LUNDS UNIVERSITET

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Electrophysiological correlates of generation induced forgetting - Manipulating retrieval success

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Bachelor's thesis/ Kandidatuppsats vt 2010

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Abstract

Although memory serves numerous functions, it is often not reflected upon until it fails us. Previous research has shown that both retrieval and generation of information may lead to forgetting of related items sharing the same cues and is referred to as retrieval induced forgetting (Anderson, Bjork & Bjork 1994; Bäuml 2002). The aim of this study was to investigate the electrophysiological correlates of semantic generation that has been shown to lead to similar detrimental effects assumingly attributed to inhibition. 18 participants were included in this study using electroencephalogram and a computerized memory experiment. The results showed that semantic generation leads to forgetting, when generation is possible but not when impossible. Analysis revealed significant interactions between task and scalp location, but no significant interaction between task and whether participants showed high or low generation induced forgetting why conclusions are hard to draw. The findings suggest that inhibition, although probably highly related to generation induced forgetting, may not be the only mechanism responsible for generation induced forgetting.

Key words: generation-induced-forgetting; GIF; retrieval-induced-forgetting; RIF; Event- related-potentials; ERP

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Introduction

Memory in many aspects forms the basis of our selves. We remember where we are and how we got here, we remember people we have met whose marks in our lives' history we wish to relive endless times, and we encounter those whose memory traces we wish we never hade to re-experience, or even want to remember we experienced in the first place.

Engaging in a conversation with a friend or performing your daily tasks at work requires memory functions you seldom consider unless something fails. You need to be able to remember who your friends are to start with, and in order to do so you need to remember who is being nice and friendly to you and you need to remember who is not trustworthy in order to avoid being hurt in the future.

To state the obvious you also need to remember the name and the face of your friend so that you do not start talking to anyone about anything and while in a conversation several memory functions are working simultaneously; you need to remember events that has happened to your friend when referring to assumed shared knowledge and you need to remember what topic interests this friend and what topics to avoid. You also need to remember a lot of facts in order to follow a conversation; if your friend has recently come home from a summer vacation in Paris it might strike her as odd if you start asking her about polar bears.

The embarrassment connected to forgetting the birthday of a loved one, or the annoying feeling you get when returning home for the third time the same morning while trying to rush off to work, realizing you forgot your wallet, keys and calendar can easily make you wish for an impeccable memory. Not to mention how delightful it would be always being able to remember the name of a recently encountered new acquaintance or in what very safe place put those important documents you never seem to find when you need them!

A flawless memory system, however, would be a double-edged sword. Although the thought of never forgetting the pleasantness in

life is appealing, never forgetting anything would also mean never to forget the sorrows and grieves in life, and recovery from a broken heart or from losing a loved one would be a never ending process. The morning efficacy expected from always remembering where you put your wallet the night before would probably be balanced out by remembering where you put your wallet every night before, and the search in memory for the right night could probably take longer than an actual search in your apartment.

Put in this light, forgetting seems to serve an adaptive function, smoothing our daily life in its way of ridding us of unimportant weight to carry. Forgiving, or at lest understanding, some of why forgetting occurs, rises the question of how- how do we forget? Is it possible that the very act of remembering sometimes leads to the forgetting of related events? Recent research on the subject suggests so. This somewhat contradictory phenomenon is known as retrieval induced forgetting (Anderson, Bjork and Bjork, 1994) which will be of focus in this study together with findings in the wake of this observable phenomenon. Measuring brain activity during events that will eventually lead to the forgetting, or remembering, of related events is another focus in this study.

In the following section I will initially provide the reader a brief overview of memory systems, followed by descriptions of retrieval induced forgetting (RIF), and also the related phenomenon referred to as generation induced forgetting (GIF).

Since one aim of this study was to investigate neural correlates of events related to later forgetting the next section is dedicated to explain the logics behind methods for measuring brain activity in general and electroencephalogram (EEG) and the logics behind Event Related Potentials (ERP) in particular. Before turning to the aim and hypothesis of this study findings linking RIF and GIF with different brain activity measurement methods will be presented.

Overview of memory

Long-term memory has generally been described as comprising two separate, but interacting, units. One is conscious and referred to as explicit memory whereas the other part is operating without our awareness but still contains a tremendous amount of information and is referred to as implicit memory. A schoolbook example of an implicit memory function could be tying your shoe; you can perform the task without difficulties, but if you were to describe verbally in detail how this action is carried out, you would probably find yourself challenged. Explicit memory has in turn been subdivided into two dimensions; episodic memory and semantic memory (Tulving, 1972). The former consists of personal experiences and is connected to recollection and the possibility to do a "mental time travel" whereas the latter is a fact-based storage of information that is not tied to a context (Tulving, 1985). Let another schoolbook example illustrate the differences; having an episodic memory about learning capitals in school a very hot summers day or to have the semantic memory of knowing that Paris is the capital of France, without remembering when or how this information was acquired.

A frequent test of episodic memory retrieval is to refer directly to a previous study phase, in which items were to be learned. Participants can be asked either to recognize previously studied items as old, and items never seen before as new, or to recall them either by cues or by free recall (Friedman and Johnsson, 2000). This leads us to one test of episodic memory functions, namely the retrieval practice paradigm, often used to investigate the aforementioned phenomenon RIF.

Retrieval Induced Forgetting

The retrieval practice paradigm

The somewhat contra intuitive finding that the very act of remembering can cause forgetting of related items was first demonstrated in an influential

study by Anderson and coworkers (1994). They employed the now widely used retrieval practice paradigm to show this phenomenon referred to as retrieval induced forgetting (RIF). The paradigm typically consists of three phases; a study phase, a retrieval practice phase and a test phase. In the study phase participants are presented with a number of items such as category-exemplar pairs (e.g. Fruit-Kiwi and Animal-Dog) presented one at a time in a randomized order. Each exemplar only appears once but the categories are shown with several different exemplars, typically six, where some can be high in typicality, for example banana and apple, and some can be low in typicality, for example litchi. In the retrieval practice phase half of the exemplars from half of the categories are to be retrieved by the participants via category plus stem cued recall (eg. Fruit-Ki__). The logic behind this is to create two conditions; in the test condition half of the exemplars are retrieved via cued recall and will henceforth be referred to as Rp+ items. The exemplars from the same categories that are not retrieved are referred to as Rp- items and items belonging to categories that do not receive any retrieval practice at all are called Nrp items. In the test phase the category and the words initial letter is given as a for all the words presented in the study phase (eg. Fruit-K__).

The results show that participants remember those words that has been practiced via retrieval are remembered best, which is in line with what you would expect. What is surprising, however, is that Rp-items are remembered significantly less that Nrp items which suggests that the retrieval of related items impairs recall for competing items. They also found retrieval induced forgetting to have the most detrimental effect on strong exemplar of its category respectively.

Theoretical models

Given the amount of different occasions in which RIF occurs described later in this section, the detrimental effect that retrieving items has on related items is now widely accepted. How this impairment comes about however,

is still being debated. Although the inhibitory account, which will be discussed below, has now taken a win over early models of RIF suggested blocking of related items to be responsible for the impairment in memory for related items, the discussion is far from settled. These blocking based account, sometimes also referred to as strength-dependent competition models of interference, hold that it is the strengthening of the retrieved item that causes blocking and thereby impaired recall for related items.

These blocking based models rest on three assumptions that constituted the foundation for the retrieval practice paradigm and were identified by Anderson and coworkers (1994). The three assumptions are *the competition assumption*, which posits that related memories are competing for recall when a shared cue is being presented and *the strength-dependent assumption* suggesting that when a competing item is being strengthened other and related items suffer in recollection. The third assumptions, *the retrieval based learning assumption*, suggests that the retrieval practice involves a learning process based on the increase in recollection of items subjected to retrieval practice. (Anderson et Al., 1994). In the light of findings reported in the sections below however, the blocking based models of retrieval induced forgetting have been challenged and provides support for the inhibitory based accounts of retrieval induced forgetting. The inhibitory-based account suggests that inhibitory mechanisms are recruited in order to overcome interference caused by competing memory traces hence acting to facilitate successful retrieval (Anderson, 2003).

Properties

Cue-independence

Retrieval induced forgetting appears to be cue independent and emerge regardless if words are words are tested with the same cue shown in the in the study phase or not. In the paradigm employed by Anderson and coworkers (1994) words were tested for using the same cue as presented

with in the study phase. If, for example the category pair FRUIT-Banana was studied, it was later tested for with the cue FRUIT-B_____ However, the tendency for RIF to occur seem to spread to other cues as well, suggesting RIF to be cue independent and to be seen even if the words presented were to be tested with novel cues, not involved in the study phase. RIF can also appear for NRP items, if they share semantic similarities with categories receiving retrieval practice. (Anderson and Spellman, 1995; Anderson and Bell, 2001)

Retreieval Specificity

Retrieval specificity refers to the tendency for retrieval to be crucial for retrieval induced forgetting to occur and it has been demonstrated that mere exposure to a related item do not lead to the same impairment for related items as do retrieval (Ciranni and Shimamura, 1999).

This has been shown in several studies where some participants practiced retrieval of the items previously shown, and others were presented for them again in an extra study phase, replicating the findings that retrieval, and not mere exposure, impairs recall for related items. (Ciranni and Shimamura, 1999; Anderson and Bell, 2001)

Interference Dependence

RIF has been demonstrated to be interference dependent and the reason behind this is suggested to be due to the typicality of the words in the retrieval practice paradigm. The stronger the relation between the category and the item, the more it interferes when another related item is to be retrieved and hence competes for recall when actively trying to retrieve the more infrequent words. (Anderson and coworkers, 1994) It is, for example, more likely that the word apple comes to mind when people (living in western countries) are asked to name a fruit than the word litchi and in order

to facilitate retrieval of the atypical words, the more typical words are thought to be inhibited and therefore suffer more retrieval induced forgetting.

Strength independence

Anderson and coworkers (1994) were first to suggest the strength independence properties of retrieval induced forgetting discussing the findings that the strengthening of an Rp+ items did not effect the memory impairment for unpracticed Rp_ items. Bäuml (2002) has also shown that strengthening items via repeated study exposure not leads to the forgetting of related items, gaining further support for the assumption.

Retrieval success independence

RIF appears to be independent of whether items are successfully retrieved or not. Storm, Bjork, Bjork & Nestojko (2006) showed this in a study where participants engaged in guided retrieval where some cues were manipulated not to represent an existing exemplar from the category it was presented with. Their results showed that RIF occurs independently of whether items are retrieved successfully or not, and Storm and coworkers (2006) suggested that it is not the retrieval *per se* that is responsible for the effect, but rather the attempt to retrieve an item. These results have been replicated in later studies (Storm & Nestojko, 2010).

Time boundaries

In the short run, the temporary forgetting that is induced by retrieving ostensibly semantically similar items might be adaptive and ease recall of the relevant information. However, it would probably not be as adaptive in

the long run, to suffer a permanent loss of related information in order to successfully retrieve the item being searched for.

MacLeod and MacRae (2001) strived to provide insight into how long this effect actually lasts and tested participants either five minutes or 24 hours after retrieval practice. Their results showed that RIF occurred when tested five minutes after retrieval but after 24 hours this effect did not emerge. The study also showed that a 24 hour delay between the learning phase and retrieval did not have the same effect. Anderson and coworkers (1994) reported RIF to occur after a 20 minutes delay between retrieval practice and test, but the exact time confines for RIF are yet to be fully explored.

Generality

Although the retrieval practice paradigm was originally employed using category-word pair, the effect has been shown relevant both in tests involving episodic, semantic memory and even false memories (Bäuml, 2002; Johnson & Anderson, 2004; Bäuml & Kuhbandner, 2003) and in a variety of different settings. One setting in which RIF is relevant is in eyewitness testimony were Migueles and García-Bajos (2007) have shown that retrieving some information about an event may have detrimental effects on related information. It has also been shown that describing a face can lead to impaired recognition on the same face. (Schooler & Engsler-Schooler, 1990)

Ciranni and Shimuamura (1999) showed that the effect works on visuo-spatial materials as well in a study were participants were to learn the colour and location of objects. The results showed that retrieving information about an object led to the forgetting of objects with the same shape, but not for differently shaped objects.

Another setting in which retrieval induced forgetting appears to operate is in social context and it has been shown to play a role in

memory of traits and to be connected to stereotypical beliefs. Dunn & Spellman (2003) showed that retrieving individuating information about a person led to retrieval induced forgetting of stereotypic traits for that person. They also showed that the effect was moderated by participants' belief in the stereotype: the more belief they had in it, the less susceptible they were to retrieval induced forgetting. MacRae & MacLeod (1999) also showed how RIF is relevant in impression formation by letting participants learn trait about to characters. By retrieving half of the traits for one person, memory for the other traits for the same person were impaired as compared to the control condition, which was the other person about whose traits no retrieval practice was involved.

While the retrieval practice paradigm uses retrieval of recently studied items, and hence focus on episodic memory, recent research point to a similar function in semantic memory, referred to as generation induced forgetting (GIF) which will be the focus of the following section.

Generation Induced Forgetting

Since participants in studies on RIF experience a learning phase and are subsequently shown words presented in that phase, the typical retrieval practice paradigm tap episodic memory functions. Recent result have shown that a similar effect is shown in semantic memory.

The first study to test whether semantic generation has the same effect on memory as retrieval of previously studied items was Bäuml (2002) who replaced the retrieval phase with a semantic generation task. As in the traditional retrieval practice paradigm participants were shown a list of category-exemplar pairs that they were instructed to learn. In the retrieval phase however the were not to retrieve half of the exemplar of half of the studied categories, but to generate, via cued guidance, objects for half of the categories from their semantic memory. Their results indicate that semantic generation has the same effects on memory as episodic retrieval and hence leads to RIF.

These findings have been replicated using semantic generation instead of episodic retrieval practice (Storm et Al., 2006) and the results have led researchers to believe that the same neural mechanisms underlying RIF are also responsible for GIF, namely inhibition.

To the best of my knowledge, thus far only one study has investigated the neural correlates of GIF and the findings from these will be described later in this section after a brief overview of the logics behind electrophysiological measurements and the technique used in this study; EEG recordings and Event Related Potentials, ERP.

Electrophysiological techniques

In the last decades emerging techniques have made possible exiting combinations of measures on behavior and brain activity. Both behavioral and neurophysiologic measurements are interesting *per se*, but by relating the two it is possible to relate behavior to certain temporal and spatial correlates in the brain.

The most common techniques to measure brain activity are by using functional magnetic reasoning (fMRI), positron emission tomography (PET) and electroencephalogram (EEG). While fMRI and PET focus on slower hemodynamic processes and have a better spatial resolution EEG measures electrical activity on the scalp and has a very good temporal resolution but is inferior the two when it comes to drawing spatial conclusions. (Luck, 2005)

The method used in the present study was EEG and Event Related Potential Techniques why these will be the focus of the next section. The last part of this section will be dedicated to neurological findings related to RIF and GIF and hence of interest for this study.

EEG and The Event Related Potential Technique (ERP)

Amplified and plotted electrical activity from the brain is called electroencephalogram (EEG). The activity consists of the sum of many

neurons since activity from single neurons is too small to measure in this way. Thus, the activity is the sum of all electrical activity measureable on the scalp and in order to make sense of all this, and relate the EEG to cognitive processes, parts of continuous EEG can be cut out and related to certain events, called Event Related Potentials, ERP. Event thought time locked and cut out, it still contains the sum of all activity at that point and hence a lot of noise, none of which is of interest. There are different ways to reduce this noise and get to the core of the ERP. One way is to reduce the amount of activity related to muscular activity by using filter. These can be both high and low pass filters, meaning that they only record activity above or below a certain threshold. Filters can also be used to reduce the impact of electrical equipment close to the recording sites and filers can be used both during recordings and after, the latter referred to as off-line filers. Eye movements and blinks give rise the characteristic signatures in the EEG and by using mathematical algorithms that recognize the patterns for each individual it is also possible to correct for ocular artifacts. (Luck, 2005)

Another way to further separate the ERP of interest is by repeating a certain type of event several times in order to create an average electrophysiological responses to that particular event. This rests on the assumption that the noise will be noise no matter what, and by comparing one type of averaged ERP with another type of averaged ERP the difference in between the two is likely to be related to a difference between the two conditions. (Luck, 2005)

Neural correlates related to RIF

Since this study builds on the assumption that semantic generation share common features with retrieval of episodic memory with respect to its detrimental effect on related memories, it is also interesting to investigate whether the underlying neurophysiologic mechanisms of the two are overlapping. Generation induced forgetting being relatively unexplored in

comparison to retrieval induced forgetting more research has of course been conducted on the former, but since the phenomena assumingly share common features, findings on RIF provides a good basis for an understanding of the hypothesis postulated in this study. Since time boundaries for this particular study limited our analysis to the retrieval phase and also because this is when inhibition is thought to act in order to facilitate recall the following section will focus on that particular phase.

The first study to investigate the neural correlates of retrieval induced forgetting was carried out by Johansson, Aslan, Bäuml, Gäber & Mecklinger (2007) in which they used ERP to investigate correlates to the retrieval practice paradigm. In order to do so they used relearning as a baseline condition to the retrieval practice with the logic behind that no inhibition would be needed in the former condition, hence a difference between the two would, given the inhibition account of retrieval induced forgetting, reveal neural correlates to inhibition. The most evident difference between the two conditions was that retrieval practice elicited larger positive going ERPs over anterior sites than did relearning. This effect was visible approximately 200 ms into and lasted throughout the whole recording epoch (2000 ms). To further investigate this effect Johansson et al (2007) divided their participants in two groups based on performance in the subsequent memory test and by so doing creating one high forgetting group and one low forgetting group. The two groups ERPs in the retrieval practice were compared and the high forgetting group showed a greater difference in amplitude in ERP at anterior sites between the two conditions compared to the low forgetting group. Finally a regression analysis was performed in order to investigate whether this difference was predictive of differences in retrieval induced forgetting. The analysis showed that it was predictive but that the prediction was restricted to bilateral anterior sites.

Neural correlates related to GIF

To the best of my knowledge the first study to investigate the neural correlates of generation induced forgetting was carried out by Johansson, Hellerstedt and Nilsson, (2010). The study used the event related potential to investigate the neural correlate of inhibitory control and later episodic forgetting by employing the somewhat modified retrieval practice paradigm. In the study participants were presented with a study list of category-item word pairs (eg DRINK- apple) and were later to engage in semantic generation of items from half of the categories. A memory test for all the studied items concluded each study block and the results revealed a significant generation induced forgetting effect for studied items belonging to categories subjected to semantic generation (Rp-) as compared to studied items belonging to categories not receiving semantic generation (Nrp items). Since this generation induced forgetting effect was larger for items high in interference compared to items low in competition the results indicated that GIF is interference-level dependent.

The study found that ERPs recorded during the semantic generation phase showed more a positive going intonation over frontal anterior sites in the high interference conditions compared to the low competition conditions. Further analysis revealed that this positive going activity was predictive of later recall in the subsequent memory test and the results found are in accord with an inhibitory account of generation induced forgetting.

Logic of the present study

The present study aimed to investigate the electrophysiological correlates of generation induced forgetting, focusing on events in the retrieval practice phase wherein inhibition is thought to act to facilitate retrieval. Two main hypotheses are proposed in relation to these claims and the logic behind these and also the logic behind the experimental design chosen to test these assumptions are described in this section.

Using impossible generation conditions, the present study was similar to the designs used by Storm and coworkers (2006) with a few changes being made. First, the study by Storm used the traditional design with Rp+, Rp- and NRP- items, where performance on NRP-items served as a baseline. In this study however, memory performance on items subjected to presentation as opposed to generation in the semantic generation phase served as a baseline. This baseline was chosen in order to best fit the electrophysiological measuring methods used in the presentation condition keeping the two conditions to be compared as similar as possible in regard to stimulus processing. Keeping everything as similar as possible in terms of conditions makes it easier to draw conclusions about the differences in ERPs between them. Because previous studies on RIF have shown that relearning of items is not sufficient for RIF to occur (Bäuml, 2002), presentation of items in this study would presumably not lead to forgetting either and hence no NRP items were considered necessary.

The second change being made in the present study was using both possible and impossible conditions in the semantic generation phase. The logic behind using this was that, if retrieval success is not necessary for RIF (and GIF) to occur, the electrophysiological correlates obtained during the impossible conditions would not be blended with episodic/semantic retrieval success and would hence provide a cleaner measurement on the inhibitory mechanisms thought to operate during retrieval.

The logic behind the first part of hypothesis stems from the findings made by Bäuml and coworkers (2002) that generation of items not previously shown in the experiment leads to forgetting of related items. The second part of the first hypothesis originates in the competition dependence assumption of retrieval induced forgetting mentioned in the introductory section above. This assumption suggests that items high in typicality compete to a greater extent for recall during retrieval and are hence subjected to more inhibition than items low in typicality and, subsequently, the former type of items suffer more forgetting than the latter type of items when final recall is being tested for. The last part of the first hypothesis

builds on findings by Storm et al. (2006) study showing that retrieval success in not necessary for RIF to occur.

The second hypothesis that semantic generation will give rise ERPs with a greater positive going amplitude over anterior regions than the baseline presentation condition, and that this effect will be more observable in high forgetters as compared to low forgetters builds on findings in previous studies (Johansson et al., 1997; Johansson et al., 2010)

In order to make following this paper easier, an explanation of the abbreviations to be used will conclude this section. HiGP items refer to items in the high competition condition (meaning a word high in typicality was shown in the presentation phase of the experiment) where generation is possible. HiGI refers to items in the high competition conditions where generation is impossible and HiP denominates items in the high competition condition being presented for. LoGP items refer to items in the low competition condition (where items low in typicality were shown in the presentation phase of the experiment) where generation is possible, and LoGI referres to the same condition but where generation is impossible. LoP items represent items being shown in the low competition condition.

Hypotheses

Hypothesis 1a. Semantic generation will lead to forgetting of items from categories subjected to semantic generation. The generation induced forgetting effect will be recognized as a decrease in memory test performance for items belonging to categories that have undergone generation as compared to those items belonging to categories subjected to presentation.

1b. The decrease in memory performance for items belonging to categories subjected to generation will be lower compared to those in the presentation conditions independently of whether generation is possible or not.

1c. The generation induced forgetting effect will be more visible for items in the high competition condition than in the low competition condition.

Hypothesis 2 The retrieval ERPs from the semantic generation phase will be more positive going in amplitude at anterior sites at latency of 200-2500 ms as compared to the presentation ERPs. This effect will be more pronounced for high forgetters as compared to low forgetters.

Method

Participants

29 Participants were recruited from various faculties at the University of Lund and received a cinema ticket (value ≈90SEK) for their participation. Of the 29 participants a total amount of 11 participants had to be excluded. Six were discarded due to too poor performance on the behavioral data and five were excluded due to an insufficient amount of accepted trials. The remaining two participants had to be discarded due to technological problems causing behavioral data not to be recorded leaving their EEG recordings impossible to interpret. The final sample included in the study

thus consisted of 18 people (9 females) with a mean age of 23,6 years (range 21-37)

All participants reported having normal or corrected to normal vision, to be right handed and to be native Swedish speakers. Normal or corrected to normal vision was a presumption for them to relax and actually see the words presented and Swedish as the mother tongue was a requirement since the experiment consisted of Swedish words. Right handedness was a requirement because left handed people sometimes are less lateralized than right handed, and this is a problem when using ERP since this method is based on averages. If not all participants have similar distributions averages will not be useful.

Material

The material consisted of an extended version of the material used in a previous study by Rasmussen & Johansson (2009). The original material included 24 distinct semantic categories, and in this study this list was extended with six new categories. Thus, a total of 30 categories were part of the final version of the experiment. Each word in every category was rated based on frequency, and from each category 12 words were selected to be included in the study. Six words from each category were frequent and included to create the high competition conditions and six words were infrequent and chosen in order to create the low competition condition. The words were chosen to consist of four to ten letters and not to begin with very unusual letters in order to avoid possible guessing on behalf of the participants. No items belonging to the same category shared the same initial letter. As far as possible, categories with semantic relatedness were assigned to different conditions in order to reduce interference. All items were given two cues one consisting of the words' two or three actual initial letters, depending on the length of the word, used in the possible conditions and one cue chosen not to represent an actual exemplar from that particular category used in the impossible condition. For counterbalancing purposes, the

categories were divided in six different sets, and for every single participant each set was assigned one of six conditions. Chance decided which set was assigned what condition and this way all categories had been assigned all the six different conditions after six participants. Thus only one of the two cues were shown to a single participant depending on what set that participant was randomly assigned. Thus individual differences across participants were balanced out.

Study list

Half of the items from each category were presented in the study lists. Each study list consisted of 36 words from six different categories. All words in the same study list were either typical or atypical exemplars of the category respectively in order to create a high or low competition condition for that particular category.

Retrieval practice

The other half of the items from each category was subjected to retrieval practice. For two thirds of the categories, participants were guided to retrieve new exemplars to categories previously shown in the study list via category-plus-initial-letters-cues. For half of these categories semantic generation was possible, but for the other half cues were manipulated not to represent an actual exemplar of that category, hence retrieval was made impossible. For the remaining third of the categories receiving semantic generation participants did not have to retrieve words, but only to read out loud the words being presented to them. Words being presented were shown in a similar fashion as the category-plus-initial-letters with the only difference that the whole word representing an exemplar and not only he initial letters were shown. Category-item pairs were only present in either

study list or retrieval practice; hence none of the words appeared in both study list and retrieval practice.

Design and procedure

The experiment consisted of five blocks containing four different phases. The four phases were study phase, retrieval practice/semantic generation, an unrelated distracter task (the Digit Stroop Task) and a final memory test. The phases in each block were identical in instructions and layout, but in each block unique categories were included hence no repetition was part of the experiment. Six categories were included in each block and assigned one of six conditions in the generation phase with one category in each. The six conditions were High Competition- Generation Possible (HiGP), High Competition- Generation Impossible (HiGI), High Competition- Presentation (HiP), Low Competition- Generation Possible (LoGP), Low Competition- Generation Impossible (LoGI) and Low Competition- Presentation (LoP).

Since typical exemplars of a category is thought to compete for recall to a greater extent than atypical exemplar, having shown typical exemplar of a category in the study phase created the High Competition Conditions, whereas having shown atypical exemplars in the study phase created the Low Competition Condition. Possible and impossible generation and presentation was manipulated via cued recall (see the Material section above).

Each session lasted approximately two and a half hour, including preparations, paperwork and debriefing. Prior to starting the session participants received and signed an informed consent paper. The experiment lasted 70 minutes and applying the electrodes and achieveing the impedance desired varied across participants, but usually took circa 50 minutes.

The experiment was computerized and programmed and shown using Eprime 2.0 software on a 17 inches screen approximately 50 cm away from the participant. Words were presented in black on a white background. The session was led by a female experimenter present in the room two meters away at the back and one meter to the left of the participant during the whole session. During the generation phase and the test phase she coded the participants' verbal responses via an external keyboard as either correct (1) or incorrect (3). Omitted responses were automatically coded as incorrect.

Before starting the experiment participants were instructed to sit as still as they possible could during the experiment and to try to restrict blinking to when the fixation cross (+) was visible on the screen or when oral responses were allowed. They were also told to focus their eyes on the fixation cross that was shown prior to every new stimulus indicating its position so no visual search of the screen would be necessary. All this was in order to reduce muscular artifacts created by body and eye movements.

A 500 ms blank screen always followed a fixation cross where the last 200 ms served as an EEG baseline for the ERP. In order to prevent time regularity associated ERPs to occur a blank screen was also shown for either 1000 or 1500 ms at the end of every presentation during the memory test.

The study phase

Each study phase began with written instruction to memorize the words to come. 36 words from six different categories were presented in a serial position and each experiment included 30 different semantic categories with either typical or atypical items depending on the randomized assignation to condition. Each word was presented with the semantic category it belonged to (eg. Animal-Horse) and participants were told that they would be given

the category and the first letter of the word as a clue in the later coming memory test. Each word-pair was presented on the screen for 2000 ms each. Before the presentation of the words participants was told to memorize the words, since their memory performance would be tested later, but also to focus on the words being presented and not to rehearse previously shown words. If participants were rehearsing words and not focusing on what was being shown interpretations would be impossible, since there would be now certain behavioral correlates to relate them to.

The semantic generation phase

In this part of the experiment participants were either to generate words that would be appropriate given certain cues, or simply to articulate the words being presented on the screen. When words were to be generated the category they belonged to was first shown on the screen for 500 milliseconds following a 2000 milliseconds retrieval phase showing the initial two or three letters, depending on the length of the word to be retrieved. This picture was followed by a question mark lasting for 2000 milliseconds and participants were instructed not pronounce the word until this was shown. These instructions were made in order to avoid artefacts and to separate the processes involved in oral responses from those associated with semantic generation.

The words to be generated were either typical or atypical exemplar of its category, or they were manipulated to be impossible. Before starting the generation phase participants were told that some words they were to come against would be more common and hence easier to think of, and some words were more unusual and would hence be more difficult to think of, but that it was important that they tried to find a word. The were also told that the categories were the same as in the preceding study phase, but that the items were new and that it would not be possible for previously shown words to fit in given the new cues.

When words not needed to be generated but only read the procedure was identical to when they were to be generated except that instead of being given the initial letters of the words, participant were shown the whole word and instructed to articulate it at the point of the question mark being presented.

Each of the categories shown in the study phase were subject to semantic generation. When the words from a category in the study phase where typical the words to be generated in the semantic generation phase were atypical and vice versa. This also held true for words in the impossible condition, but the denomination typical/ atypical was more of a theoretical one since the impossible cue was used instead of the words real cue.

The digit Stroop task

The task in this phase was to decide how many signs were being presented on the screen. The signs were either the numbers 1, 2, 3 or 4 or a square (#) shown in one of three conditions at a time. In the congruent condition the number of signs corresponded to the particular sings being presented, for example 22 or 4444. In the incongruent condition the numbers of signs did not correspond, eg 11 or 3 and in the neutral conditions one up to four squares were shown.

Prior to every trial a fixation cross was shown on the screen for 500 milliseconds to indicate location of the items, followed by a blank screen for 500 ms. Participants were told that they did not need to wait for permission to respond in this phase, but to indicate as correctly and quickly as they possibly could by pressing one of four keys: V, B, N, M. They were all told to use their right hand and to use the index finger for pressing the B key, their middle finger for B, their ring finger for N and to press the M key

with their little finger. Each phase consisted of 48 trials and lasted approximately five minutes.

The test phase

In the test phase participants were given a test on all the 36 words shown in the presentation phase. The procedure in this phase very much resembled the generation phase. Prior to every trial a fixation cross was shown for 500 ms, followed by a blank screen and then the category-plus-initial-letter cue. This was slightly different from the generation phase were participants were given the two or three first letters of the target, whereas in the test phase only the first letter was provided (eg. Animal_H). This was followed by a blank screen and the words "Vilket var ordet" (What was the word?). Analogous to the generation phase participants were instructed not to answer until this was shown in order to avoid artefacts. All the words in the each study phase were being tested for hence the test phase also included 36 trials each.

Electrophysiological methods

EEG was recorded using 38 Ag/AgCl scalp electrodes referenced online to the left mastoid and off-line to half of the activity on the right mastoid. The electrodes were mounted on a cap of the brand Easycap, to record activity on the scalp and two of those were placed on the two mastoids to be used as reference electrodes. Two additional electrodes were placed above and under the right eye in order to monitor vertical eye movement and two were placed outside the outer canthi of the eyes in order to monitor horizontal eye operations. All channels were amplified and later analyzed using Neuroscan 4.4 Aquire software. The impedance between the scalp and the electrodes were kept below 5 kOhm. Each epoch lasted for 2700 ms including a 200 ms prestimulus sampling period used for baseline correction. Prior to avaraging trials with muscular and/or recordning artefacts were rejected and

trials containing occular artefacts were corrected. The minimun requirement for accepted trails was set to16 per each condition and participant.

Results

Behavioural data

Retrieval practice responses

Generated responses in the semantic generation phase are presented in table 1. As in previous studies by Storm and coworkers (2006) and Storm and Nestojko (2010) responses in the impossible condition were often reflections of highly creative participants, or of participants' special knowledge of words belonging to certain categories, which the experimenter had failed to recognize when creating the impossible word stems. The reason participants failed to respond with perfect accuracy in the presentation condition was often due to them forgetting or misunderstanding the instructions.

Table 1. Participants percentatage of generated responses in the six different conditions

	Generated responses, %	
	M	SD
HiGP	41	8.4
HiGI	4	3.8
HiP	83	14.6
LoGP	58	10.5
LoGI	4	3.4
LoP	87	14.4

Memory test performance

In the first stage of the analysis the average performance in the subsequent memory test for the six different conditions was computed. The results yielded are shown in table 2 which gives a summary of the average recall rates in each condition respectively.

Table 2. Mean recall rate for participants for words subjected to the six different conditions respectively.

	Generated responses, %	
	M	SD
HiGP	39	11
HiGI	36	11
HiP	40	14
LoGP	32	13
LoGI	30	13
LoP	38	15

Thereafter, the amount of forgetting was calculated by creating a generation induced forgetting index. This index was created by memory performance in the four generation (HiGP, HiGI, LoGI, HiGI) conditions subtracted by the memory performance in the two presentation conditions (HiP, LoP) respectively. The results are presented in table 3.

Table 3. Generation induced forgetting index for items receiving possible and impossible generation in the high and low interference condition respectively.

	Generation induced forgetting	
	GIF	Sig.
HiGIFP	0.06	0.07
HiGIFI	0.01	0.69
LoGIFP	0.06	0.05
LoGIFI	0.04	0.13

The next step in the analysis of the behavioral data was collapsing the generation induced forgetting across the conditions which revealed a reliable generation induced forgetting (t_{17}=0.04, P<0.001) indicating that semantic generation leads to forgetting of related items. The last step in the analysis was to contrast the generation possible condition and the generation impossible condition with the baseline presentation condition. Item recall was significantly lower for target items following possible generation as compared to baseline (t_{17}=0.007, P<0.001) and close to significant in the generation impossible condition (t_{17}=0.03, P=0.054)

ERP Data

Figure 1 shows grand averages of the ERPs obtained in the intermediate phase as a function of reprocessing condition. The primary difference between the ERPs elicited in the two generation conditions as contrasted to the presentation condition is apparent bilaterally over posterior regions. The difference begins at around 1000ms and shows a continued time course lasting throughout the epoch.

ERP waveforms were quantified by measuring the mean amplitude in three successive time windows (early: 1000-1500 ms, mid: 1500-2000 ms and late: 2000-2500 ms). In order to investigate interactions a repeated measures analysis of variance (ANOVA) was carried out using three factors; Task (3 levels; GP, GI and P), Anterior-Posterior (5 levels:

frontopolar, frontal, central, parietal and occipital) and Hemisphere (3 levels: left, mid, right). Analysis of the first time window revealed a reliable 3-way interaction between task, location and hemisphere ($F_{2,16=}$ 144.8, P<0,01) and supplementary analysis showed that this interaction as a function of task was restricted to right frontal ($F_{2,16=}$ 14.8, P<0,001), central ($F_{2,16=}$ 21, P<0,001), left parietal ($F_{2,16=}$ 23.3, P<0,001), right parietal ($F_{2,16=}$ 2.16, P<0,001) and occipital regions ($F_{2,16=}$ 25.4, P<0,001). In the intermediate time window analysis revealed interactions between processing condition and hemisphere ($F_{4,14}$=3.23, P<0,001), task and location ($F_{8,10}$=9.36, P<0,05) and hemisphere and location ($F_{8,10}$=3.87, P<0,05), characterized by more negative going ERPs in the generation conditions as compared to the presentation condition in right frontal ($F_{2,16}$=3.85, P<0,045), central ($F_{2,16}$=8.85, P=0,003),left parietal ($F_{2,16}$=10.2, P=0,003), right parietal ($F_{2,16}$=15.9, P<0,001) and occipital ($F_{2,16}$=16.7, P<0,001). Testing the third time window also showed a significant interaction between condition and hemisphere ($F_{4,14}$=2.54, P=0,0042) and condition and location ($F_{8,10}$=6,20, P=0,005). The difference in amplitude as a function of condition was spread over frontopolar ($F_{2,16}$=4.22, P=0,034), left frontal ($F_{2,16}$=6.29, P=0,01), central ($F_{2,16}$=5.32, P=0,017), left parietal ($F_{2,16}$=3.69, P=0,048), right parietal ($F_{2,16}$=7.67, P=0,005) and occipital ($F_{2,16}$=7.68, P=0,005) regions.

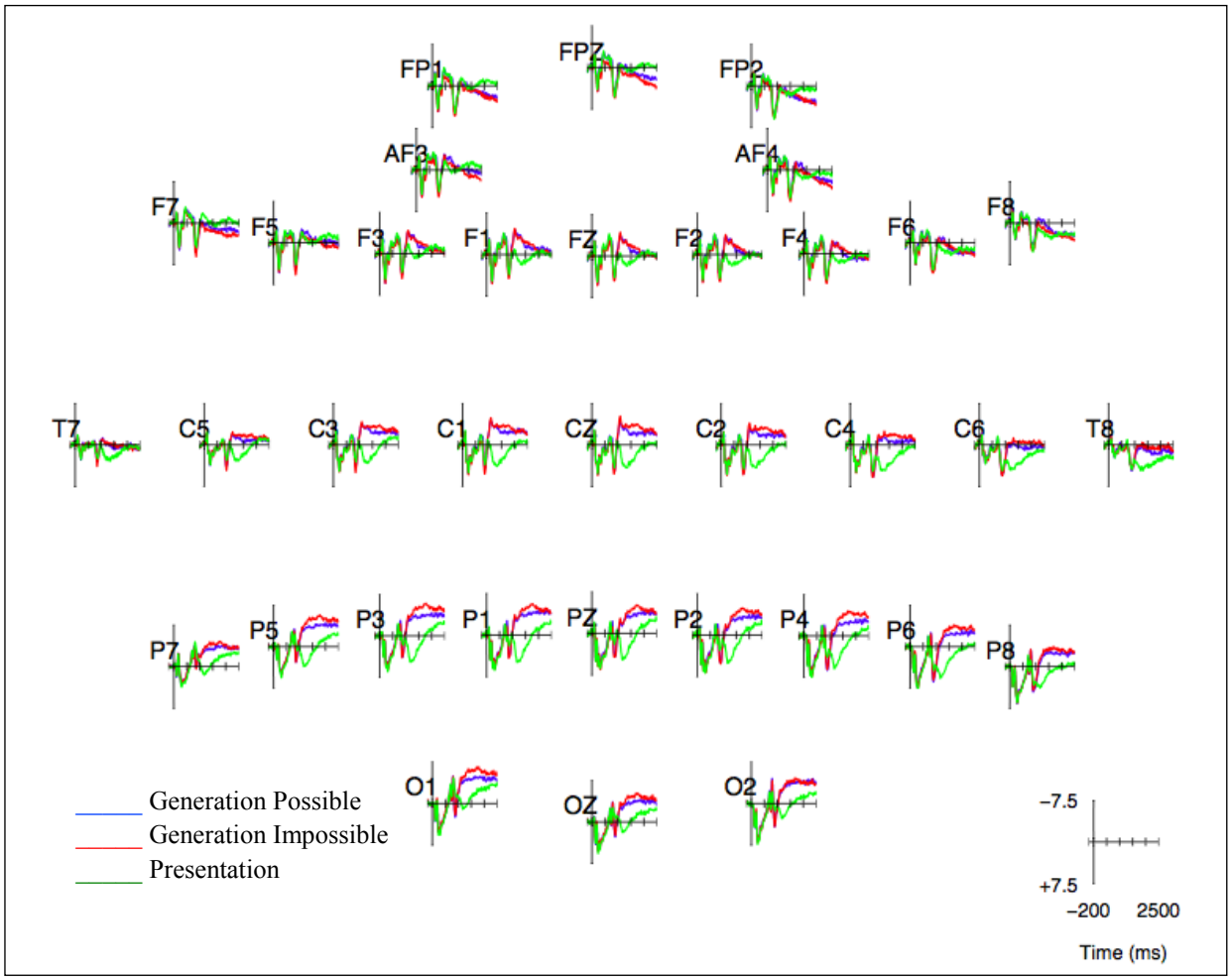

Figure 1. Grand averages elicited as a function of reprocessing condition (GP- blue, GI- red and P-green) in the Semantic Generation Phase. Electrodes on the top represents anterior parts on the scalp, thus the electrodes are arranged as if looking down at the scalp, the nose would be pointing upwards.

A second set of analysis focused on differences in these ERPs and their relation to individual differences in generation induced forgetting. Since no significant generation induced forgetting effect was achieved as a function of the generation impossible condition in the behavioral data the condition of interest here is the generation possible condition and what differs between subjects showing high levels of GIF (henceforth referred to as high forgetters) versus those showing low levels of GIF (low forgetters). In order to create the two groups a forgetting index was calculated by subtracting memory performance in the generation possible condition from memory performance in the presentation condition. A median split separated participants into two groups, high forgetters and low forgetters. Since three

participants shared the same generation induced forgetting value, they were randomly assigned to either the low forgetting group or the high forgetting group. Forgetting was significantly induced in the high forgetting group (t_8=0.1167, P<0,001) but did not reach significance in the low forgetting group (t_8=-0.004, NS).

ERPs in the two conditions generation possible and presentation were contrasted with the between-subject factor of forgetting group. A mixed analysis of variance was carried out for each of the three time windows and in the regions where a significant interaction between condition and location were found (see section above). The analysis revealed a significant interaction between forgetting group and condition at left anterior sites in the late time window (F=3.70, P=0.049) and an interaction that was close to significant in the left frontal region in the early time window (F=3.24, P=0.068). However, subsidiary pair wise comparisons failed to show a reliable interaction between the three different conditions and the two groups (high/low forgetting).

Discussion

This study aimed at investigating neural correlates of generation induced forgetting. Two hypotheses were proposed and the results in relation to those will be discussed before turning the limitations of this study and then moving on to a general discussion. Implications for further research will close not only this section, but also this whole report.

A significant and general generation induced forgetting effect was visible indicating that generating exemplars from a category leads to impaired memory for related items belonging to semantically similar categories. Hence, hypothesis 1a was supported *(Semantic generation will lead to forgetting of items from categories subjected to semantic generation. The generation induced forgetting effect will be recognized as a decrease in memory test performance for items belonging to categories that have*

undergone generation as compared to those items belonging to categories subjected to presentation) and the results are in line with previous research showing that generation can cause forgetting of related items (Bäuml, 2002; Storm, et al., 2006)

When comparing participants generation induced forgetting in the possible condition to the impossible condition however, the generation induced forgetting effect in the impossible condition failed to reach statistical significance. Thus, hypothesis 1b did not gain support. *(The decrease in memory performance for items belonging to categories subjected to generation will be lower compared to those in the presentation conditions independently of whether generation is possible or not.)* Although the results indicate that generation leads to forgetting of related item, this only occurs when successful generation is possible. This is contradictory to previous findings by Storm et al. (2006) and Storm et Nestojko (2010) and one possible explanation could be that participants guessed that some of the categories actually were impossible and gave up even before trying. If this was the case it would be likely for inhibition not to be necessary and as a result retrieval forgetting would not occur. Given that the instructions being made warned participants that some of the items to be generated would represent atypical exemplars of that category and hence could feel difficult and the fact that no participant said they had been giving up trying during debriefing, it is not the most satisfactory explanation.

Another explanation, yet not satisfactory either, could be that participants were trying so hard to generate an exemplar that would fit that they inhibited more than the items needed, causing forgetting for the control items in the presentation condition as well. This would mean that the retrieval induced forgetting effect would be invisible and hidden in the general forgetting. However, since generation induced forgetting actually was visible in the possible condition, this is not likely either.

Nor are explanations about other moderators that has been shown to reduce retrieval induced forgetting like stress (Koessler, Riether

Engler & Kissler, 2009) and negative affect (Bäuml & Kuhbandner, 2007) adequate. The experiment was indeed quite stressful, and some participants revealed in the debriefing that they thought the experiment was fast and difficult and some disclosed feeling frustrated, but even this effect is likely to have been visible if the possible condition, if this were the case.

More likely is it that participants were engaging in some condition specific activity during the impossible generation trials that prevented generation induced forgetting to occur. One possible explanation could be that participants were going through previously shown items in order to find an exemplar that would fit. Even though the instructions given explicitly declared that no items in the generation phase would fit the cues provided, when no better options were at hand it is possible that participants turned to the items they had just been presented for. If that were the case, the ERPs obtained during the impossible generation phase would not necessarily reflect a clean measure of inhibition, but attempted episodic retrieval. Beyond the limits of this paper, however, interesting analysis could be made in order to test this post hoc hypothesis. Electrophysiological correlates to episodic memory related to reconstruction of previous study episodes have been observed as a negative going slow wave visible in posterior regions. This is late posterior negativity is assumed to have two subcomponents, one wich is related to source retrieval and is visible when participants are remembering events related to the study episode. (Johansson & Mecklinger, 2003) If the assumption about participants engaging in episodic retrieval during the impossible generation phase were true, a more pronounced late posterior negativity might have been observed in the low forgetting participants as compared to the high forgetters.

When comparing the two possible and impossible conditions with respect to whether the words were high or low in competition, no significant results were found to support the assumption that the degree of competition is a moderator of GIF. Hence, hypothesis 1c did not gain support either which is conflicting with results from previous studies using the same words in similar generation conditions (Johansson et. Al., 2010). A

replication of the present study would therefore be desirable before discarding the significance of the competition assumption in relation to generation induced forgetting (*The generation induced forgetting effect will be more visible for items in the high competition condition than in the low competition condition.)*

Turning to the ERP data interesting findings were made, although not completely in line with the hypotheses postulated. Interactions were found between conditions and locations but these were more concentrated in posterior regions, rather than anterior, as postulated. In the late time window however, a significant interaction between task and location was found at left frontal electrode sites but a follow up analysis failed to show significant interactions between the different processing conditions why hypothesis 2 (*The ERPs from the semantic generation phase will be more positive going in amplitude at anterior sites a latency of 200-2500 ms as compared to the presentation ERPs. This effect will be more pronounced for high forgetters as compared to low forgetters.)* is not supported. Since no significant interaction was found between the different conditions with regards to whether participants were high or low forgetters there is no behavioral measure to contrast the ERP against.

General discussion

The most important finding from the present study suggest that, although inhibition is likely to be a major contributor to generation induced forgetting, it may not necessarily be the only one. Other aspects, as the reconstruction of previous study episodes are possible to contribute to the phenomena given the results in this study. If generation is too hard, or even impossible as was the case in our study, instead of turning to inhibition in order to facilitate retrieval, other memory functions may be recruited, as the search among previously studied items, in order to solve the problem of retrieving items. This may be an important aspect to consider when

conduction research in the field and designing experiments chosen to measure RIF and GIF.

As far as the world outside the lab and the filed of neuropsychology goes, the findings from the previous study may be applicable even there. When it comes to research on stereotypes where retrieval, if not yet generation, induced forgetting has been discovered to operate this might be an interesting finding. If you never encounter representatives of groups that you hold stereotypical believes about, you might be more inclined to think of the stereotype every time the group is mentioned, and by so doing rather strengthening your stereotypical believes than broaden your horizons. In the educational world the findings could be considered when developing surprise tests and practice exercises. If the generation of semantic information leads to forgetting of related items, this might not be beneficial in the long run. If, however, questions that are, or at least are perceived to be, impossible to answer are posed the detrimental effect on memory for related items might not be the same, although teaching methods of this kind probably would have other, mood and motivational related consequences.

Limitations of the present study

The aim of this study was to investigate the neural correlates of generation induced forgetting, comparing impossible and possible generation conditions to a baseline presentation condition. The logic behind using the impossible condition was, as mentioned earlier, that since no retrieval was possible, a correlate to the inhibition thought to operate during the retrieval phase would be obtained that would not be mixed up with successful retrieval.

However, not acquiring the hypothesized result with respect to the impossible condition, no conclusion of the kind can be drawn. Nor did we gain support to the previous findings that high frequency exemplars from a category are more susceptible to retrieval induced forgetting why the

generalisations that would be possible to draw from the findings in the previous study about neural correlates underlying generation induced forgetting are limited to conditions in which generation is possible, without respect to degree of competition amongst items.

Other limitations of the study are related to the material used in the experiment. Although the categories were chosen in order to minimize inter category-relation some categories could be thought to relate. The two most striking examples of this would be the relation between the categoris "Musikstil" (music genre) and "Dansstil" (Dance type) and between the categoires Hundras (Dog race) and Fyrbenta djur (four legged animals) were the former could be a subcategory of the latter. However using 30 categories that would still be possible for most participants to relate to in order to not make the experiment to hard inter relations were hard to minimize to zero, and the in order to downplay its effect, categories with similarities were assign different conditions in different blocks. The word stems used in the impossible condition were chosen not to represent any existing exemplar of the category it belonged to, still participants sometimes managed to generate correct answers why a replicator of the study would be wise to revise the material even further in order to exclude those cases. An example of this is the category-word pair "Yrke_Go" that was thought to be impossible, but where Golfintruktiör for example would fit in.

Even though pilot studies were made in order decrease the amount of fault of this kind, some cases were not discovered until at a later stage in the data collection which leads us to another limiter: time. The time limits of this present study lead to a limited amount of pilot studies and participants. If the sky was the limit with respect to time, more pilot studies would have been made in order to first investigate the behavioural results of the experiment, and more participants would have been tested using EEG recordings.

Inexperience on behalf of the experimenter also led to the loss of some participants data due to low quality recordings and technical difficulties that an veteran experimenter probably would have foreseen and

avoided. The final amount of participants however, is still corresponding to the amount of participants in similar studies.

Implications for further research

The findings from the present study need to be replicated further in order to investigate both the behavioural parts of generation induced forgetting and the underlying neuropsychological mechanisms.

In order to further investigate under which conditions impossible retrieval conditions actually leads to forgetting, and when it does not it would be interesting to execute a modified version of the present study. One possible change could be to prolong the time limits for semantic generation. If, as discussed above, participants during the semantic generation went through previously studied items in order to find a suiting exemplar according to the cue provided, and the time frame window given was too small to both go through previously studied items and inhibit the irrelevant ones, then we would no longer be obtaining ERPs for inhibition, but for episodic retrieval. If the generation phase were prolonged however, then maybe inhibition of the previously studied items would come about. An alternative to prolonging the generation phase could be to use several semantic generation phases on the same material in order to increase the probability for competing items to be inhibited. Further changes could be made in the material considering the findings that whether words were high or low in typicality did not seem to effect the amount of generation induced forgetting they suffered. Given this, only items high(er) in typicality could be used in order to make life easier for participants.

Once having modified the behavioural material used to investigate the nature of generation induced forgetting, it would be interesting to further investigate the electrophysiological and neurological mechanisms underlying GIF. Although EEG methods are very good to capture temporal aspects of neurophysiologic correlates to GIF, other methods would be better at capturing the spatial nature of it. Using fMRI however would be more suiting and very interesting in order to investigate

what regions in the brain are active during semantic generation, but also during the subsequent memory test. Investigating this further, a regression analysis could be preformed in order to investigate if activity in any of the regions active during generation could predict the amount of forgetting in the succeeding test.

With regards to the inhibitory account of retrieval induced forgetting, it would be interesting to investigate further complementary aspects could be added. Inhibition is probably still a very important moderator of RIF and GIF, but perhaps other, equally important mechanisms are operating to help moderate the two and more studies investigating the impact simultaneously operation mechanisms could help uncover interesting findings in this area.

The time frames given to this particular paper were not sufficient to fully explore all possible relations to be found in the collected data, but given more time several connections would be interesting to explore: investigating low forgetters in the impossible generation conditions in relation to previous findings on episodic retrieval to see if a relationship there might explain why their memory performance did not suffer to the same extent as the high forgetters. A follow up analysis to test the post hoc hypothesis that Late Posterior Negativity (LPN) was predictive of the amount of retrieval induced forgetting would also be interesting to do. If, as suggested, LPN relates to source retrieval and the reconstruction of previous study episodes, then LPN of greater amplitude would perhaps be more visible at low forgetters, that were thought to rehearse previously studied items, as opposed to high forgetters, who maybe were more prone to engage in inhibition. Maybe it is two different strategies?

Maybe, and perhaps more likely, several different mechanisms contribute to the act of forgetting and interact to constitute the adaptive phenomena that is human memory. This study has made a small contribution to the quest for answers on how our memory system works, but a lot more work needs to be done before this riddle has got a certain answer.

Acknowledgments

I would like to thank my supervisor Mikael Johansson for giving me the opportunity to take part in this project, and for contributing with valuable ideas, knowledge and dedication. Without his inspiration I would probably not have ended up in this field and I am very thankful for everything I have learned thus far and I am hoping to learn even more from him in the future. I would also like to thank Robin Hellerstedt for patiently teaching me the methods used in this study and for offering great support and help with the analysis. I also owe gratitude to Emelie Stiernströmer for help and support during the data collection as I do to Gerd Waldhauser for letting me practice with Easycap in his lab and to William Meere for his thoughtful comments on the early version of the manuscript. Last but not leas all the participants deserves a great thank you for your precious time and devotion!

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