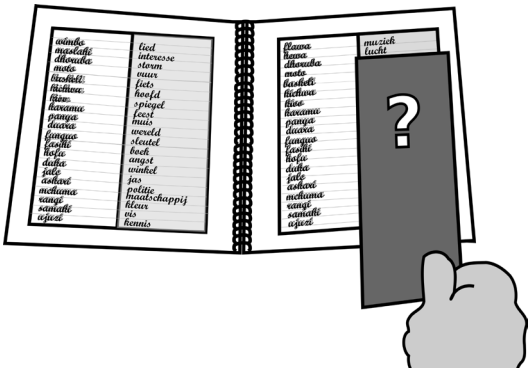

Figure A.1 A learner practices the retrieval of words from memory, thereby making it easier to later recall the words again. Such self-testing or *retrieval practice* leads to better long-term outcomes than other forms of *restudying*, like repeated reading. This phenomenon is called the *testing effect.*

1 This is a summary for a broad audience. A more comprehensive summary is given in the general discussion in Chapter 7.

The first part of **this dissertation** focuses on the cognitive and neural underpinnings of the testing effect**.** In spite of a wealth of research showing testing effects, the underlying mechanisms are poorly understood. I measured reaction times and brain activation during retrieval and restudying, to explain why retrieval practice is beneficial for the long-term retention of words. The second part of the dissertation focuses on the integration of memory retrieval in vocabulary exercises. This part first reports several classroom experiments in which I tested the effect of retrieval prompts with high school students who practiced vocabulary words with an adaptive computer program. Then, I discuss the effect of contextual information during retrieval on word learning. Finally, the dissertation – and this summary - conclude with practical recommendations on how to create opportunities for retrieval during vocabulary learning.

PART I. WHY RETRIEVAL PRACTICE ENHANCES WORD RETENTION

REACTION TIMES AFTER RETRIEVAL AND RESTUDY

In Chapters 2 and 3, I showed that learners not only recall *more* words after retrieval practice (compared to restudy practice), but also recall the words more *quickly*. Thus, there is a testing effect not only on the accuracy of later recall but also on recall speed. This **faster recall speed suggests that words become more accessible in memory with retrieval practice,** which supports theoretical accounts from the literature which hold that retrieval becomes more efficient with practice. Possibly, the mental search for vocabulary items becomes easier every time a word is retrieved from memory. A requirement for such effects is that the retrieval is successful: In several experiments reported in the dissertation, **later recall only benefited from retrieval practice, when participants managed to retrieve words from memory during practice.**

DIFFERENCES IN BRAIN ACTIVITY DURING RETRIEVAL AND RESTUDY

Chapters 3 and 4 present neuroimaging data that was collected while participants practiced vocabulary words in an MR scanner (see Figure A2). Differences in brain activation during retrieval practice and restudy practice were measured with functional magnetic resonance imaging (fMRI), a technique that picks up changes in regional blood flow due to the magnetic properties of oxygen in the blood. Comparing brain activations during retrieval and restudy practice, there were two main findings:

1. Retrieval likely involves more mental effort than restudying, which is reflected in higher activations in frontal brain areas. The effort is reduced with practice, and likewise frontal activations decrease with practice.

Areas in the front of the brain, specifically in the ventrolateral prefrontal cortex (VLPFC), showed higher activation during memory retrieval than during restudying. These brain areas are often involved in tasks that require cognitive control, that is, concentration and an intentional focus of attention. Cognitive control enables, for example, the selection of relevant information among distracting, irrelevant input. **Higher VLPFC activation during retrieval than during restudying likely reflects stronger demands on cognitive control** during retrieval. Controlled, effortful practice often leads to better long-term learning outcomes than less effortful practice, and more effort during retrieval than restudying could therefore be an explanation for testing effects. In addition, over the course of repeated retrieval practice and after prior retrieval practice compared to prior restudying, activations in VLPFC decreased. Together, these findings suggest that **retrieval leads to more effortful, controlled processing than restudying but it becomes easier with practice.**

2. Activations in brain areas important for semantic (meaningful) processing suggest that retrieval practice might lead to a focus of attention on relevant information and strengthen associations that make later recall easier.

During retrieval practice, activations in inferior parietal and middle temporal brain areas were higher when participants practiced words that they later *remembered* than when participants practiced words that they later *forgot*. During restudying, there was no such difference. I tentatively explain these findings with differences in the quality of semantic processing during retrieval and restudying, because the areas involved are thought to play an important role in semantic processing. Retrieval practice might direct attention more to relevant semantic associations than restudying does, leading to a stronger relation between brain activation and later performance. **A focus on relevant associations during retrieval might lead to a stronger memory representation that can be better recalled later-on.** In contrast, although restudying seemed to involve more semantic processing overall than retrieval practice, this processing did not predict better later recall. This may be because more irrelevant information was activated during restudying, possibly due to mind-wandering and lapses of attention.

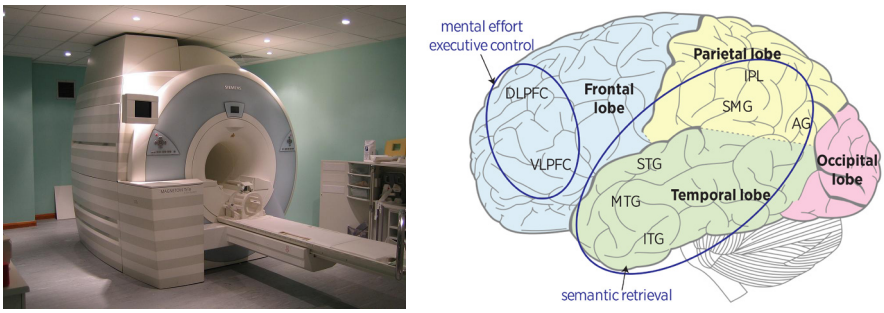

Figure A.2 Left: Photo of an MR scanner. In Chapters 3 and 4, results are presented from neuroimaging studies in which adults practiced vocabulary words through retrieval practice or restudying in an MR scanner. (Photo: Image Editor, 2006.). The activation of different parts of the brain was measured using functional magnetic resonance imaging, a technique that is based on the coupling between neural activation and regional blood flow. Right: The second illustration shows a view on the left side of the brain (Carter, 1918). The most important brain areas that are discussed in Chapters 3 and 4 are highlighted. See Figure 4.2 for further information.

PART II. HOW TO USE RETRIEVAL PRACTICE IN VOCABULARY EXERCISES

FEEDBACK AND HINTS DURING RETRIEVAL PRACTICE

In the second part of the dissertation, I investigate retrieval during vocabulary exercises. In Chapter 5, I describe three experiments with high school students who practiced vocabulary words at the computer, using retrieval practice. Different feedback formats are compared to test if it is beneficial to provide hints during practice.

Feedback increases the benefits of retrieval practice, because it allows learners to correct their errors and makes them more confident in their responses. In contrast, if a learner cannot retrieve a word from memory and there is no feedback, the retrieval attempt has few benefits. Most studies on retrieval practice contain simple feedback in which the correct answer is shown. In Chapter 5, I test whether feedback becomes more effective if learners first receive hints that allow them to correct their answer (see Figure A3).

The experiments reported in Chapter 5 produced no evidence that hints during retrieval practice are beneficial for learning. The hints did not reduce (repeated) errors during practice and there was also no positive effect on a later vocabulary test. On the contrary, because it took students time to process the hints, less time remained for further repetitions and students practiced fewer words overall. Moreover, benefits of hints were only found when the hints from practice were also available on the

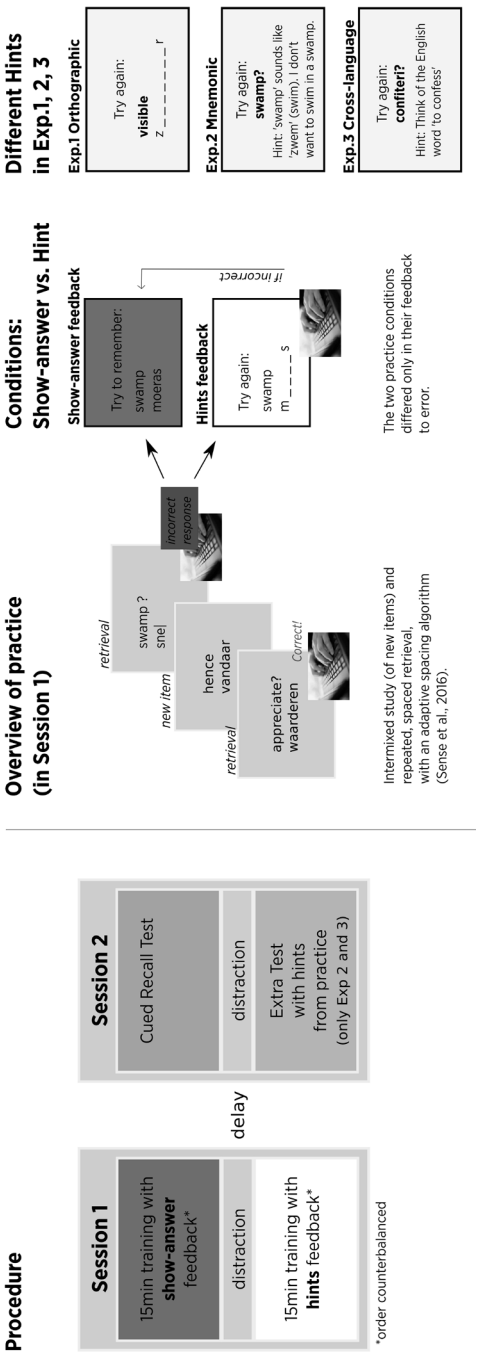

Figure A.3 In the experiments described in Chapter 5, high school students practiced English or Latin vocabulary items with different versions of an adaptive computer program. The program timed the repetitions of vocabulary items based on typical forgetting rates and increased the delays between repetitions of the same word over the course of practice. If students made an error during practice, they received either standard *show-answer feedback* or *hints feedback* that consisted of different types of hints in the three experiments. The hints did not enhance performance during practice or on a later vocabulary test, unless that test contained the same hints from practice. In addition, some hints reduced the time available for further practice trials.

subsequent vocabulary test. This suggests that, during practice with hints, word knowledge became partly dependent on the availability of hints. Thus, **feedback with hints had no benefits for recall on a later test without hints.**

CONTEXTUAL INFORMATION AND RETRIEVAL PRACTICE

In a different study on the effect of retrieval during vocabulary exercises, reported in Chapter 6, I found that new words were better remembered when participants practiced retrieving the words from memory, than when they inferred word meaning from a relevant, informative context. Participants studied new words (e.g., the word *funguo*) and then practiced the words either in an uninformative sentence ("I need the *funguo*.") or in an informative sentence ("I want to unlock the door. I need the *funguo*."). Participants had to retrieve the word meaning from memory when practicing with the uninformative sentences, but could infer word meaning when practicing with

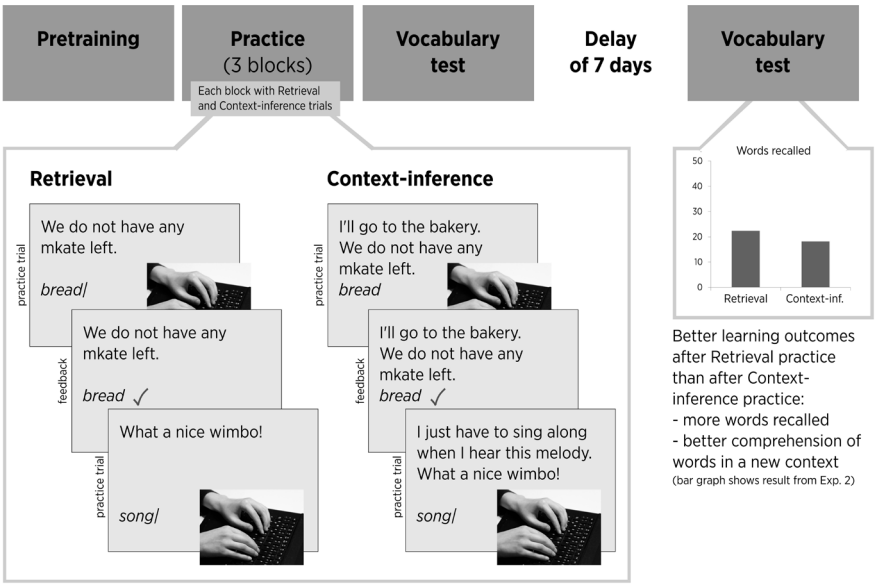

Figure A4 In the experiments reported in Chapter 6, participants studied new words (e.g., the word wimbo = song) and then further practiced the words either in an uninformative Retrieval sentence ("What a nice *wimbo*!") or in an informative context-inference sentence ("I just have to sing along when I hear this melody. What a nice *wimbo*!"). Participants had to retrieve the word meaning from memory when practicing with the uninformative sentences but could infer word meaning from the informative sentences. Practice with Retrieval sentences led to significantly higher performance on vocabulary tests, both immediately and several days after learning. The graph shows one of several significant differences found in Experiment 2.

the informative sentences (here: *funguo* = key). The informative sentences thus made it easier to understand words during practice. However, a vocabulary test several days later showed that participants remembered words better after retrieval practice with uninformative sentences.

The finding that the uninformative context led to more word learning than the informative context is counter-intuitive, because contextual information is typically a beneficial source of information that learners can use to understand new words. However, **when a learner understands a word in context, that does not automatically mean that the learner also remembers the word over time**. In line with this, Chapter 6 showed that a manipulation that made it easier to understand the target words (namely: adding contextual information during practice), made it *less* likely that the words were remembered over time. The uninformative context, which required effortful retrieval of the word from memory, led to better long-term retention than the informative context, which allowed learners to infer the word meaning from context. These experiments demonstrate that the **benefits of retrieval can be evoked through the context in which a word appears. Reducing contextual information to trigger memory retrieval can enhance learning.**

CONCLUSIONS AND PRACTICAL RECOMMENDATIONS

The retrieval of information from memory is not a simple readout process; each retrieval act increases the accessibility of the retrieved information. This makes retrieval practice a powerful technique to remember information over time.

This dissertation presents converging evidence from behavioral and neuroimaging studies regarding the cognitive mechanisms that underlie the benefits of retrieval practice for vocabulary learning. It suggests that retrieval is an effortful process that becomes facilitated with practice. This facilitation may be due to a selective focus on information necessary to achieve the retrieval, such as the association between novel word form and meaning in vocabulary learning. This may strengthen the memory representation in such a way that it can be reactivated more easily later on.

The studies reported in the thesis also highlight a number of requirements for the successful integration of retrieval practice during vocabulary exercises, from which practical recommendations can be derived for the design of learning situations.

Practical recommendations

- **The retrieval of information from memory, for example during self-testing, is a powerful learning technique.** Therefore, do not only present key information to the learners but let them produce target information from memory during practice.
- **Combine retrieval with feedback.** This allows learners to encode information that they cannot yet retrieve from memory. Unsuccessful retrieval has few, if any, benefits without feedback.
- **Provide repeated retrieval opportunities**. This way, later retrieval becomes increasingly facilitated. Repetition also ensures that there is a new chance for a successful retrieval after a prior error.
- **Aim for retrieval practice that fits the learners‘ abilities. Ideally, practice should be successful but challenging.** Conditions that increase the ease of retrieval too much may lead to high performance and confidence during practice, but to worse retention over time.
- **Ensure that the conditions of retrieval practice fit the learning goal.** For example, practice with hints may not enhance later recall without hints. Similarly, a multiple-choice test may not enhance later free recall. Therefore, be conservative with support during practice and consider whether the support is also available later-on.
- **Distinguish between fluency of retrieval during practice and benefits of practice for later performance.** Fluency during practice is not a good predictor of later performance, if the practice situation facilitates the retrieval in an undesirable way (e.g., through massed repetition).
- **Integrate opportunities for retrieval in different learning situations.** Small manipulations of exercises can suffice to trigger retrieval, for example, by first presenting a word in an un-informative context and only later in an informative context that reveals word meaning.

IMAGE CREDITS

Figure A2:

Image Editor. (2006). *01 Siemens MAGNETOM Trio* [Digital image]. Retrieved from Flickr: https://www.flickr.com/photos/11304375@N07/3081315619/sizes/o/. Creative Commons Attribution License.

Carter, H.V. (1918). Principal fissures and lobes of the cerebrum viewed laterally. Figure 728 from H. Gray (Ed.), *Anatomy of the human body* (20th edition, revised by Warren H. Lewis). Philadelphia: Lea & Febiger. Image edited by O. Räisänen for wikimedia [Public domain]. Retrieved from https://commons.wikimedia.org/wiki/File:Lobes_of_the_brain_NL.svg