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Electrophysiological correlates of generation-induced-forgetting

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Abstract

The aim of the present study was to examine the electrophysiological correlates of semantic generation, to study how repeated semantic generation, repeated study and repeated test opportunities affect memory performance and to create a non-verbal Stroop task. Earlier research has showed that cued semantic generation, also referred to as word generation, can cause forgetting of other memories associated to the same cue as the generated words. Cognitive inhibition has been assumed to be the underlying neural mechanism, which causes this generation-induced-forgetting effect. The present study was the first study to examine the neural correlates of generation-induced-forgetting. Twenty four participants, with a mean age of 25, were included in the study. The memory experiment was computerized and the participant's electroencephalogram (EEG) was measured continuously from 40 scalp electrodes during the experiment. The results from behavioural data showed that the expected generation-induced-forgetting effect was evident in all tests and that the newly constructed Stroop task worked. The event-related-potential (ERP) analysis surprisingly revealed that generation-induced-forgetting and retrieval-induced-forgetting are predicted by non-overlapping patterns of brain activity. The pattern of ERPs predicting generation-induced-forgetting suggests that the phenomenon is caused by cue-overload and cognitive inhibition.

Key words: generation-induced-forgetting; GIF; retrieval-induced-forgetting; RIF; Event-related-potentials; ERP; cue-overload; cognitive inhibition; retrieval inhibition; Stroop task

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Introduction

The capacity of the human memory is probably one of the fundamental cognitive abilities that separate the human from other animals and our outstanding ability to remember is certainly one of the reasons why we have gained a superior position over other animals. Our memory makes it possible for us to speak several different languages, to learn to produce and to use tools, to learn a lot of facts about a topic, to reflect upon who we are, to learn to play a musical instrument, to remember feelings respectively sensations from important emotional life events and to find our way back home. Even though our memory is incredibly complex and constantly filled with new impressions, experiences from events and facts about our environment, we rarely reflect upon or notice our memory. The moments when we pay most attention to our memory are paradoxically when we get frustrated by its limitations. Most of us have for example experienced the uneasy feeling of suddenly being unable to recall the code to our credit card, been ashamed of the inability to recall the name of a very famous author in a quiz or searched every inch of our home for something we forgot that we had put in our pocket.

Given how frustrating forgetting can be, it is tempting to wish for an ability to remember everything. Would not it be wonderful to remember everything you have ever learned? Imagine how it would be to remember every sensation you have ever had, every line you have ever read, every feeling you have ever had, every conversation you have ever been part of etcetera. All memories and experiences are not positive however and a huge disadvantage of being unable to forget would be that unpleasant memories would be recalled every time you were presented for an associated cue. Another problem you would encounter if you were able to remember every moment of your life would be to sort out relevant memories from the enormous amount of interfering irrelevant memories in a given situation. If you for example try to remember where you parked your car this particular morning, remembering where you parked it yesterday, a month ago or any other time will not help you. It is likely that the older irrelevant memories interfere with the context relevant memory and make it very effortful and difficult to access the relevant memory. Thus, forgetting can facilitate the retrieval of more relevant memories in a given context and protect us from unpleasant memories. Earlier research has shown that people tend to forget information that is related to memories they are actively trying to retrieve (Anderson, Bjork & Bjork, 1994). This forgetting phenomenon is referred to as retrieval-induced-forgetting and the majority of the evidence from the research field of cognitive neuroscience of memory suggest that the mechanism behind this type of forgetting is a form of cognitive control, called inhibition (Andersson, 2003). When we try to retrieve a memory with the help of a cue all memories which are associated to the same cue will be activated. Neurons in the frontal lobe of the brain inhibit the irrelevant memories to facilitate the retrieval of the relevant memory (for example to facilitate the retrieval of memories related to where you have parked your car this morning). As a consequence of being inhibited the irrelevant memories will be hard to retrieve if they suddenly become relevant. You could for example be unable to recall where you parked your car yesterday if someone asked you, shortly after you were trying to recall where you parked it today. Earlier research has shown that trying to generate a word matching a cue impairs recall for words associated with that cue in the same way as retrieval practice of previously studied words does (Bäuml, 2002; Storm, Bjork & Bjork, 2008). The fact that retrieval practice and semantic generation have similar effects on memory performance has led researchers to assume that retrieval-induced-forgetting and generation-induced-forgetting are two sides of the same coin. The neural processes underlying the generation-induced-forgetting effect have however never been examined, so it is possible that retrieval-induced-forgetting and generation-induced-forgetting are caused by two distinct neural mechanisms. The present study examined the electrophysiological correlates of semantic generation and the effects of repeated semantic generation, relearning and cued recall test on later memory performance. To the best of my knowledge, this is the first neuroimaging study to examine the neural correlates of generation-induced-forgetting.

Before the present study is described in detail, a theoretical background, which provides the theoretical foundation of the present study, will be presented. The first part gives the reader information about previous studies of retrieval-induced-forgetting. Different properties of the memory impairment are provided together with demonstrations of the generality of retrieval-induced-forgetting. Since the present study examines the neural correlates of generation-induced-forgetting and eventual similarities or dissimilarities to retrieval-induced-forgetting, the following section will focus on previous event-related-potential (ERP) and functional magnetic resonance imaging (fMRI) studies of retrieval-induced-forgetting, which the findings in the present study will be interpreted in relation to. The focus then turns to the forgetting phenomenon studied in the present study: namely generation-induced-forgetting. Next, the theoretical background of the digit Stroop task, which was used as a distracter task in the present study, is introduced. This section is followed by a brief introduction to the event-related-potential (ERP) technique before the aims and hypotheses of the present study are presented.

Retrieval-induced-forgetting

The retrieval practice paradigm

The original retrieval practice paradigm was introduced by Anderson, Bjork and Bjork (1994) and consists of a learning phase, a retrieval practice phase and a memory test phase. In the learning phase participants study category-exemplar word pairs (e.g., fruit-apple, fruit-mango) from several categories (for example fruits, cities, birds). All members of one category share the same cue (e.g. fruit) and are therefore thought to compete for conscious retrieval during retrieval practice when the category is presented as cue. Competition arising during retrieval is called retrieval competition in the literature (Anderson et al. 1994).

Half of the exemplars from half of the categories are practiced in the retrieval practice phase with help from a cue consisting of the category name plus the initial two letters of the exemplar (e.g., fruit-ma____). The division of the material creates two conditions: one practice condition and one control condition. The practiced exemplars in the practice condition are referred to as Rp+ items and items in the practice condition which are members of the same categories as the Rp+ items, but do not receive retrieval practice are referred to as Rp- items. The items in the control condition are referred to as Nrp items.

In the final test phase the participants are instructed to recall all the studied exemplars from the learning phase with the category names as cues. The typical finding is that retrieval practice of Rp+ items leads to improved memory performance for these items compared to both Rp- and Nrp items. This phenomenon are often referred to as the testing effect and it shows that testing leads to improved memory for the tested items independent of if feedback about the correctness of the answers during the tests is provided (Roediger & Karpicke, 2006). A much more surprising finding however is that memory for Rp- items are impaired compared to memory for Nrp items during the memory test. This effect is referred to as retrieval-induced-forgetting (Anderson, Bjork & Bjork, 1994).

Properties

Cue-independence

There is a tendency for the retrieval-induced-forgetting effect to generalize to novel test cues not included in the retrieval practice events that caused the impairment (Anderson & Spellman, 1995). This tendency is commonly referred to as cue-independence. An example of cue-independence is that learning of the word pair food - tomato and retrieval practice of the same word pair (food - to____) leads to forgetting of the word tomato even if the cue is changed from food to red (red - t_____) during the test. Cue-independency in retrieval-induced-forgetting have been shown in several studies with varying materials (Anderson & Bell, 2001; Anderson & Spellman, 1995).

Interference dependence and retrieval specificit

Evidence has been provided that retrieval practice causes retrieval-induced-forgetting whereas extra study exposures do not and this property of retrieval-induced-forgetting is referred to as retrieval specificity (Anderson & Bell, 2001; Ciranni & Shimamura, 1999; Johansson, Aslan, Bäuml, Gäbel, & Mecklinger, 2007). Importantly retrieval is necessary but not sufficient for retrieval-induced-forgetting to occur. Anderson, Bjork and Bjork (1994) concluded that the typicality of the non-practiced Rp- items, which compete with the Rp+ items for conscious retrieval during the retrieval practice phase, is crucial for the effect. The more strongly associated the Rp- item was to the cue the greater the memory impairment for that particular item was. Atypical exemplars of categories (for example fruit – pomegranate) were almost unaffected by retrieval practice when they were used as Rp- items. Consequently retrieval competition which is often also is referred to as interference, is necessary for retrieval-induced-forgetting to occur.

Retrieval success independence

Given that retrieval is essential for retrieval-induced-forgetting it is a bit surprising that retrieval success is not necessary for the effect to occur (Storm, Bjork, Bjork & Nestojko 2006). The evidence from the study by Storm et al. (2006) suggests that the act of trying to retrieve items associated to the same cue as the studied items leads to retrieval-induced-forgetting regardless of if the retrieval attempt is successful or not. Storm et al. (2006) used some possible and some impossible cues, which did not fit any word in the category at all, in the retrieval practice phase of their experiment. The results showed that retrieval-induced-forgetting occurred despite the unsuccessful retrieval.

Strength independence

The strength independence property of retrieval-induced-forgetting refer to the finding that the memory impairment of unpractised Rp- items is independent of the strength of the practised Rp+ items (Anderson, 2003). An example of strength independece is that extra study exposures of exemplars from a category do not lead to retrieval-induced-forgetting of other exemplars belonging to the same category (Anderson & Bell, 2001; Ciranni & Shimamura, 1999; Johansson, Aslan, Bäuml, Gäbel, & Mecklinger, 2007).

Number of retrieval practice attempts dependent or independent?

The retrieval practice phase was repeated three times and each item was practiced one time in each retrieval practice phase in the present study. Macrae and MacLeod (1999) showed that the amount of retrieval-induced-forgetting does not increase with the number of retrieval attempts during retrieval practice. They found no statistically significant differences in the amount of retrieval-induced-forgetting between groups who attempted to retrieve each item one, three or six times during the retrieval practice phase of their experiment. A rather surprising finding in the light of the Macrae and MacLeod study is Storm, Bjork and Bjork's finding that retrieval-induced-forgetting of Rp- items correlates positively with the number of retrieval practice phases (Storm, Bjork & Bjork, 2008). The participants in this study performed one, two or three retrieval practice phases during the experiment (with one retrieval practice attempt for each item in every retrieval practice phase) and the results showed that the more times the participants performed retrieval practice the more their memory of related material was impaired by retrieval-induced-forgetting. A big difference between these two studies is that all retrieval practice attempts were done in the same retrieval practice phase in the McRae and MacLeod (1999) study whereas Storm et al. (2008) distributed the retrieval practice attempts over three phases with one attempt in each phase. Another important difference between the designs in these studies was that Storm et al. (2008)

gave their participants two opportunities to relearn the Rp- items between the three retrieval practice phases in their study. The differences in design makes it hard to compare these two studies and more research on number of retrieval practice attempts consequences for retrieval-induced-forgetting is needed before any conclusions can be reached.

Time boundaries

Is the retrieval-induced-forgetting effect a time limited memory impairment or a permanent memory loss? This question was examined in a study by MacLeod and McRae (2001). In this study participants were either tested five minutes or 24 hours after the retrieval practice phase. The retrieval-induced-forgetting effect was detected in the five minutes condition, but not in the 24 hours condition. So the retrieval-induced-forgetting effect diminishes over time and is therefore a time limited memory impairment. This finding is reasonable, since it would be very strange if retrieval of memories led to permanent loss of associated memories. A question which follows the conclusion that retrieval-induced-forgetting is time limited is: how long does the effect last? The answer to this question is still unknown and therefore needs to be studied further in the future. Anderson, Bjork and Bjork (1994) provided evidence that the effect remains after a 20 minutes delay between retrieval practice and test, so it is probably endurable enough to affect our memory in daily life outside the laboratory. Another interesting finding in MacLeod and McRae’s (2001) study is that a 24 hours delay between retrieval practice and test affects the strength of the retrieval-induced-forgetting effect whereas a 24 hours delay between the learning phase and the retrieval practice phase does not. This finding suggests that the duration of the effect is dependent on the delay between retrieval practice and test. In real life situations retrieval practice may occur repeatedly over time and it is therefore plausible to assume that repeated retrieval-induced-forgetting can affect the same material for longer time periods than 24 hours (Anderson, 2003). When you try to learn a new code for your credit card for example the old code will interfere strongly each time you try to recall the new code. After you have used the new card a couple of times the old code will stop to interfere and you can easily recall the new code, but would suddenly have problem to remember the old code since the retrieval practice of the new code leads to retrieval-induced-forgetting of the old code. Storm, Bjork and Bjork (2008) studied the effect of repeated retrieval practice and repeated relearning. The results from this study shows that repeated retrieval practice leads to increased retrieval-induced-forgetting for Rp- items compared to Nrp items. Another interesting finding in this study is that Rp- items seem to benefit more from relearning than Nrp items.

Generality

Evidence from the field of retrieval-induced-forgetting has shown that the effect generalizes to numerous materials, contexts and tasks. This is of course of great importance, since it suggests that it is possible to generalize the conclusions from laboratory studies like the present study to other contexts and materials. This section will therefore provide examples of the generality of retrieval-induced-forgetting.

Retrieval-induced-forgetting is not restricted to verbal material. Ciranni and Shimamura (1999) showed that retrieval-induced-forgetting can occur for visuo-spatial material. They let their participants learn the location of coloured objects. Retrieving the location of an item with a particular shape caused forgetting of the location and colour for other items with the same shape, but not for items with other shapes. In different variations of the experiment they induced retrieval-induced-forgetting in their participants for colour, shape and location. Anderson and Bell (2001) showed that retrieving facts about a topic causes forgetting for other facts of that topic. It is easy to relate this finding to preparations before examinations in school. Most of us have probably experienced that retrieval practice of hard to remember facts of a topic can lead to surprising forgetting of easy to remember facts on the day of an important examination. Another school related interesting example of the generality of retrieval-induced-forgetting is the finding that naming objects in a newly acquired second language leads to impaired accessibility of the phonology of the objects name in the subjects' native language (Levy, McVeigh, Marful, & Anderson, 2007).

Several studies have provided evidence that retrieval-induced-forgetting can impair memory in eye-witness contexts (for example MacLeod, 2002, Migueles & García-Bajos, 2007). MacLeod and Saunders (2008) have suggested a link between misinformation effects in eye-witness memory and retrieval-induced-forgetting. The misinformation effect is operating when an eye-witness to a crime scene gets misinformation about the crime scene afterwards and is unable to distinguish between memories of the misinformation and memories of what he or she really saw. Saunders and MacLeod (2002) showed that participants were more likely to falsely remember misinformation about an event as true on a test when they had practised retrieval of other aspects of the event before the test. The studies of eye-witness memory and retrieval-induced-forgetting shows that retrieval-induced-forgetting can impair our memory for other people's actions and characteristics. Evidence provided by Koustaal, Schacter, Johnson and Gallucio (1999) shows that retrieval-induced-forgetting not only can distort memory for other peoples actions, but also memory for our own actions. They found that memory for novel actions are impaired if some of the actions are retrieved from memory before test. The subjects in the study by Koustaal et al. first performed the novel actions (for example trace the outline of this boomerang or remove tissue from this box) and then came back to the laboratory two days later and watched photographs of other people performing some of the actions and tried to recall which actions the photographs illustrated. A control group performed the same novel actions, but copied line drawings instead of practicing recall of the actions with help from photographs. Finally the participants were given a free-recall task and memory was impaired for the experimental group for novel actions which they hadn't practiced compared the control group's memory for the same actions.

Retrieval-induced-forgetting has also been shown to impair memory in social psychological studies. An example of retrival induced forgetting in a social psychological context comes from McRae and MacLeods (1999) study. The participants in this study learned personality traits of two fictitious characters named John and Bill. In the second phase of the study they practiced retrieval of half of the traits of one of the characters and in the last phase of the study they received a cued recall test of all the traits of both characters. The results showed that retrieval practice of half of one characters traits (for example John) caused memory impairment for the unpractised traits (Rp- items) of the same character compared to memory of the control character's (for example Bill) traits. Additional evidence for retrieval-induced-forgetting's relevance in the understanding of social psychological phenomena comes from Dunn and Spellman (2003). They showed that retrieval of individuating traits of a person leads to retrieval-induced-forgetting for stereotypic traits of the same person. The retrieval-induced-forgetting effect in this study was moderated of the participants' belief in the stereotypical traits. Participants who believed in the stereotypical traits were less likely to forget the stereotypical traits compared to participants who did not believe in the stereotypical traits. The amount of belief in the stereotypical traits was measured with questionnaires.

Theoretical models

Different theoretical models have been developed to explain the detrimental effects of cuing and retrieval in general and retrieval-induced-forgetting in particular. The standard explanation of detrimental effects of retrieval has for a long time been the retrieval blocking theory (Anderson, 2003). According to Bäuml (2007), the retrieval blocking theory assumes that both re-exposure and retrieval of items strengthen items' memory representations. When trying to remember the non-strengthened items people, unintentionally sample the strengthened items repeatedly, which blocks the access to the non-strengthened items. Anderson, Bjork and Bjork (1994) identified three core assumptions of the retrieval blocking theory models. The three assumptions are: the competition assumption, the strength dependence assumption and the retrieval based learning assumption. The competition assumption implies that memories associated to the same cue compete for conscious recall when that cue is presented and the strength dependence assumption asserts that the cued recall of an item decreases in proportion to the increases in the strengths of the competitors' associations to the cue. Finally, the retrieval based learning assumption poses that retrieval of an item leads to subsequent improved recall of that item. Blocking models of retrieval-induced-forgetting has been challenged in the light of the empirical findings mentioned in the properties section above.

The strength independence and retrieval success independence of retrieval-induced-forgetting is for example incompatible with the strength dependence assumption. Extra presentations of a subset of items does not impair memory for associated items (Johansson et al., 2007) and blocking models cannot explain the finding that the typicality of Rp- items rather than Rp+ items influences the magnitude of the effect (Anderson et al., 1994). Moreover, blocking theories of retrieval-induced-forgetting also have hard to explain the cue-independence of the effect (Anderson & Spellman, 1995; Anderson & Bell, 2001). A final example of the inconsistency between research findings and the retrieval blocking model is that the blocking model predicts that retrieval-induced-forgetting should be restricted to tasks in which retrieval competition between items is high and many items share a common cue and cannot therefore explain how retrieval-induced-forgetting can occur in tasks where item-specific probes are presented as retrieval cues. The incompatibility between empirical findings and the retrieval blocking theory have led to the development of a new theoretical model: namely the inhibitory control account.

According to the inhibitory control account, retrieval of context relevant memories is facilitated if competing irrelevant memories are inhibited. The inhibition of the context irrelevant memories can cause time limited memory impairment for these memories if the context changes and they suddenly become relevant. There are at least two possible explanations of how inhibition can cause retrieval-induced-forgetting. The inhibitory processes either deactivate the route between the forgotten Rp- item and the cue or directly suppress the Rp- item's memory representation (Bäuml, 2007). Inhibition is thought of as a cognitive control mechanism that solves interference between memories competing for recall, analogous to how inhibition of movements helps us to control our bodies and protects us from possibly harmful movements in a given context. Properties of retrieval-induced-forgetting, like strength independence, cue-independence and interference dependence are in accordance with the inhibitory control account, whereas they are in conflict with a retrieval blocking explanation of the phenomenon (Anderson, 2003). It should be noted that the debate of the cause of retrieval-induced-forgetting is far from over and that some researchers remain sceptical to the inhibitory control account (Butler, Williams, Maki & Zacks, 2001; Perfect et al., 2004). Both Butler et al. (2001) and Perfect et al. (2004) question the cue-independence of the retrieval-induced-forgetting effect and Butler et al. (2001) provides examples of experiments with item specific cues in which retrieval-induced-forgetting fails to occur whereas Perfect et al. (2004) report results from experiments in which the impairment fails to occur when the cues are exchanged between the retrieval practice phase and the test phase.

Neural correlates of retrieval practice, retrieval inhibition and retrieval-induced-forgetting

During the retrieval practice phase

The findings described in this section are relevant for the present study, since the event-related-potential-correlates of semantic generation, examined in the present study, were related to the ERP-correlates of retrieval practice, found in previous studies, to examine to what extent the neural correlates of generation-induced-forgetting overlap the neural correlates of retrieval-induced-forgetting.

Johansson, Aslan, Bäuml, Gäbel and Mecklinger (2007) compared brain activity measured with ERP between retrieval practice and a baseline condition, involving extra study exposures. Differences between the retrieval practice ERPs and the relearning ERPs were thought to reveal neural correlates of inhibition since inhibition should only be present in the retrieval practice condition, given the retrieval dependence and interference dependence properties of retrieval-induced-forgetting. The primary difference between the two conditions, found in the results, was that the retrieval practice ERPs were more positive going than the relearning ERPs over anterior electrode sites. This effect started to be evident approximately 200 milliseconds after stimulus onset and lasted until the end of the recording epoch (2000 milliseconds). Johansson et al. (2007) divided their sample into two groups based on the amount of retrieval-induced-forgetting shown by the participants and hence created one group of participants with high amounts of retrieval-induced-forgetting and one group with low amounts of retrieval-induced-forgetting. An analysis of the difference between the low- and high-forgetting groups ERPs during the retrieval practice phase showed that the difference at frontal electrode sites between retrieval practice and relearning was bigger in the high forgetting group than in the low forgetting group. A regression analysis revealed that the positive going difference between high- and low- forgetters at frontal electrode sites during retrieval practice predicted individual differences in retrieval-induced-forgetting during the subsequent memory test. The same analysis also showed that the activity predicting retrieval-induced-forgetting in the final recall test was restricted to bilateral anterior electrode sites.

Functional magnetic resonance imaging (fMRI) is a well suited method for investigating where in the brain activity linked to different cognitive phenomena takes place because of it is high spatial resolution (Banich, 2004). Kuhl, Dudukovic, Kahn and Wagner (2007) studied the neural correlates of inhibition during retrieval practice with fMRI. Each Rp+ item were practiced three times in the retrieval practice phase, in this study, and they predicted that prefrontal cortex regions should be more activated in first retrieval practice trials compared to third retrieval practice trials. The logic behind this prediction is that prefrontal regions are hypothesized to detect and resolve competition and competition should be highest in the first retrieval practice attempt before Rp- items have been inhibited and Rp+ items have been strengthened. The results in the Kuhl et al. (2007) study revealed that reduced activity in the anterior cingulated cortex (ACC) and the right anterior ventro-lateral prefrontal cortex (VLPFC) across the three retrieval practice attempts was associated with retrieval-induced-forgetting. The finding that retrieval-induced-forgetting leads to decreased activation in the ACC and the right anterior VLPFC was seen as evidence for neural processing benefits of retrieval-induced-forgetting because it suggest that the forgetting is accompanied by decreased demands on cognitive control. Earlier research has suggested that the ACC are related to competition detection (Bush, Luu & Posner, 2000). The results of the Kuhl et al. (2007) study supports this hypothesis of the role of the ACC because ACC activation was greatest under conditions with high degrees of competition. Activation in the right dorsolateral prefrontal cortex (DLPFC) was related to both the activity in the ACC and the strengthening of Rp+ items. In sum, the results from this important study suggests that the ACC detects competition whereas the right DLPFC strengthens the Rp+ items and the right anterior VLPFC either selects the relevant memory representation among the competing candidates in a top-down manner or directly inhibits the competing Rp- items. Another fMRI study has recently replicated the finding that subregions in the prefrontal cortex are associated with retrieval-induced-forgetting (Wimber, Rutschmann, Greenlee & Bäuml, 2009). The memory impairment were however associated with the left DLPFC and the ACC in that study. Additionally to the difference in lateralisation of the DLPFC activity associated with the ACC the results from the Wimber et al. (2009) study also differs from the findings in the Kuhl et al. (2007) study in that no evidence was provided for retrieval practice related left VLPFC activation. The different subdivisions of the prefrontal cortex roles in cognitive inhibition and their interactions with medial temporal lobe regions needs to be further investigated in the future.

During the test phase

This section is less important for the hypothesis of the present study, because it was not possible to analyse the ERPs during the test phase within the time limits of the present master's thesis. Nevertheless, neural correlates of retrieval-induced-forgetting during retrieval in the test phase provides a deeper understanding of the cognitive inhibition causing retrieval-induced-forgetting and are therefore included anyway.

Wimber et al. (2008) studied retrieval of Rp- and Rp+ items during the recall test in the retrieval practice paradigm. The main finding in this study was that activity in distinct brain areas correlated with retrieval-induced-forgetting of the Rp- items and retrieval facilitation of the Rp+ items. More specifically, final recall of Rp- items was associated with more activation in two left VLPFC areas (Brodmann area (BA) 45 and 47) and with less activation in medial, lateral and parietal areas compared to retrieval of Rp+ items. Activity in the anterior left VLPFC (BA 47) and in posterior lateral temporal cortex was predictive of the degree to which participants was impaired by retrieval-induced-forgetting whereas activity in the right medial and lateral parietal cortex was predictive of retrieval induced enhancement.

Badre and Wagner (2007) reviewed evidence from fMRI studies of the function of the left VLPFC and found support for a double dissociation between left anterior VLPFC (BA 47) and left mid-VLPFC. They suggest a two process model of the left VLPFC in which left anterior VLPFC supports controlled retrieval of stored semantic representations in the lateral temporal cortex in a top-down manner whereas the mid-VLPFC is active during post retrieval selection when multiple memory representations compete for conscious retrieval. Both left anterior VLPFC and mid-VLPFC are more active when participants retrieve Rp- items than when they retrieve Rp+ items at test, but only the anterior VLPFC could predict the degree of retrieval-induced-forgetting in participants (Wimber et al. 2008). The finding that the left anterior VLPFC predicts the degree of retrieval-induced-forgetting provides evidence for the inhibitory account of retrieval-induced-forgetting, given that the two-process model of the left VLPFC are correct, since this account predicts that recall of inhibited Rp- items requires more controlled retrieval than Rp+ items because they are weakened. Blocking theories would in contrast predict that more competition resolution is needed during recall of Rp- and these models have a hard time explaining the finding that left anterior VLPFC activity predicts the degree of retrieval-induced-forgetting.

Further evidence for the hypothesis that different neural mechanisms mediates the beneficial and detrimental effects of retrieval practice are provided in a recent ERP-study by Spitzer, Hanslmayr, Opitz, Mecklinger and Bäuml (in press). Effects of retrieval practice were measured during a recognition test in a somewhat altered version of the retrieval practice paradigm in this study. The results showed that recognition of Rp- items was associated with reduced amplitudes of the P2 ERP component compared to recognition of Rp+ items. Frontal old/new effects in the P2 time window have been hypothesized to be related to modality specific implicit priming and the reduction in the P2 wave might reflect a reduction in the material’s memory representations caused by inhibition. Recognition of Rp+ items was associated with a stronger late parietal positive (LPP) component. Earlier research has linked the LPP to recollection (Rugg & Curran, 2007). Recollection is considered a deeper form of recognition memory, leading to the retrieval of episodic contextual details in addition to the more shallow feeling of familiarity. The stronger LPP in practiced material, compared to control Nrp items (items which do not receive retrieval practice and are not associated to categories which received retrieval practice), might thus imply a form of episodic strengthening of the Rp+ items. Importantly recognition of RP+ items compared to Nrp items was not associated with an increase in P2 amplitudes and the recognition of Rp- items compared to Nrp items was not associated with a reduced LPP. The detrimental and the beneficial effects of retrieval practice were thus qualitatively dissociable and probably moderated by two separate processes (Spitzer et al. in press).

Is retrieval-induced-forgetting absent in groups with underdeveloped or damaged PFC?

The growing evidence of the relationship between the PFC and retrieval-induced-forgetting described above has led researchers to examine whether intact PFC functioning is necessary for retrieval-induced-forgetting to occur. Evidence from a study with frontal lobe lesion patients suggests that it is not (Conway & Fthenaki, 2003). Conway & Fthenaki (2003) showed that patients with unilateral frontal lobe lesions show normal amounts of retrieval-induced-forgetting relative to, age and years in education, matched controls. It is however worth to note that Conway & Fthenaki did not control for output interference, so it is possible that the observed forgetting effect was caused by output interference rather than retrieval-induced-forgetting. Other populations which have been hypothesized to show reduced retrieval-induced-forgetting are children and older adults. Earlier research has suggested that children and older adults have a general deficit in inhibition (Bjorklund & Harnishfeger, 1990; Hasher, Stoltzfus, Zacks & Rypma, 1991). A general inhibition deficit would probably also affect memory functions and could partly explain the reduced memory performance of children and older adults (Bäuml, 2007). The inhibitory model of retrieval-induced-forgetting and the general deficit hypothesis would predict that children and older adults should be less impaired by retrieval-induced-forgetting than young and middle aged adults. Research results from studies of retrieval-induced-forgetting in different age groups has surprisingly shown that retrieval-induced-forgetting is intact for most part of the lifespan (Aslan, Bäuml, & Pastötter, 2007; Zellner & Bäuml, 2005). Aslan et al. (2007) showed that retrieval-induced-forgetting is intact in 60 to 79 years old adults and Zellner and Bäuml (2005) provided evidence that the memory is equally impaired by retrieval-induced-forgetting in children (first, second and fourth graders) as in young adults. The results from these studies can be seen as evidence for that at least some forms of cognitive inhibition is intact throughout most part of the lifespan, which indicates that the general inhibition deficit hypothesis is partly wrong and needs to more specified.

Generation-induced-forgetting

Bäuml (2002) substituted the intermediate retrieval practice phase in the classical retrieval practice paradigm for a semantic generation phase. Semantic memory refers to knowledge of word meanings, objects, facts and people without connection to any particular time or place (see Patterson, Nestor & Rogers, 2007 for review) and semantic generation in the present study refers to generation of words, which has not been studied during the learning phase and thus need to be retrieved from semantic memory. Bäuml's (2002) study was the first study using the retrieval practice paradigm, which exchanged the retrieval practice phase for a semantic generation phase. In the semantic generation phase, the participants were instructed to generate words with help of two letter word stem cues. An interesting finding in Bäuml's study is that retrieval-induced-forgetting can occur even if the retrieved and non-retrieved items belongs to different experimental episodes and tasks. This finding has been replicated in other studies (Storm, Bjork, Bjork & Nestojko, 2006; Storm, Bjork & Bjork 2008). The effect of semantic generation on memory performance resembles the memory impairment caused by retrieval-induced-forgetting in behavioural data and this resemblance has led researchers using the semantic generation phase in their designs to believe that the same mechanisms (cognitive inhibition controlled by subdivisions in the frontal lobes) cause generation-induced-forgetting and retrieval-induced-forgetting (Bäuml, 2002; Storm et al. 2006, Storm et al. 2006). The neural mechanisms of generation-induced-forgetting has however never been examined and it is possible that semantic generation is not caused by inhibition.

Neural correlates of semantic memory retrieval

Since semantic generation involves semantic memory retrieval this section will provide a short overview of what is currently known about the neural correlates of semantic memory retrieval. The content of the semantic memory is thought to consist of a network of perception and action related information distributed in different sensation and action related areas of the cortex (Patterson, Nestor & Rogers, 2007). Evidence from lesion studies and studies of semantic dementia suggests that the left anterior temporal lobe is essential for semantic memory retrieval (Damasio et al., 2004; Patterson et al., 2007) and Patterson et al. (2007) claim that this part of the left temporal lobe serves as a hub through which other parts of the cortical network of semantic memory communicates during encoding and retrieval of semantic memories. A relevant finding for the present ERP-study is that semantic generation of verbal material has been associated with more positive going ERPs over frontal and temporal regions in the left hemisphere compared to control conditions (Rowan et al., 2004). An area in the left prefrontal cortex has been shown to be important in semantic retrieval in addition to the temporal cortex (Badre & Wagner, 2007). More specifically, the left anterior VLPFC has been associated with cognitive control of semantic memory retrieval.

The digit Stroop task

The present study contained a Stroop task which served as a distracter task between the last semantic generation and the cued recall test in each block. The original Stroop task was introduced by J.R. Stroop in 1935 (Bush et al., 1998). In this task words such as red, green, yellow and blue are written in matching or mismatching colours of ink. The word red can for example be written in red, (congruent trial) or blue ink (incongruent trial). Participants in a Stroop task are instructed to name the colour of the ink in which the words are written in. This is of course an easy task on congruent trials, but it is far more difficult on incongruent trials since the participant needs to ignore the semantic content of the word and this causes large amounts of interference because the word meaning is automatically activated in memory whenever a word is read. Bush et al. (1998) created an fMRI version of the Stroop task based on numbers. Methodological constraints makes it impossible to have verbal responses in fMRI and Bush et al. (1998) thought that it would be too time consuming to let participants learn the mapping of colour and buttons if they used manual responses. Therefore they used numbers written in words (for example one one). The number of words presented on the screen varied between one and four and the participants were instructed to report the number of words shown on the screen via a button press and ignore the semantic meaning of the words. A congruent trial in this experiment could for example be: *two two* or *three three three*, whereas *three three* is an example of an incongruent trial in the same experiment.

In the present study a similar task were constructed since it is desirable to avoid oral responses when measuring reaction times and EEG at the same time because the muscular activity in the face during a oral response creates excessive artefacts in the EEG, which makes it impossible to measure the underlying ERPs. It would however be problematic to use the counting Stroop task by Bush et al. (1998) in the present experiment because verbal material were used in the other parts of the experiment and participating in a Stroop task with verbal material before the memory test could possibly cause undesirable side effects on the to be remembered material. Therefore a new version of the counting Stroop, called digit Stroop, was created. The digit Stroop differs from the counting Stroop in that the numbers are written in digits instead of words. Earlier research has shown that the Stroop task becomes harder when the majority of the trials are congruent (Engle, 2002). Engle found that the Stroop task discriminates the most between participants with high and low working memory spans if 75 percent of the trials are congruent. The participants in the present study were healthy young adults and therefore a hard version of the Stroop task with a large proportion of congruent trials was used in the digit Stroop task in the present study to enhance the probability of getting widely distributed performance scores. In the present study squares (for example # #), digits which corresponded to the number of digits on the screen and digits which did not correspond to the number of signs on the screen were used as stimulus material. The squares are neutral trials because they do not contain any useful semantic meaning for this task. Trials with digits corresponding to the number of signs on the screen are congruent trials since the semantic meaning of the digits facilitates the task and the trials with digits which do not correspond to the number of signs on the screen are incongruent trials because the semantic meaning of the digits makes the task harder (since it needs to be ignored). Unfortunately it was impossible to analyze the ERP-data from the distracter task within the time limits of this master’s thesis. The data will however be analyzed later on in the research project.

The event-related-potential (ERP) technique

It is possible to measure the brain’s electrical activity by placing electrodes on the scalp, amplifying the signal and plotting the changes in voltage for each electrode over time (Luck, 2005). The measured electrical brain activity is called the electroencephalogram (EEG). In order to study the brain activity related to cognitive processes researchers have to cut out time locked event related parts of the continuous EEG. These event related parts are called event-related-potentials or ERPs. In order to be able to see the ERPs in the continuous EEG, one has to remove noise from the EEG. This noise can come from various sources like electrical equipment in the laboratory or electrical activity created by the participant's muscle movements. There are several ways to access the clean ERP signals from the noisy EEG. First of all filters are applied to filter out high frequency muscle artefacts and alternating current artefacts. Second it is possible to remove noise if one measures the brain activity related to a specific event many times and then averages the activity of all these measures. The logic of this procedure is that the noise is random across trials (individual measures) whereas the underlying ERPs consists of similar brain activity in each trial. Averaging the ERP-signal from many trials thus removes noise and reveals the underlying ERP. Finally artefacts with particular signatures in the EEG like eye movements or blinks can be removed or corrected by applying mathematical algorithms, that recognize the known artefact signatures and subtract them from the trials containing the artefacts, or signals the need for trials to bee excluded before averaging. The ERPs consists of the sum of many neurons' synchronized activity, since it is not possible to measure the activity of a single neuron from the scalp because the electrical activity associated to every single neuron is too small. The research evidence of today suggests that the bio physiological origin of ERPs is the sum of many synchronized post-synaptic potentials (Luck, 2005).

Aim of the present study

The aim of the present study was to examine the electrophysiological correlates of semantic generation, to study how repeated semantic generation, repeated study and test opportunities, affect memory performance and to create a non-verbal Stroop task. Three main hypotheses are postulated in relation to this aim. The logic behind the experimental design and each of the three hypotheses is provided before the hypotheses are presented.

The design in the present study is similar to the design in the study by Storm, Bjork and Bjork (2008) because it contains multiple semantic generation phases and relearning phases between study and test. There are however two important improvements in the present study's design compared to the design by Storm et al. (2008). First the design in the present study is a within subjects design. The advantage this brings about is that possible benefits from being forgotten cannot be confounded with differences in susceptibility to retrieval-induced-forgetting between groups of participant's, which was a possible explanation of the beneficial effect observed in the previous study because a between subjects design was used. The second improvement is a consequence of the first one: namely that a cued recall test was added before the relearning of each item, which made it possible to examine the effects of repeated semantic generations on subjects' memory performances, in a within subjects design. The first hypothesis in the present study predicts that the generation-induced-forgetting effect will occur in all tests and is based on the previous studies on generation-induced-forgetting (Bäuml, 2002; Storm, Bjork, Bjork, & Nestojko, 2006; Storm et al., 2008). The second part of the first main hypothesis is based on the assumption that the strengthening of the relearned items during the relearning phases will lead to increased retrieval competition in the following semantic generation phase when again atypical exemplars associated to the same categories should be generated. Increased retrieval competition leads to increased need for inhibition, which in turn leads to increased generation-induced-forgetting on later tests (because all tests are preceded by semantic generation phases). Hypothesis two is based on the assumption that the digit Stroop task created for the present study will cause the typical Stroop effect seen in previous versions of the task. The hypotheses that the ERPs over frontal electrode sites will be more positive going in a time window of approximately 200 ms to 2000ms for high forgetters (participants with high amounts of semantic generation-induced-forgetting) compared to low forgetters (participants with low amounts of semantic generation-induced-forgetting) and that only electrodes over frontal areas will predict individual differences in generation-induced-forgetting are based on the ERP correlates of retrieval-induced-forgetting reported in the study by Johansson, Aslan, Bäuml, Gäbel and Mecklinger (2007).

A short explanation of the abbreviations of the four different conditions in the present study is provided at the end of this section to make it possible formulate the hypotheses in a more concise way. The abbreviation RNG (relearning no semantic generation items) refers to items associated with categories that were relearned but did not receive semantic generation, RG- (relearning semantic generation (the minus indicates that other exemplars associated with the category, but not these particular items were generated during the semantic generation phase)) refers to items belonging to categories which received both relearning and semantic generation, NRG- (no relearning semantic generation) refers to items associated with categories that were not relearned, but received semantic generation and finally NRNG refers to items which neither received relearning nor semantic generation.

Hypotheses

Hypothesis 1a. The semantic generation phase will cause generation-induced-forgetting of items associated with categories which underwent semantic generation. The generation-induced-forgetting will be indicated by decreased memory performance for RG- and NRG- items compared to RNG and NRNG items both at the recall tests in the relearning phases and in the final recall test in the test phase.

1b. The difference in memory performance between RG- items and NRG items will increase with every test phase. This means that the generation-induced-forgetting effect will be smallest in the test during the first relearning phase, intermediate in the test during the second relearning phase and largest during the final recall test.

Hypothesis 2 As compared to neutral trials, the reaction times will be shorter for congruent trials and longer for incongruent trials in the digit Stroop task.

Hypothesis 3a. The retrieval ERPs from the semantic generation phase at anterior electrode sites will be more positive going in amplitude at a latency of approximately 200-2000 milliseconds for high forgetters compared to low forgetters.

3b. Activity over frontal electrodes during semantic generation will predict the amount of semantic generation-induced-forgetting whereas activity over posterior areas will not.

Method

Participants

Forty participants gave informed consent before they participated in return for a cinema ticket worth 90 Swedish crowns. Sixteen of the participants were excluded from the study because of excessive noise in the EEG-data and too few usable trials (the term trial refers to a single presentation of a particular condition). The sample included in the study hence consisted of 24 participants (19 females) with a mean age of 25 (range 20-37). All the participants were right handed (determined by self report), native Swedish speakers and had normal or corrected to normal vision. The reason why only right handed people were included in the sample is that cognitive functions tend to be less lateralized in left handed people (Banich, 2004) and the ERPs of people with different lateralization of cognitive functions differs from people with normal lateralization. The difference in ERPs, between people with normal and people with abnormal lateralization, is of course problematic when the average of all participants is calculated and that's why only right-handed people are included in most ERP studies.

Material

The stimulus material consisted of word lists from 24 distinct semantic categories selected from an earlier study by Rasmussen & Johansson (2009). Once the categories were selected, 12 exemplars were chosen from each category. Since previous studies has provided evidence that typical category exemplars are more susceptible to retrieval-induced-forgetting than less typical category exemplars (Anderson, Bjork & Bjork, 1994), six typical and six less typical were selected from each category and the typical words were used as target items whereas the less typical words were used in the semantic generation phase. The level of typicality for each word was obtained from frequency of report scores from the study by Rasmussen and Johansson (2009). The most frequently reported word in each category received taxonomic frequency rank 1 and the second most frequently reported word in each category received taxonomic frequency rank 2 and so forth. Across all categories, the mean taxonomic frequency was 10.4 for targets and 36.6 for non-targets. The length of the words ranged from four to ten letters. Words shorter than four letters and words with a taxonomic frequency rank below four were omitted to reduce the probability that participants would be able to guess the correct word during the memory test. For the same reason, words with uncommon initial letters were avoided as far as possible. Each word had a unique initial letter within categories since the first letter was used as cue during relearning and test. The non-target words had a unique second letter within blocks to avoid interference between categories caused by non-targets sharing the same semantic generation cue. Semantically related categories were assigned to different blocks as far as possible to avoid interference between categories. The 24 categories were divided into four sets containing six categories each. The sets were balanced on the variables taxonomic frequency and word length for both targets and non-targets. In a single experiment, each set was assigned to one of the four conditions. The condition a particular set was assigned to varied across participants. This way each set had been assigned to each condition across four participants. This is important because it means that all categories were assigned to each condition equally often and the logical consequence that follows is that possible differences in difficulty between categories influenced the memory performance for each condition equally across experiments. Since chance decided which categories that would be assigned to each condition for every participant, individual differences between participants in ability to remember certain categories influenced the results in a random and equal fashion across experimental conditions.

Design and procedure

The experiment was computerized (programmed with E-prime 2.0 software) and all stimuli were presented in black on white background on a 17 inches screen. The memory experiment had a duration of approximately 90 minutes and the whole experimental session lasted for about two and a half hours plus minus 30 minutes depending on how long time that needed to be spent in reducing the impedance between the scalp and the electrodes. The experiment consisted of three blocks and each block contained one study phase, three semantic generation phases, two relearning phases, one distracter phase and one test phase each as illustrated in the experiment structure depicted in Table 1. Eight categories were included in the study phase in each block. These eight categories were assigned to four different conditions with two categories in each condition. Items which were assigned to the first condition received relearning but not semantic generation (relearning no-semantic generation (RNG) items), items in the second condition received relearning and semantic generation (relearning semantic generation (R-G) items), items which were assigned to the third condition did not receive relearning but received semantic generation (no relearning semantic generation (NR-G) items) and items in the fourth condition neither received relearning nor semantic generation (no relearning no semantic generation (NRNG) items). During the semantic generation phase, the relearning phase and the test phase the experiment leader sat approximately two meters behind and one meter to the left of the participant and registered the verbal responses from the participant. The responses were registered as correct or wrong via button clicks on a numeric keyboard. Trials on which the participants failed to respond in the response time window were automatically coded as incorrect by the computer. To avoid artefacts in the ERP epochs as far as possible, the participants were instructed to be still, relax, focus their gaze at the centre of the screen and blink during the response time windows. In all the different phases of the experiment the presentations of the stimulus material started with a fixation cross (presented for 500 milliseconds (ms) at the centre of the screen) which showed were the stimuli were going to be presented (to minimize eye-movements, which creates artefacts in the electrophysiological recordings). A blank white screen were shown next in all presentations for 500 ms. The electrophysiological recording during the last 200 ms of the presentation of the blank screen served as an EEG baseline for the ERPs. A blank screen was presented either 1500 or 1000 ms in the end of each presentation during the memory test. The randomised 1500 or 1000 ms long blank screen presentations served as jitter and prevented ERPs related to time regular presentations to occur. The different phases of the experiment are described in the following sections.

Table 1. The structure of the experiment and a description of which conditions. Sg = semantic generation phase, Rel = relearning phase, R = relearned items, NR = not relearned items, G- = non-generated items from categories receiving semantic generation. NG = non-generated items from categories, which did not receive semantic generation.

Study	Sg1	Rel1	Sg2	Rel2	Sg3	Stroop	Test
RG-	RG+	RG-	RG+	RG-	RG+		RG-
RNG		RNG		RNG			RNG
NRG-	NRG+		NRG+		NRG+		NRG-
NRNG							NRNG

The study phase

The participants were instructed to learn category and example word pairs so that they could recall the example with help of a cue, consisting of the category and the example's initial letter in the test phase. They were also instructed to focus on the words that were currently presented on the screen and to avoid rehearsal of the previously presented words. The reason behind these instructions is that it is impossible to measure the electrophysiological correlates of the encoding of a particular word if the participants are rehearsing other words at the same time. The category-exemplar word pair appeared on the screen for 2000 ms. In total, 48 examples from eight categories were presented in the study phase of each block.

The semantic generation phase

In this phase, the participants were given cues consisting of a category and the first two initial letters a word and they were instructed to try to generate an existing word that matches the cue. Moreover, they were also told that the categories had been presented in the study phase, whereas the exemplars were new and begun with different letters than the studied words, so it was impossible to complete the word stem cue with an exemplar from the study phase. A cue consisting of the category and the initial two letters of the exemplar was presented for 2500 ms followed by a question mark (presented for 2000 ms). The participants were told to say a word that matched the cue when the question mark was presented on the screen. The reason behind this instruction is that muscular activity during oral responses creates artefacts in the electrophysiological recordings and one need to separate it in time from the retrieval from semantic memory during semantic generation in order to be able to measure the ERP correlates of this retrieval. Four of the categories from the study phase were included in the semantic generation phase and the participant was given 24 cues (six per category) in every semantic generation phase. Each cue matched an exemplar with low taxonomic frequency. The semantic generation phase was repeated three times in each block and the same cues were presented in all three phases. The participants were told that they were allowed to recycle words they had generated in previous semantic generation phases when the associated cues reappeared in the second and the third semantic generation phase of the block.

The relearning phase

It is important to note that the relearning phase in the present study was different from the relearning phases in previous studies by for example Johansson, Aslan, Bäuml, Gäbel and Mecklinger (2007) and Storm, Bjork and Bjork (2008) since it consisted of a cued recall test in addition to the extra study exposure, which relearning usually refers to in the retrieval-induced-forgetting literature. The participants were instructed that they were going to receive cues, consisting of the category and the initial letter belonging to a previously learned exemplar and that their task was to recall the specific exemplar from the study phase that matched the cue. Another instruction they received was that they were going to get feedback (see the correct answer) after the response time window had ended independently of if they answered correctly, incorrectly or failed to answer within the response time window. A retrieval cue, consisting of a category and the initial letter of the to be recalled example, was then presented for 2500 ms. The cue was followed by an exhortation to say the word (presented for 2000 ms) and the participants were instructed to respond when the exhortation appeared on the screen, for reasons mentioned above. After the response time window had ended a fixation cross was followed by a blank white baseline screen before the correct answer was presented for 2000 ms.

The digit Stroop task

In this phase the participants were told that signs were going to appear on the screen and that their task was to count the number of signs and respond correctly as fast as possible. The signs could either be squares (e.g. # #), digits which corresponded with the number of signs (e.g. 2 2) or digits which did not correspond with the number of signs on the screen (e.g. 3 3). The participants responded via button presses on a keyboard with their right hand. Each presentation started with the fixation cross and the blank baseline screen (presented for 500 ms each). Then the signs appeared on the screen for 300 ms and were followed by a 1500 ms long response window. The Stroop task was approximately 5 minutes long and contained 96 trials per block (25 percent (24 per block) of the trials were incongruent).

The test phase

Similarly to the relearning phase, cues consisting of the category and the first letter of the exemplars were presented and the participants' task was to recall a cue-matching exemplar from the exemplars they learned during the study phase. An important difference between the test phase and the relearning phase was that all the 48 exemplars from the study phase were included in the recall test in the test phase, whereas only 24 exemplars were included in the relearning phase. A retrieval cue, consisting of a category and the initial letter of the to be recalled example, was then presented for 2500 ms before the question "what word was it?" appeared on the screen (for 2000 ms). The participants were instructed to respond orally when the question appeared on the screen.

Electrophysiological methods

Neuroscan 4.4 Acquire software and NuAmps amplifier system were used during the recording of the EEG. The EEG was recorded continuously from 40 silver/silver chloride (Ag/AgCl) electrodes mounted to an elastic cap. The layout of the 40 electrodes can be seen in Figure 1 below. The electrodes were referenced to the left mastoid online and re-referenced offline to the average of the left and the right mastoid. Electrodes were placed over and below the left eye and outside the outer canthi of both eyes to measure vertical and horizontal eye movements. All channels were digitized with 32 bit resolution at a sample rate of 500 Hz. Impedances between the scalp and the electrodes were kept below 5 kΩ. The duration of the ERP epochs was 2000 ms preceded by a 200 ms prestimulus sampling period used for baseline correction. Trials containing muscle, recording artefacts and artefacts caused by horizontal eye-movements were rejected whereas trials containing vertical artefacts were corrected. A challenging problem in using brain imaging methods in general and the ERP method in particular is that the whole brain is more or less active all the time and therefore one needs to prove that the recorded brain activity is related to the cognitive phenomenon of interest. There are different ways to separate activity related to the phenomenon from activity which is not related to the phenomenon. A classical way is to use a control condition which is as similar to the experimental condition as possible, with the exception that the cognitive phenomenon of interest is absent. In the present study another way was used. The ERP-waveform in the group of individuals who showed a high level of generation-induced-forgetting was compared to the ERP-waveform in the group of individuals who showed a low level of generation-induced-forgetting. The association between the differences in ERPs between these two groups and the generation-induced-forgetting effect was thus based on the assumption that the differences in ERP-waveforms between the high- and low-forgetters are related to the forgetting effect. A regression analysis was also conducted to examine whether the potential ERP correlates of forgetting was predictive of individual differences in generation-induced-forgetting. In this regression analysis a forgetting-index (based on amount of generation-induced-forgetting for each participant (calculated by subtracting performance for G- items on the final recall test from performance for NG items on the final recall test)) was used to examine if ERPs recorded at different electrode sites could predict individual differences in generation-induced-forgetting.

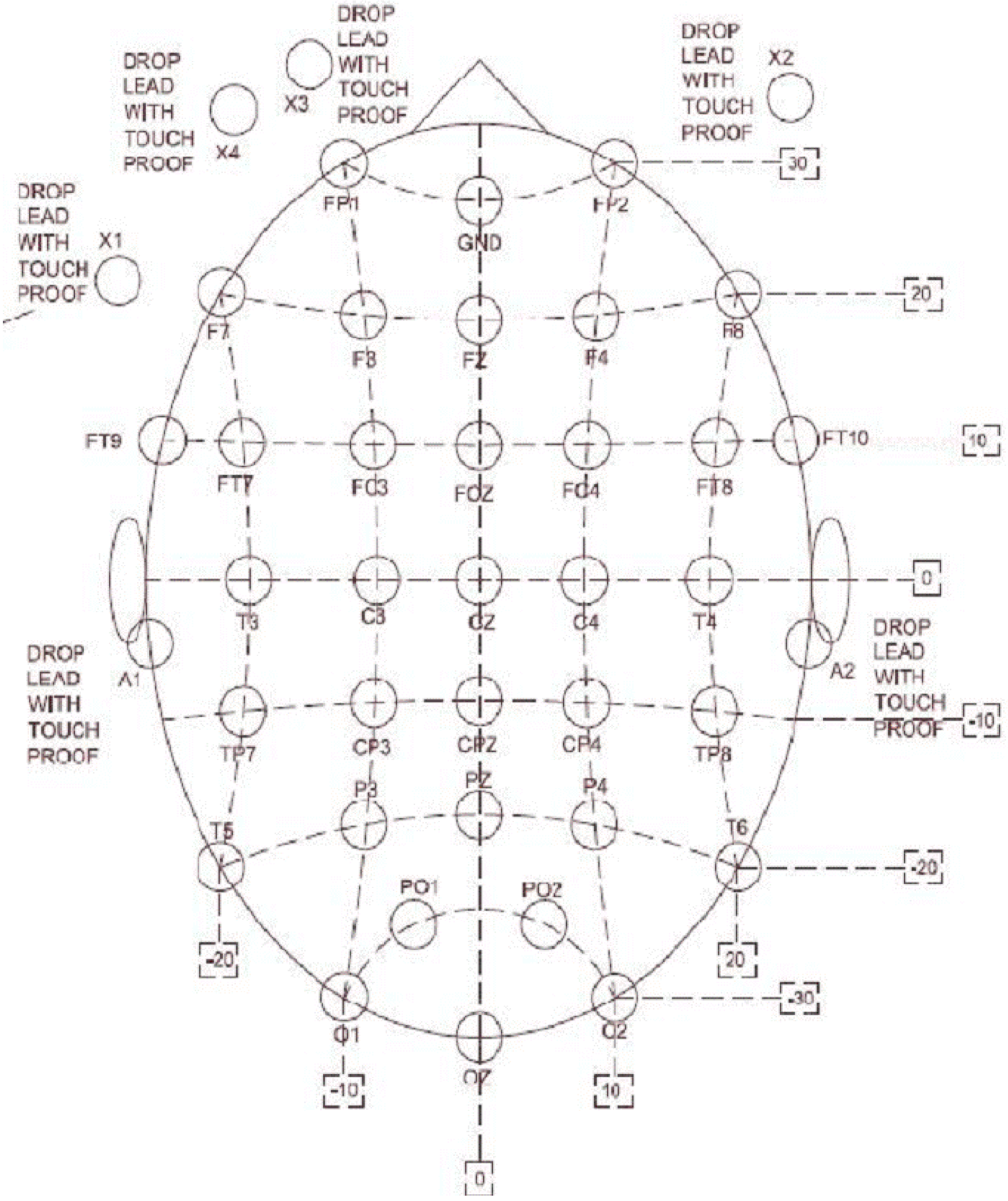

Figure 1. The layout of the 40 electrodes in the NuAmp 40 channel system used in the present study. The nose is plotted upwards. The picture is created by Neuroscan and is downloaded from www.neuroscan.com.

Results

This section begins with an analysis of reaction times in the digit Stroop task, followed by the results from the analysis of behavioural data from the memory tests. The section ends with a presentation of the results of the ERP analysis of neural correlates of generation-induced-forgetting during the semantic generation phase.

Behavioural data

The digit Stroop task

Mean reaction times were computed for all three conditions in the Stroop task (congruent , congruent and incongruent) and paired *t*-tests were conducted to examine whether a statistically significant Stroop effect was evident. The expected classical Stroop results were obtained, namely that the reaction times for congruent items were shortest ($M = 557$ ms), the reaction times for incongruent trials were longest ($M = 640$ ms) and the reaction times for neutral items were intermediate ($M = 593$ ms). The results from the paired two-tailed *t*-tests showed that the reaction times were significantly longer for incongruent trials compared to neutral trials ($t = 5.658$, $df = 23$, $p < .001$), that the reaction times were significantly longer for neutral trials compare to congruent trials ($t = 7.959$, $df = 23$, $p < .001$) and hence that the reaction times were significantly longer for incongruent trials compared to congruent trials ($t(23) = 8.655$, $p < .001$). The mean reaction times for each condition are shown in Figure 2.

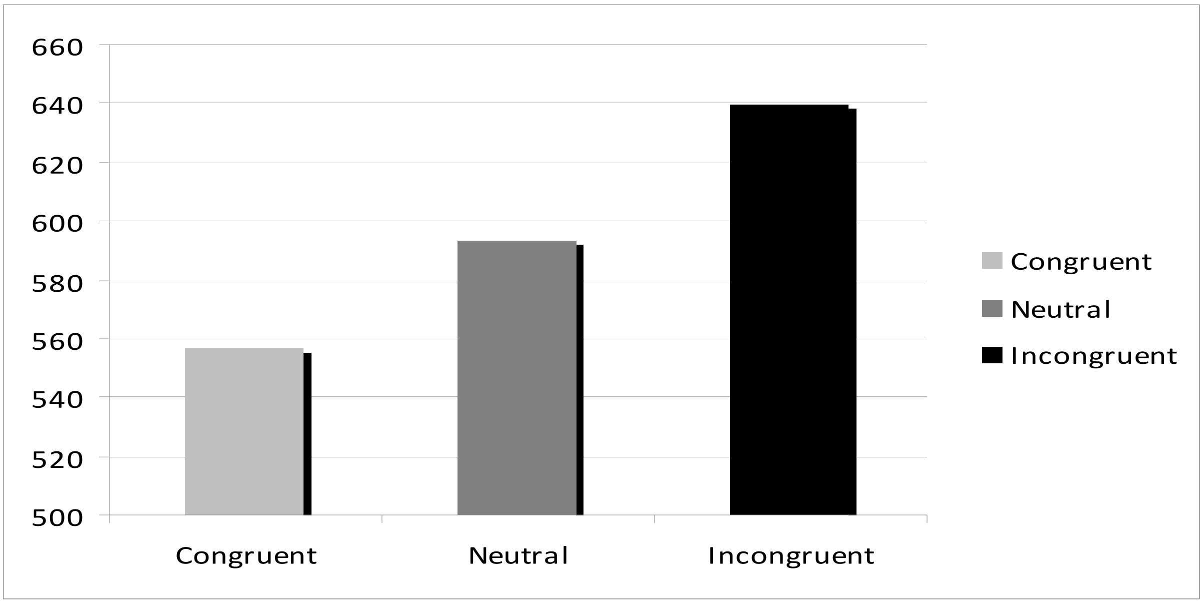

Figure 2. Mean reaction times for the three conditions in the Stroop task.

The memory experiment

First the mean memory performance was computed in all tests for all item types. The results are shown in table 2 and figure 3 below.

Table 2. *Percentage of correct answers on the three recall tests for each condition. R = relearned items, NR = not relearned items, G- = non-generated items from categories receiving semantic generation. NG = non-generated items from categories, which did not receive semantic generation.*

Condition	Relearning phase 1	Relearning phase 2	Final recall test
RG-	40	62	76
RNG	47	73	83
NRG-			32
NRNG			41

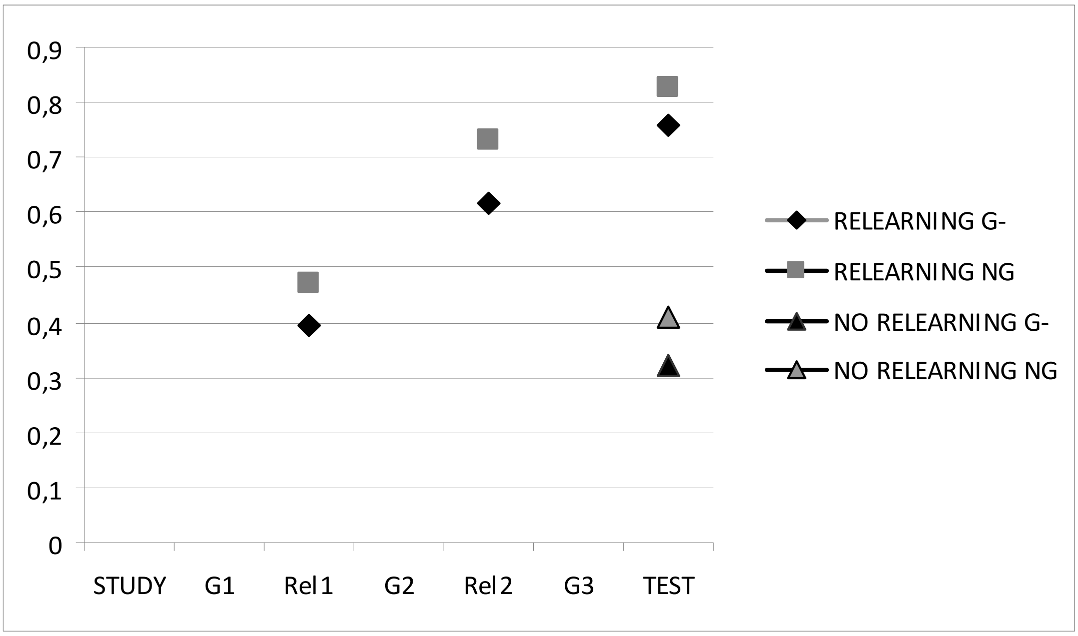

Figure 3. Percentage of correct answers on the three recall tests for each condition G- = non-generated items from categories receiving semantic generation. NG = non-generated items from categories, which did not receive semantic generation.

A two way 2 x 2 (relearning: relearned/not relearned x semantic generation: semantic generation/no semantic generation) repeated measures analysis of variance (ANOVA) was conducted with memory performance on the final recall test as the dependent variable to assess whether semantic generation and relearning had any statistically significant effects on memory performance on the final recall test. In accordance with expectancies, the results demonstrated significant main effects for both semantic generation $F(1,23) = 28.404$, $p < .001$ and relearning $F(1,23) = 438.697$ $p < .001$. These results mean that generation leads to lower memory performance, in the final recall test, independently of if the items were relearned and that relearning leads to improved memory performance, in the same test, independently of if the categories the items are associated with received semantic generation.

Next, a two way 2x3 (semantic generation: semantic generation/no semantic generation x test: the test in the first relearning phase/the test in the second relearning phase/) repeated measures ANOVA was conducted with memory performance as dependent variable and semantic generation as the first factor with two levels (semantic generation or no semantic generation) and test as the second factor with three levels (the test during the first relearning phase, the test during the second relearning phase and the final recall test) to test whether the amount of generation-induced-forgetting increases as a function of the number of semantic generation phases the categories have received. The analysis showed two significant main effects for semantic generation (*F*(1,23) = 35.941, $p < .001$) and test (*F*(2,46) = 303.648, $p < .001$). The two main effect on the test factor indicates that memory performance is increased as a function of how many times the items were tested independent of if the category they are associated with had received semantic generation and that semantic generation leads to decreased memory performance independent of which test the memory performance is measured in. The expected interaction effect between semantic generation was borderline significant (*F*(2,46) = 2.907, $p = .065$). Since the predicted interaction effect was close to reach statistical significance, a follow up contrast analysis was performed and revealed a statistically significant quadratic effect of test *F*(1,23) = 6.758, $p = 0.16$. This effect reflects the fact that the difference between RG- and RNG items was largest in the second relearning phase (as is evident in Figure 2). It is possible that a ceiling effect can explain why the amount of generation-induced-forgetting was reduced rather than increased between the second relearning phase and the final recall test and hence why the contrast effect between semantic generation and test was quadratic rather than linear (as predicted), because the mean performance in the final recall test was as high as 82.6 percent (*SD* = 10 percent).

Finally a generation-induced-forgetting index was calculated by subtracting the recall rates on the final recall test of G- items from the recall rates from the final recall test of NG items (NG items – G- items) and the total number of generated words by each participants in all semantic generation phases over all blocks and the generations induced forgetting indexes were calculated for each participant. The two measures (forgetting index and total number of generated words during the semantic generation phases) were converted to z-scores before they were correlated to test the post hoc hypothesis that amount of generation success will be positively correlated with amount of generation-induced-forgetting. The results from the Pearson's parametric test of correlation showed no significant correlation between these measures $r = -.105$, $N = 24$, $p = .626$.

ERP data

A median split on the semantic generation-induced-forgetting index measure, described above, created a high- and low- forgetting group of participants. ERPs from each of the three semantic generation phases were contrasted with the between subject factor of forgetting group (high versus low). The difference between the two groups' ERPs elicited in the three semantic generation phases was that the high-forgetting groups ERPs were more positive going at an onset of approximately 300 ms. The left lateralisation of the differences in amplitudes in each semantic generation phase can be seen in the difference scalp topographies in Figure 4. The ERP curves measured at electrode sites T5 (T is an abbreviation for temporal and the uneven number 5 indicates that the electrode is located over the left hemisphere) and FP1 (FP is an abbreviation of frontopolar and the uneven number 1 indicates that the electrode is located over the left hemisphere) for both groups in each semantic generation phase can be seen in the three pictures in the same Figure (the localisation of electrode T5 and FP1 can be seen in Figure 1). These differences in activity between high- and low-forgetters would not be especially interesting if they were not related to generation-induced-forgetting. Therefore a regression analysis was conducted to test if the differences in amplitude between high- and low-forgetters were predictive of individual differences in generation-induced-forgetting. Surprisingly and interestingly the results reveal that differences in activity between high- and low-forgetters over left prefrontal cortex, temporal cortex and parietal electrode sites can explain between approximately 25 percent to approximately 45 percent of the individual variance in generation-induced-forgetting, in the time window of 300 to 800 ms. The results were surprising given that only differences over anterior electrode sites has been predictive of retrieval-induced-forgetting in previous research (Johansson, Aslan, Bäuml, Gäbel & Mecklinger, 2007) and given that semantic generation has been thought to produce the same memory impairment as retrieval practice (Bäuml, 2002). The R^2_{adj} scores from the regression analysis is presented in Figure 5, 6 and 7 below.

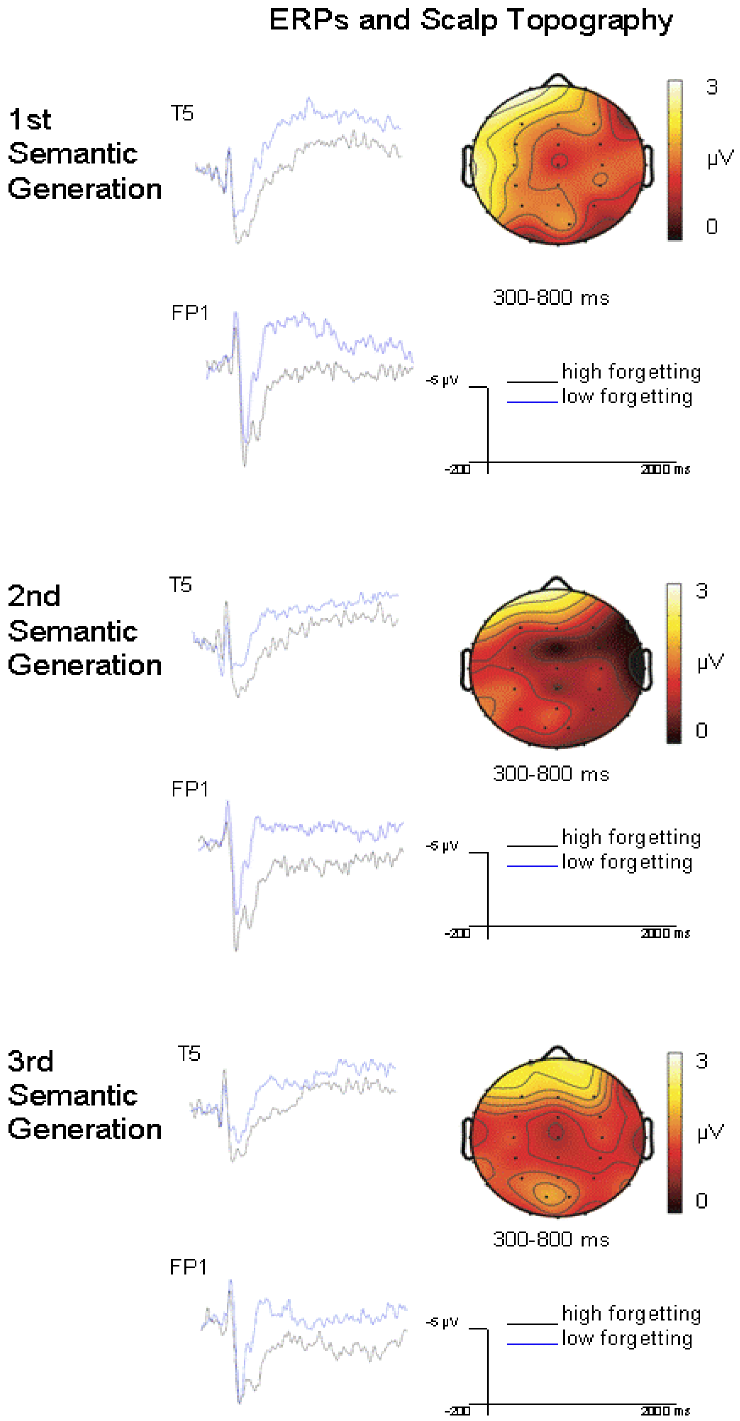

Figure 4. ERP-waveforms from two electrode sites (T5 (temporal left lateralized) and FP1 (frontopolar left lateralized electrode sites, can be seen to the left. The black line shows the ERP-waveform measured during semantic generation for high-forgetters whereas the blue ERP-waveform shows low-forgetters activity at the same electrode site during the same task. The two groups were created by a median split on a generation-induced-forgetting-index-variable. The generation-induced-forgetting-index was calculated by subtracting accuracy rates on the final recall tests for RG- items from accuracy rates for RNG items on the same tests. The ERP-waveforms' scale (-5 µV with minus plotted upwards) can be seen to the right of the FP1 waveforms. The scalp topographies shows the mean difference between high- and low-forgetters in the time window where the two groups ERPs differed the most (300-800 ms).

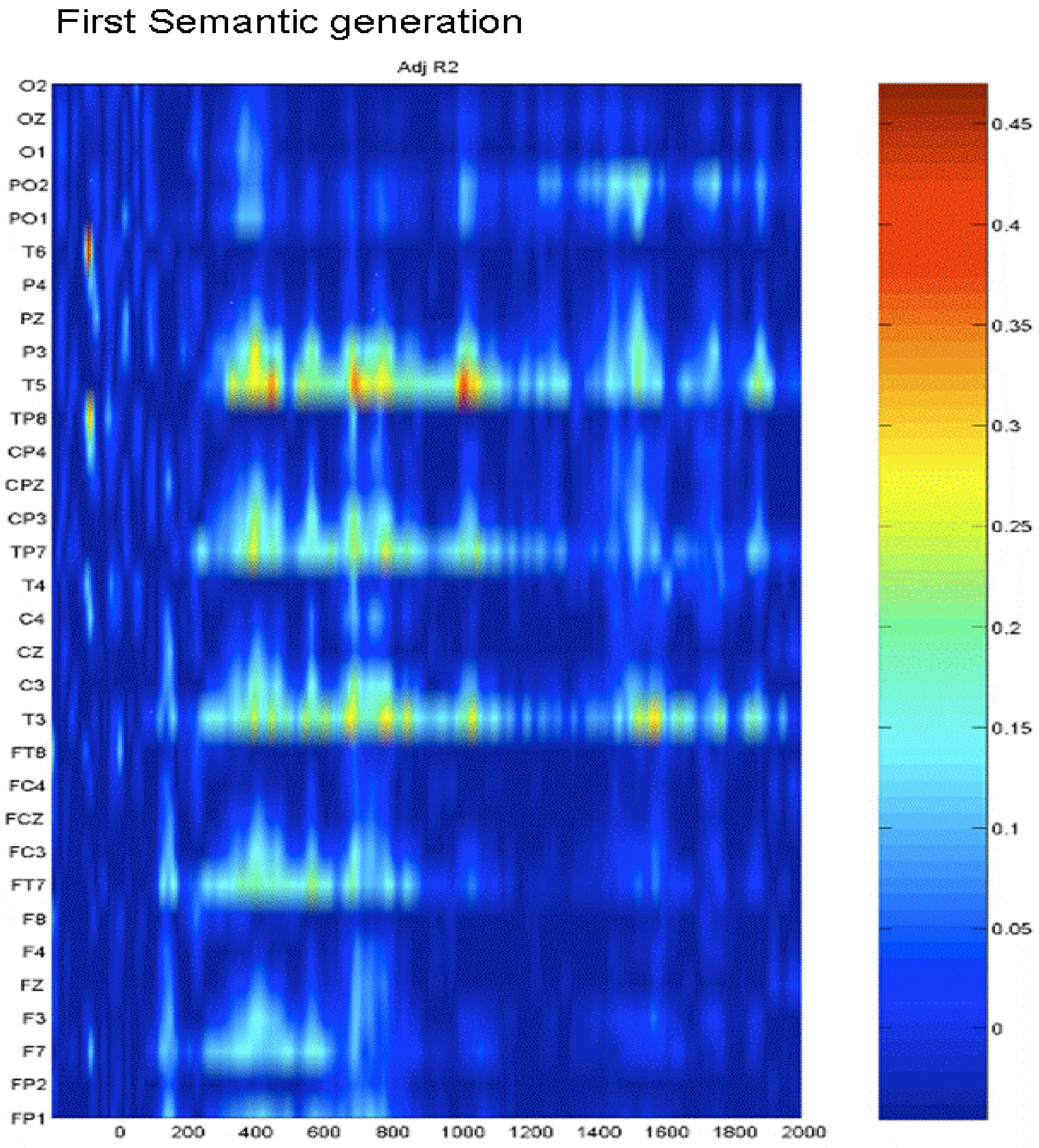

Figure 5. This picture shows adjusted R^2 scores (explained variance) from the regression analysis which tested whether activity at the different electrode sites, during the first semantic generation phase, could predict the amount of generation-induced-forgetting on an individual level. The generation-induced-forgetting-index, described in the first part of this figure description, was used as a continuous variable in this regression analysis. The anterior electrode sites are plotted in the lower part, the central electrodes are plotted in the middle and the posterior electrode sites are plotted in the upper part in this figure. The electrode sites are plotted to the left. The regression analysis figure illustrates predictive activity during the whole recording epoch and time is shown below the picture in milliseconds.

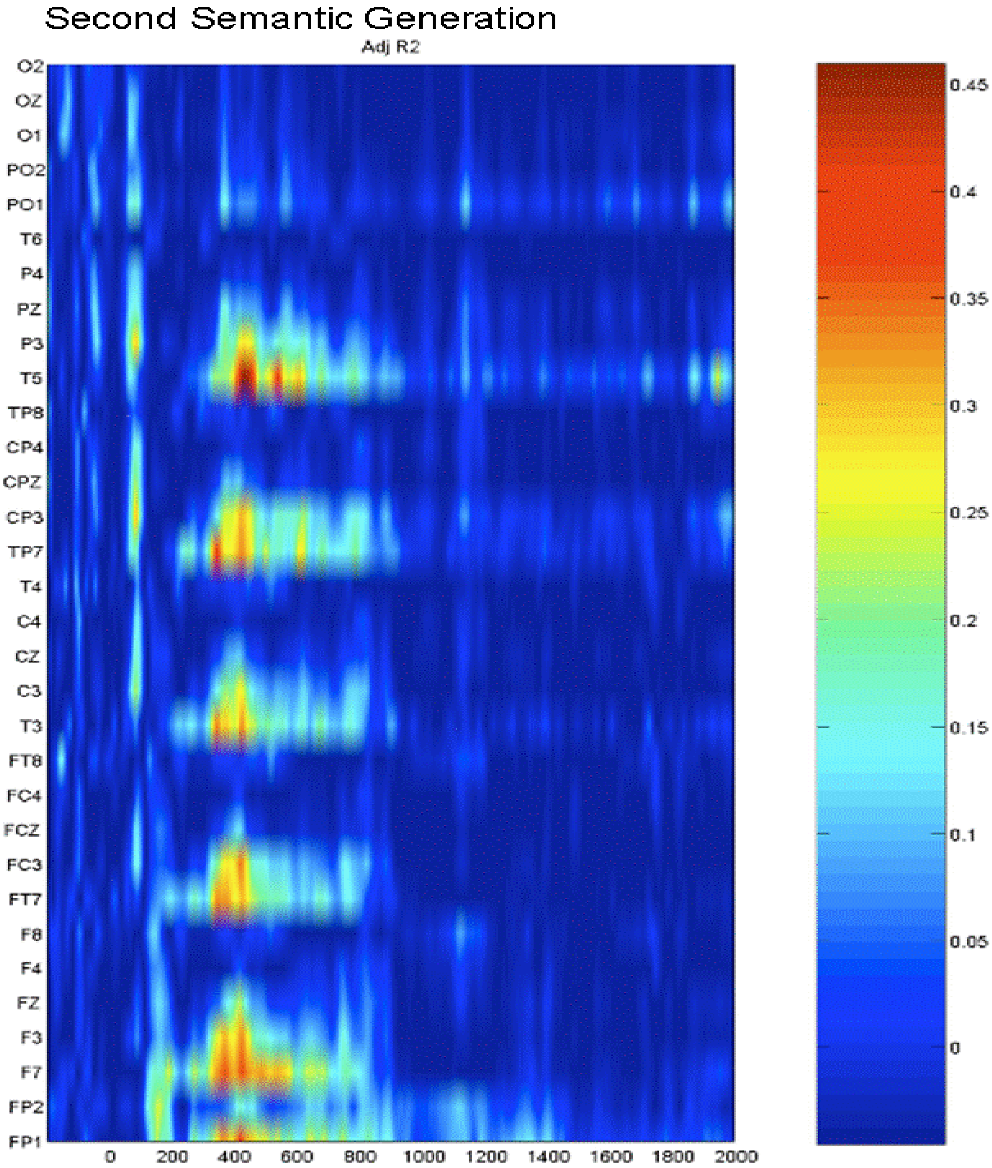

Figure 6. This picture shows adjusted R^2 scores (explained variance) from the regression analysis which tested whether activity at the different electrode sites, during the second semantic generation phase, could predict the amount of generation-induced-forgetting on an individual level. The generation-induced-forgetting-index, described in the first part of this figure description, was used as a continuous variable in this regression analysis. The anterior electrode sites are plotted in the lower part, the central electrodes are plotted in the middle and the posterior electrode sites are plotted in the upper part in this figure. The electrode sites are plotted to the left . The regression analysis figure illustrates predictive activity during the whole recording epoch and time is shown below the picture in milliseconds.

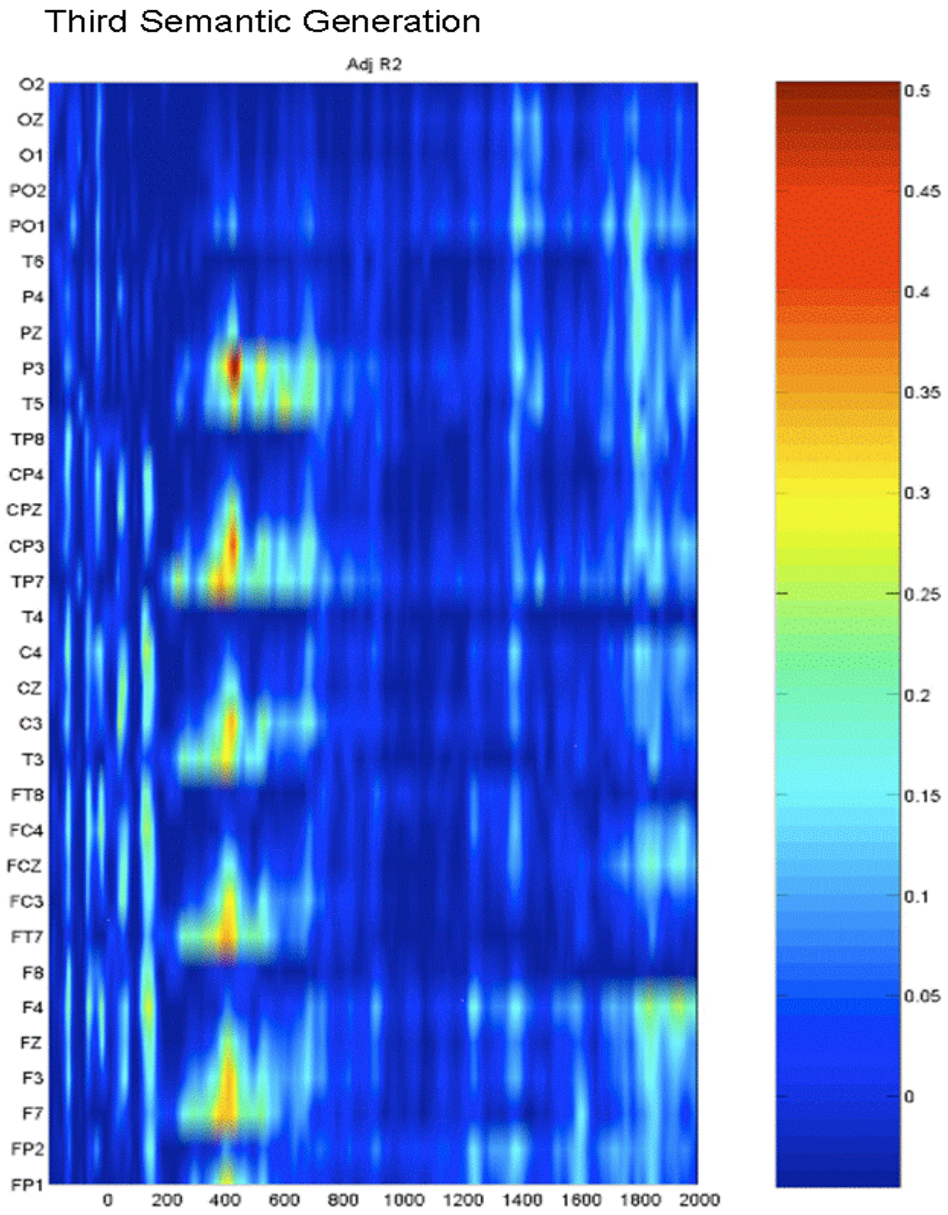

Figure 7. This picture shows adjusted R^2 *scores (explained variance) from the regression analysis which tested whether activity at the different electrode sites, during the third semantic generation phase, could predict the amount of generation-induced-forgetting on an individual level. The generation-induced-forgetting-index, described in the first part of this figure description, was used as a continuous variable in this regression analysis. The anterior electrode sites are plotted in the lower part, the central electrodes are plotted in the middle and the posterior electrode sites are plotted in the upper part of this figure. The electrode sites are plotted to the left. The regression analysis figure illustrates predictive activity during the whole recording epoch and time is shown below each picture.*

Discussion

This study aimed to examine the electrophysiological correlates of semantic generation, to study how repeated semantic generation, relearnings and tests affect memory performance and to create a non-verbal Stroop task. The first part of this discussion section provides interpretation of the results in relation to this aim and the three postulated hypotheses.

Statistically significant robust generation-induced-forgetting effects is evident in all three tests both for relearned and not-relearned items. Hence, hypothesis 1a (*the semantic generation phase will cause generation-induced-forgetting of items associated with categories which underwent semantic generation*) is supported. Generation-induced-forgetting occurs whether or not the items are tested and relearned one or two times as long as a semantic generation phase precedes the test. The results from the final recall test provide evidence that the generation-induced-forgetting effect occurs even when participants engage in a five minutes distracter task between semantic generation and test. The results are in line with previous research on generation-induced-forgetting (Bäuml, 2002; Storm, Bjork, Bjork & Nestojko 2006; Storm, Bjork & Bjork 2008). Hypothesis 1b (*the difference in memory performance between RG- items and NRG items will increase with every test phase*) is only partly supported by the results since the interaction effect between test and semantic generation was not significant, but borderline significant ($p = 0.065$). A possible explanation to why the increase in generation-induced-forgetting after the first relearning phase did not continue to increase between the second relearning phase and the final recall test is that a ceiling effect for RNG items might be present in the final recall test (see Figure 2). This argument is supported by the fact that 82.6 percent, *SD* = 10 percent (30 of 36 items in raw score) of the RNG items was recalled in the final recall test. The mean performance of 82.6 percent means that 30 of 36 items were correctly remembered on average in the sample.

The second hypothesis (*the reaction times will be shortest for congruent trials and longest for incongruent trials in the digit Stroop task)* was confirmed by the results of the paired *t*-tests of mean reaction times for the three conditions in the digit Stroop task. The results showed the expected pattern namely that: incongruent trials had longer reaction times than congruent trials was expected and neutral trials had longer reaction times than congruent trials. The classical explanation of the phenomenon that neutral trials have longer reaction times than congruent trials is that the processing of congruent items benefits from the semantic meaning of the digits. It is also reasonable to assume that a contributing factor to the occurrence of this effect is that as much as 75 percent of the trials, in the present study, were congruent and it was hence possible to use the semantic meaning of the digits for guidance in response selection in the majority of the trials.

The most surprising and far most important finding in this study was the finding that ERP-activity in electrodes localized over left lateralized temporal, parietal and frontal instead of exclusively bilateral frontal electrodes predicted the generation-induced-forgetting. Consequently hypothesis 3a (*the retrieval ERPs from the semantic generation phase at anterior electrode sites will be more positive going in amplitude at a latency of approximately 200-2000 milliseconds for high forgetters compared to low forgetters*) and hypothesis 3b (*Activity over frontal electrodes during semantic generation will predict the amount of semantic generation-induced-forgetting whereas activity over temporal, parietal and occipital areas will not*) was not supported by the ERP-results. The distribution of generation-induced-forgetting predictive ERP activity differs from the distribution of ERP-activity predicting retrieval-induced-forgetting in the Johansson, Aslan, Bäuml, Gäbel and Mecklinger (2007) study. These ERP results strongly suggest that generation-induced-forgetting and retrieval-induced-forgetting is caused by two non-overlapping neural mechanisms. A logical consequence of the finding that non-overlapping neural mechanisms causes generation-induced-forgetting and retrieval-induced-forgetting is that generation-induced-forgetting is not only caused by cognitive inhibition. Cognitive inhibition has been associated with activity in the prefrontal cortex (Kuhl, Dudukovic, Kahn & Wagner, 2007; Johansson et al., 2007; Badre & Wagner, 2007) and the brain activity predictive of generation-induced-forgetting would accordingly have been restricted to electrodes over frontal areas (as hypothesised) if generation-induced-forgetting only would have been caused by cognitive inhibition. It is however probable that cognitive inhibition interacted with the cue-overload effect, given the left anterior activity predictive of generation-induced-forgetting.

If generation-induced-forgetting is not only caused by cognitive inhibition, what is it then caused by? The ERP-results (shown in Figure 5, 6 and 7) show that ERP activity over left lateralized frontal, temporal and parietal areas predict generation-induced-forgetting. As previously described in the theory section these areas are associated with semantic retrieval. Remember that the left temporal lobe have been associated with retrieval success for semantic memories (Patterson, Nestor & Rogers, 2007) and that activity in the left prefrontal cortex have been associated with effortful semantic memory retrieval (Badre & Wagner, 2007). Semantic generation of verbal material has for example been associated with more positive going ERPs over frontal and temporal regions in the left hemisphere, compared to control conditions, in a previous study (Rowan et al., 2004) and this pattern of activity is similar to the pattern of activity predictive of generation-induced-forgetting in the results from the regression analysis in the present study. Moreover, Patterson et al.'s model of semantic memory claims that sensation related information is recruited from sensation related areas in the cortex, including the parietal cortex, during semantic memory retrieval. Evidence from lesion studies and studies of semantic dementia also suggests that the left anterior temporal lobe is essential for semantic memory retrieval, since lesions and atrophy in this area are associated with inability to retrieve semantic memories (Damasio, Tranel, Gabrowski, Adolphs & Damasio, 2004; Patterson et al., 2007). Further evidence of the left parietal cortex role in binding of context in memory retrieval is provided in the ERP literature on recognition memory. A positive going effect over left parietal electrodes has been shown to be an ERP-correlate of recollection, which is a form of episodic recognition memory where information about the study context is added to the more shallow sense of familiarity (Rugg & Curran, 2007). The onset latency and the duration (300-800 ms) of the ERP-modulations predictive of generation-induced-forgetting was observed in a time window in which successful retrieval has been shown to occur in previous studies (Rugg & Curran, 2007). Taken together these findings suggest that the activity pattern which are predictive of generation-induced-forgetting, in the present study, reflects retrieval of semantic memories. So, the act of retrieval of semantic memories can itself cause forgetting of the associated studied memories, but why? A possible explanation is that the memory impairment for associated memories is caused by cue-overload.

Cue-overload is a principle stating that the efficacy of a retrieval cue in facilitating retrieval of associated items decreases as the number of associated items increases (Watkins & Watkins, 1975). When the participants, in the present study, try to generate words matching the cue, during the semantic generation phase, they generate a lot of exemplars associated to the category in search for an exemplar that fits the entire category plus word stem cue. Both the cue-matching generated exemplars and the non-matching exemplars are increasing the retrieval competition for the associated category. The reason for the enhanced retrieval competition is that each time the cue (in this case the category) is presented memories associated to the cue automatically impede one another's retrieval (Anderson, Bjork & Bjork 1994). The large amount of exemplars associated with the cue leads to cue-overload. An example of cue-overload all of us have encountered in daily life is that the longer a list of to be remembered words is the harder it is to remember the words on the list. It is easy to imagine that it for example is harder to remember what vegetables to buy if you have written a long list of to be shopped vegetables compared to if you have written a short list of the same grocery category before you go shopping in the local grocery store. In the same way the list of associated words becomes longer for the categories that received semantic generation compared to the categories that did not receive semantic generation in the present study. The longer list of possible answers makes the retrieval of RG- and NRG- items more difficult compared to retrieval of RNG and NRNG items and the increased difficulty leads to the generation-induced-forgetting effect. The effect caused by cue-overload is often referred to as the fan effect by cognitive researchers (see for example; Radvansky, 1999). The possibility that the generation-induced-forgetting increases with every semantic generation phase is also consistent with the view that cue-overload causes the effect, because it is reasonable to assume that the participants would be able to successfully generate more and more exemplars associated with the cue every time it is presented. If generation-induced-forgetting is caused by cue-overload there should be a significant correlation between the number of words each participant successfully generates and their amount of generation-induced-forgetting. As can be seen in the results section a correlation between these two measures was computed to test the post hoc hypothesis. This correlation failed to reach statistical significance. A null result can of course never prove that a hypothesis is wrong and there are two reasonable explanations of why this correlation failed to reach significance. First of all the study was not designed for such a correlation and thus has low power, which means that it is unlikely that the correlation between these measures in the present study would be significant even if the hypothesis that they do correlate is true. Secondly, only exemplars which the participants said aloud was coded and it is likely to assume that the participants generated a lot of other exemplars covertly, which contributed to the cue-overload, but was not included in the correlation analysis.

General discussion

What implications do the findings in the present study have for the broader field of memory research in cognitive neuroscience? The most important implication is the finding that generation-induced-forgetting and retrieval-induced-forgetting has non-overlapping neural correlates, which shows that temporal and parietal regions contribute to generation-induced-forgetting in addition to the frontal regions, in which activity have been shown to be predictive of retrieval induced forgetting. The consequence of this finding is that that the experiments conducted by Storm, Bjork, Bjork and Nestojko in 2006 and Storm, Bjork and Bjork in 2008 probably examined temporal and parietal mechanisms related to cue-overload in addition to the frontal associated mechanism called cognitive inhibition, which was the only mechanism they intended to examine. Accordingly it can be concluded that future studies aiming to study the effects of cognitive inhibition and retrieval-induced-forgetting should avoid replacing retrieval practice with semantic generation. The results also implicated that the digit Stroop task works and it is therefore recommendable to use it in future ERP and fMRI studies. The finding that generation-induced-forgetting occurred in all tests is in line with previous research in this field. The classical testing effect was also replicated in the results because the memory performance was increased with every test. It should however be noted that it is impossible to separate the effects of testing from the effects of extra presentations of the stimuli in the present design, since the relearning phase consisted of both test and extra exposure of the correct answers. What implications do these results have in a wider context outside the realm of cognitive neuroscience? In daily life, the results related to generation-induced-forgetting implies, that trying to recall every fact one knows about a topic can lead to a subsequent inability to recall a other fact associated with the same topic. Retrieval of all countries you know could for example cause cue-overload and subsequent generation-induced-forgetting of the name of a particular country. Dividing the countries in to subgroups associated with separate cues would however reduce the amount of generation-induced-forgetting given that the post hoc hypothesis is correct and generation-induced-forgetting is caused by cue-overload.

Limitations of the present study

The majority of the limitations of the present study are related to that the author of this paper had limited prior experience of EEG-recording with neuroscan equipment and needed practice before decent data-quality was reached. This was the primary reason why data from numerous recordings needed to be excluded from this study. The included number of participants and trials from the participants is however comparable to published studies in this ERP research of memory phenomena. Exactly the same number of participants was for example included in the ERP study by Johansson, Aslan, Bäuml, Gäbel and Mecklinger (2007), which the ERP-results in the present study is most readily compared to.

Another problem related to inexperience in EEG-data collection was that it was hard to give precise information about the length of the experiment to participants, since it was hard to estimate the time needed for application of the electrodes. An additional EEG-related problem was that a liberate rejection threshold had to be used for horizontal eye-movement artifact rejection in the data analysis, since too many participants would have been needed to be excluded from the study otherwise. The consequence of the use of a liberate rejection threshold is that some of the lateral anterior electrodes (for example FT7 and FT8) still contain horizontal eye-movement artifacts. There is however no reason to think that these artifacts differ systematically between the four conditions or the two groups of participants, used in the analysis, and the results are therefore not compromised by these artifacts even though the ERPs would have been purer without them. A final limitation of this study was that a few substandard items were included in the material, although three pilot studies were conducted and a lot of time was spent on optimizing the material before the actual ERP study begun. The worst case was that the word cider was included in the category non-alcoholic drinks despite that it is not a non-alcoholic drink.

Future research questions and suggestions of related future studies

The results in the present study need to be replicated by future neuroimaging studies studying the neural correlates of generation-induced-forgetting. It would be very interesting to conduct experiments, in which the neural correlates of retrieval practice, semantic generation and extra study exposures were compared to each other within subjects. Evidence of differences in the predictive neural activity during the different conditions in such a study would provide even stronger evidence for the non-overlapping predictive activity of generation-induced-forgetting and retrieval-induced-forgetting. Another interesting future research question is to examine the exact brain regions in which activity predicts generation-induced-forgetting. Investigating the exact neural sources of the differences in ERPs between high- and low forgetters will make it possible to further understand the mechanisms causing generation-induced-forgetting. The ERP-method used in the present study does not have enough spatial resolution to answer this question. The fMRI method has enough spatial resolution investigate this question however, so it would be interesting to conduct an fMRI experiment which provides difference images between high- and low-forgetters during the semantic generation phase. The present study has contributed to the work on discovering and separating different neural mechanisms associated with forgetting. An even more challenging task for future research in the cognitive neuroscience of memory will be to investigate how different forgetting mechanisms interact with each other and how these forgetting mechanisms interact with mechanisms leading to facilitated memory retrieval. A lot of pieces still remain to be discovered in the puzzle of human memory, but every new finding provides a small step forward in the solving of the complex puzzle.

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Appendix A: Informed consent form

LUND
UNIVERSITY

Department of Psychology
Mikael Johansson, PhD
Projektansvarig

NFORMATION TILL FORSKNINGSPERSON

Tillfrågande om deltagande

Du tillfrågas härmed om Du vill deltaga i denna studie som inkluderar datoriserade beteendetest och EEG/ERP-undersökning.

Bakgrund och syfte

Det generella syftet med undersökningen är att öka förståelsen för grundläggande minnesfunktioner. För att förstå hur hjärnan möjliggör dessa minnesfunktioner kommer Din hjärnas elektriska aktivitet att mätas (elektroencefalogram, EEG; even-related potential, ERP). Detta sker via elektroder som appliceras i hårbotten, en metod som är helt ofarligt och som inte medför några risker. EEG/ERP-data har en mycket hög tidsupplösning, data kan lagras varje millisekund från samtliga elektroder, vilket möjliggör en viktig inblick i när olika aspekter av informationsbearbetning äger rum och i hur samspelet mellan olika regioner av hjärnan sker.

Syftet med studien är att förstå hur minnesfunktioner och tankeverksamhet är organiserade i hjärnan. Avsikten är att kartlägga hur hjärnan arbetar under det att vi lagrar och plockar fram information ur minnet, att förklara varför vi ibland glömmer, samt att belysa samspelet mellan olika hjärnregioner.

Studiens genomförande och risker

Sessionen börjar med att elektroderna appliceras på rätt plats med hjälp av en elastisk mössa. Efter det att kvaliteten på EEG-registreringen fastställs ges detaljerade instruktioner inför minnestestet.

Experimentet består av två huvuddelar. I en del kommer ett antal stimuli (t ex ord, bilder) att presenteras och Din uppgift är att försöka lägga dessa på minnet och i en andra del kommer Din minnesprestation för det inlärda materialet att mätas.

Experimentet är helt datoriserat, vilket innebär att Du kommer att presenteras för olika typer av stimuli på en datorskärm och att alla Dina bedömningar samlas in för lagring via knapptryckningar.

Som angetts ovan är EEG-registrering helt ofarlig och smärtfri. Dock bör det nämnas att den i sällsynta fall kan orsaka lindrig och övergående hudirritation.

Undersökningstiden är mellan två och tre timmar, inkluderande applicering av elektroder.

Hantering av data

Persondata från studien kommer att lagras i ett register och databehandlas. Dina uppgifter är sekretesskyddade och ingen obehörig har tillgång till registret. Då data från studien publiceras kommer enskilda individer inte att kunna identifieras. Hanteringen av Dina uppgifter regleras av Personuppgiftslagen (SFS1998:204). Se bifogad bilaga med allmän information om behandling av personuppgifter i forskningssyfte vid Lunds universitet.

Sekretess

Vi behandlar resultaten av studien konfidentiellt.

Frivillighet

Du deltar helt frivilligt och kan när som helst avbryta Din medverkan i studien utan att behöva ange någon anledning.

Ytterligare information

Förutom denna skriftliga information kommer Du att bli muntligen informerad före undersökningen. Då får Du också möjlighet att ställa frågor. Du är också välkommen att ringa projektansvarig för att få ytterligare information.

Mikael Johansson, projektansvarig
Fil. dr., bitr. universitetslektor
Neuropsykologiska avdelningen
Institutionen för psykologi
Tel: 046 – 222 36 39

Jag har muntligen informerats om studien och tagit del av den skriftliga informationen. Jag är medveten om att mitt deltagande i studien är fullt frivilligt och att jag när som helst och utan närmare förklaring kan avbryta mitt deltagande.

______________________ Datum	______________________ Datum
______________________ Deltagarens signatur	______________________ Studieansvarigs signatur
______________________ Deltagarens namnförtydligande	______________________ Studieansvarigs namnförtydligande

Appendix B The stimulus material

Amerikansk delstat	Alaska	target
Amerikansk delstat	Colorado	target
Amerikansk delstat	Hawaii	target
Amerikansk delstat	Idaho	target
Amerikansk delstat	Minnesota	target
Amerikansk delstat	Utah	target
Amerikansk delstat	Oregon	nontarget
Amerikansk delstat	Georgia	nontarget
Amerikansk delstat	Kansas	nontarget
Amerikansk delstat	Louisiana	nontarget
Amerikansk delstat	Virginia	nontarget
Amerikansk delstat	Wyoming	nontarget
Blomma	Blåklocka	target
Blomma	Lilja	target
Blomma	Nejlika	target
Blomma	Prästkrage	target
Blomma	Tussilago	target
Blomma	Vitsippa	target
Blomma	Gerbera	nontarget
Blomma	Hundkäx	nontarget
Blomma	Iris	nontarget
Blomma	Krokus	nontarget
Blomma	Orkidé	nontarget
Blomma	Snödroppe	nontarget
Leksak	Bilbana	target
Leksak	Gunghäst	target
Leksak	Hopprep	target
Leksak	Klossar	target
Leksak	Pussel	target
Leksak	Nalle	target
Leksak	Leklera	nontarget
Leksak	Dockskåp	nontarget
Leksak	Frisbee	nontarget
Leksak	Skallra	nontarget
Leksak	Målarbok	nontarget
Leksak	Tennfigur	nontarget
Musikstil	Blues	target
Musikstil	Country	target
Musikstil	Dansband	target
Musikstil	Klassisk	target
Musikstil	Soul	target

Musikstil	Reggae	target
Musikstil	Electro	nontarget
Musikstil	Funk	nontarget
Musikstil	Progg	nontarget
Musikstil	Metal	nontarget
Musikstil	Opera	nontarget
Musikstil	Trance	nontarget
Fisk	Abborre	target
Fisk	Braxen	target
Fisk	Karp	target
Fisk	Makrill	target
Fisk	Sill	target
Fisk	Tonfisk	target
Fisk	Flundra	nontarget
Fisk	Hammarhaj	nontarget
Fisk	Långa	nontarget
Fisk	Piraya	nontarget
Fisk	Rödspätta	nontarget
Fisk	Öring	nontarget
Yrke	Advokat	target
Yrke	Brandman	target
Yrke	Frisör	target
Yrke	Ingenjör	target
Yrke	Rörmokare	target
Yrke	Städare	target
Yrke	Designer	nontarget
Yrke	Präst	nontarget
Yrke	Tandläkare	nontarget
Yrke	Massör	nontarget
Yrke	Väktare	nontarget
Yrke	Kock	nontarget
Textilmaterial	Kashmir	target
Textilmaterial	Manchester	target
Textilmaterial	Nylon	target
Textilmaterial	Polyester	target
Textilmaterial	Sammet	target
Textilmaterial	Ylle	target
Textilmaterial	Chiffong	nontarget
Textilmaterial	Elastan	nontarget
Textilmaterial	Denim	nontarget
Textilmaterial	Goretex	nontarget
Textilmaterial	Tyll	nontarget
Textilmaterial	Velour	nontarget
Sjukdom	Influensa	target
Sjukdom	Diabetes	target
Sjukdom	Klamydia	target
Sjukdom	Leukemi	target
Sjukdom	Malaria	target
Sjukdom	Tuberkulos	target
Sjukdom	Benskörhet	nontarget
Sjukdom	Epilepsi	nontarget
Sjukdom	Herpes	nontarget
Sjukdom	Njursten	nontarget
Sjukdom	Parkinsons	nontarget

Sjukdom	Reumatism	nontarget
Dansstil	Balett	target
Dansstil	Disco	target
Dansstil	Foxtrot	target
Dansstil	Jitterbug	target
Dansstil	Polka	target
Dansstil	Salsa	target
Dansstil	Rumba	nontarget
Dansstil	Lambada	nontarget
Dansstil	Magdans	nontarget
Dansstil	Quickstep	nontarget
Dansstil	Twist	nontarget
Dansstil	Wienervals	nontarget
Seriefigur	Fantomen	target
Seriefigur	Nemi	target
Seriefigur	Tintin	target
Seriefigur	Långben	target
Seriefigur	Skalman	target
Seriefigur	Rocky	target
Seriefigur	Dilbert	nontarget
Seriefigur	Homer	nontarget
Seriefigur	Ernie	nontarget
Seriefigur	Buster	nontarget
Seriefigur	Kronblom	nontarget
Seriefigur	Obelix	nontarget
Fågel	Duva	target
Fågel	Fiskmås	target
Fågel	Papegoja	target
Fågel	Rödhake	target
Fågel	Svala	target
Fågel	Talgoxe	target
Fågel	Albatross	nontarget
Fågel	Gråsparv	nontarget
Fågel	Häger	nontarget
Fågel	Kungsörn	nontarget
Fågel	Nötskrika	nontarget
Fågel	Undulat	nontarget
Fyrbent djur	Flodhäst	target
Fyrbent djur	Giraff	target
Fyrbent djur	Lejon	target
Fyrbent djur	Råtta	target
Fyrbent djur	Tiger	target
Fyrbent djur	Varg	target
Fyrbent djur	Antilop	nontarget
Fyrbent djur	Björn	nontarget
Fyrbent djur	Dromedar	nontarget
Fyrbent djur	Hyena	nontarget
Fyrbent djur	Ekorre	nontarget
Fyrbent djur	Panter	nontarget
Fotbeklädnad	Galosch	target
Fotbeklädnad	Pumps	target
Fotbeklädnad	Känga	target
Fotbeklädnad	Mockasin	target
Fotbeklädnad	Socka	target

Fotbeklädnad	Träsko	target
Fotbeklädnad	Boots	nontarget
Fotbeklädnad	Damask	nontarget
Fotbeklädnad	Ridstövel	nontarget
Fotbeklädnad	Innesko	nontarget
Fotbeklädnad	Nätstrumpa	nontarget
Fotbeklädnad	Joggingsko	nontarget
Frukt	Ananas	target
Frukt	Citron	target
Frukt	Kiwi	target
Frukt	Mango	target
Frukt	Plommon	target
Frukt	Vindruva	target
Frukt	Rambutan	nontarget
Frukt	Fikon	nontarget
Frukt	Guava	nontarget
Frukt	Litchi	nontarget
Frukt	Nektarin	nontarget
Frukt	Satsumas	nontarget
Sport	Badminton	target
Sport	Höjdhopp	target
Sport	Innebandy	target
Sport	Golf	target
Sport	Pingis	target
Sport	Simning	target
Sport	Cricket	nontarget
Sport	Fäktning	nontarget
Sport	Rodd	nontarget
Sport	Karate	nontarget
Sport	Diskus	nontarget
Sport	Vattenpolo	nontarget
Stad	Berlin	target
Stad	Uppsala	target
Stad	Köpenhamn	target
Stad	Madrid	target
Stad	Paris	target
Stad	London	target
Stad	Chicago	nontarget
Stad	Glasgow	nontarget
Stad	Santiago	nontarget
Stad	Auckland	nontarget
Stad	Istanbul	nontarget
Stad	Dubai	nontarget
Krydda	Basilika	target
Krydda	Oregano	target
Krydda	Rosmarin	target
Krydda	Saffran	target
Krydda	Vitpeppar	target
Krydda	Chili	target
Krydda	Anis	nontarget
Krydda	Dill	nontarget
Krydda	Ingefära	nontarget
Krydda	Koriander	nontarget
Krydda	Mynta	nontarget

Krydda	Persilja	nontarget
Bilmärke	Ferrari	target
Bilmärke	Honda	target
Bilmärke	Opel	target
Bilmärke	Porsche	target
Bilmärke	Renault	target
Bilmärke	Skoda	target
Bilmärke	Bentley	nontarget
Bilmärke	Chevrolet	nontarget
Bilmärke	Jeep	nontarget
Bilmärke	Lada	nontarget
Bilmärke	Mitsubishi	nontarget
Bilmärke	Trabant	nontarget
Klädesplagg	Jacka	target
Klädesplagg	Kofta	target
Klädesplagg	Linne	target
Klädesplagg	Mössa	target
Klädesplagg	Skjorta	target
Klädesplagg	Trosor	target
Klädesplagg	Baddräkt	nontarget
Klädesplagg	Fluga	nontarget
Klädesplagg	Halsduk	nontarget
Klädesplagg	Overall	nontarget
Klädesplagg	Pullover	nontarget
Klädesplagg	Vantar	nontarget
Köksredskap	Durkslag	target
Köksredskap	Gryta	target
Köksredskap	Mixer	target
Köksredskap	Rivjärn	target
Köksredskap	Stekspade	target
Köksredskap	Visp	target
Köksredskap	Brödkniv	nontarget
Köksredskap	Fruktpress	nontarget
Köksredskap	Hålslev	nontarget
Köksredskap	Kavel	nontarget
Köksredskap	Osthyvel	nontarget
Köksredskap	Ugnsform	nontarget
Alkoholfri dryck	Cider	target
Alkoholfri dryck	Iste	target
Alkoholfri dryck	Juice	target
Alkoholfri dryck	Kaffe	target
Alkoholfri dryck	Oboy	target
Alkoholfri dryck	Nyponsoppa	target
Alkoholfri dryck	Lemonad	nontarget
Alkoholfri dryck	Päronsoda	nontarget
Alkoholfri dryck	Milkshake	nontarget
Alkoholfri dryck	Ramlösa	nontarget
Alkoholfri dryck	Smoothie	nontarget
Alkoholfri dryck	Välling	nontarget
Land	Australien	target
Land	Italien	target
Land	Japan	target
Land	Ryssland	target
Land	Kanada	target

Land	Finland	target
Land	Bolivia	nontarget
Land	Colombia	nontarget
Land	Schweiz	nontarget
Land	Holland	nontarget
Land	Egypten	nontarget
Land	Portugal	nontarget
Musikinstrument	Cello	target
Musikinstrument	Flöjt	target
Musikinstrument	Harpa	target
Musikinstrument	Munspel	target
Musikinstrument	Saxofon	target
Musikinstrument	Trombon	target
Musikinstrument	Gurka	nontarget
Musikinstrument	Dragspel	nontarget
Musikinstrument	Luta	nontarget
Musikinstrument	Oboe	nontarget
Musikinstrument	Ukulele	nontarget
Musikinstrument	Banjo	nontarget
Kroppsdel	Hand	target
Kroppsdel	Mage	target
Kroppsdel	Näsa	target
Kroppsdel	Bröst	target
Kroppsdel	Rumpa	target
Kroppsdel	Armbåge	target
Kroppsdel	Lunga	nontarget
Kroppsdel	Tand	nontarget
Kroppsdel	Kind	nontarget
Kroppsdel	Svanskota	nontarget
Kroppsdel	Vrist	nontarget
Kroppsdel	Örsnibb	nontarget