Neural processes underlying conceptualization in language production

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Contents

Abbreviations

ANOVA	Repeated-measures analysis of variance
BOLD	Blood-oxygenation level dependent effect
EEG	Electroencephalography
ERP	Event-Related Potential
FMRI	Functional magnetic resonance imaging
LIFG	Left inferior frontal gyrus
LMTG	Left middle temporal gyrus
LSTG	Left superior temporal gyrus
MEG	Magnetoencephalography
PET	Positron emission tomography
RT	Reaction time
SOA	Stimulus onset asynchrony
SMA	Supplementary Motor Area
SVO	Subject Object Verb sentences
VOL	Voice Onset Latency

I. Theoretical background

1.1. General Introduction

Having a conversation is not as easy as it seems. During one-to-one discourse, one has to take several factors into account to have an understandable conversation both for the speaker and for the listener. As a speaker, the starting point is one's own knowledge about a specific topic, followed by the message one wants to convey. To make sure the listener understands one has to take his/her knowledge into account, as well as the information this person gathered in the conversation already. Of course, this 'tuning' of speaker and listener also depends on the type of discourse. If one gives a lecture, the 'discourse rules' (i.e. what is one's role in the conversation and how does one translate ideas into speech best to fit that role) will be different compared to a one-on-one conversation in a pub. During a typical pub conversation, several topics will be covered. Switching between different topics may seem effortless without forgetting what was talked about. However, to keep track of the mentioned topics one needs to store them in a so called 'discourse model'. That model will be adjusted every time a new topic or new information about a mentioned topic comes up. This task entails that both, speaker and listener, have to keep 'a list' of the topics talked about. This prevents repetitions but moreover, this is also important in case one wants to refer to an already mentioned topic again. These kinds of decisions mentioned here are made during the conceptualization phase, the first phase of speech production according to psycholinguistic models (Caramazza 1997; Humphreys, et al. 1988; Levelt, et al. 1999; Peterson and Savoy 1998).

These models describe different stages that one has to go through in order to articulate a message. Although the different speech production models agree on the existence of the different stages, there is some discrepancy about how these stages interact. Conceptualization however, is viewed as the first stage and can be separated in two different sub-stages: macro – and micro planning (Levelt 1989; 1999). The detailed understanding of these two stages of conceptualization during language production will be the focus of this thesis.

The first phase, macro-planning, involves choosing an idea/intention ('what do I want to say') and the linguistic ordering of this idea within a sentence. The linearization problem that occurs here (i.e., choosing what to say first, what will follow etc.) is usually solved by using a chronological order strategy (Levelt 1989). This means that an event that occurred first in time is also mentioned first in speaking. To tap into the details of linearization and macro-planning, we compared the production of chronologically ordered sentences (sentences starting with 'After') with sentences where this strategy was violated (sentences starting with 'Before').

During the second phase, micro planning, ideas are translated into preverbal messages by means of accessible concepts (Levelt 1989). This means that a speaker, once a topic has been chosen, has to think about how to introduce this topic. A topic can either be un-accessible ('new') or accessible ('already known') for a listener. In case a topic has not been mentioned before, ('new'), the speaker will choose a full description of the topic to give the listener as much information as possible.

However, when a topic has already been in discourse, speakers tend to reduce the size of referential expressions when referring to this topic. An example of reduction is the use of pronouns; referring to a person that has already been mentioned is done by the use of a pronoun (Levelt 1989). ('Yesterday, I met *a woman*. *She* was wearing a blue sweater.'). We investigated reduction and the use of pronouns by letting subjects create utterances in which two new topics were introduced (nominalization condition; use of two nouns) and sentences in which one topic was introduced and repeated (pronominalization condition; use of a noun and a pronoun).

In order to gain initial understanding of the neural correlates underlying macro- and micro-planning processes, I employed event-related potentials (temporal information) as well as slow event-related functional magnetic resonance imaging (spatial information).

After giving an overview of the speech production theories and the different stages it entails, I will go into the timing and the neuroanatomical location of these stages. Next, conceptualization and the sub-stages macro- and micro planning will be described in more detail, leading to the experiments done for both stages.

1.2. Speech production

Children take approximately six years to learn their language, or more specifically, to develop a constructive language network (Bloom 2001). As babies, we spend the first year of our lives babbling, creating all kinds of articulatory gestures that do not bear any meaning. Babies learn the word 'mama' by picking it up from the environment first and carefully attending to the sounds. As they get more tuned to their mother tongue, it starts to sound more and more like real-word output although it still does not have any meaning for the child (De Boysson-Bardies and Vihman 1991). Real word production starts when babbling ('mama') gets connected to the meaning of the word (the lexical concept). During the next step in the development the child's lexicon expands enormously and it re-organises its lexicon by means of phonemization; words become represented by their phonological segments (phonological encoding stage; the word 'mama' is stored as the repetition of the one syllable 'ma'). At the moment the child is about four years old it starts producing multi-word sentences. To do so, it creates a 'lemma system'. These lemmas contain the syntactical information for each lexical concept (for the word 'mama', this would be 'noun', 'gender is female' and so on). In sum, within the first six years of our lives, we change from a two-stage language model (from lexical concept to articulatory gesture) to a four-level processing model, going from (1) activating a lexical concept and (2) retrieval of the belonging syntactical information (lemmas) to (3) phonological and (4) phonetic encoding in order to produce the right articulatory gesture (Bock 1982; Garrett 1975; Kempen and Huijbers 1983; Levelt 1989).

Other evidence for these four different stages comes from speech errors (Fromkin 1973; Garrett 1975) and picture naming studies (Lupker 1979; Potter, et al. 1984; Rosinski, et al. 1975). Speech error studies showed that word exchange errors (replacing one word for another one; 'She *took* it and *bought* it with her' instead of 'She *bought* it and *took* it with her') can span quite some distance between the replaced words without changing the grammatical category and function of the exchanged clauses. On the other hand, sound/ form exchange errors ('*k*ite *w*hite' instead of '*w*hite *k*ite') only occur between closed-spaced words without preserving grammatical category (Garrett 1975). These were two important findings that supported the notion that stages preceding speech production can be divided into two levels of processing; one level where syntactic information gets assigned and a second level where form encoding (morpheme and phoneme information) is organised. Another important finding came from Shattuck-Hufnagel (1979) who showed that sound errors tend to preserve syllable position ('p*o*pe sm*i*ker' instead of 'p*i*pe sm*o*ker'), therefore concluding that phonemes contain a syllable specified position when retrieved from the lexicon. This was seen as extra evidence for a separate phonological encoding level.

A second line of research addressing language production uses the picture naming paradigm. In picture-word interference tasks, subjects have to name a visually presented object that is combined with a printed (or acoustically presented) distractor word (Glaser and Düngelhoff 1984; Glaser and Glaser 1989; La Heij, et al. 1990). These studies showed that a semantic related distractor word (for example 'goat' when the picture depicts a 'sheep') inhibited the response of the subjects whereas a phonological related distractor facilitated the response (for example ‘sheet’ when the target word is ‘sheep’). When varying the stimulus-onset asynchrony between the object and the distractor (the distractor can be presented before, simultaneously, or after presentation of the object), it turned out that semantically related distracters have their maximum effect on response latencies at shorter SOAs than phonological distracters, revealing an important temporal order effect that led to the conclusion that semantical information must be processed earlier than phonological information (for an overview see Levelt et al., 1999). This confirmed the idea of different levels of speech production.

1.3. Speech production models and the different stages

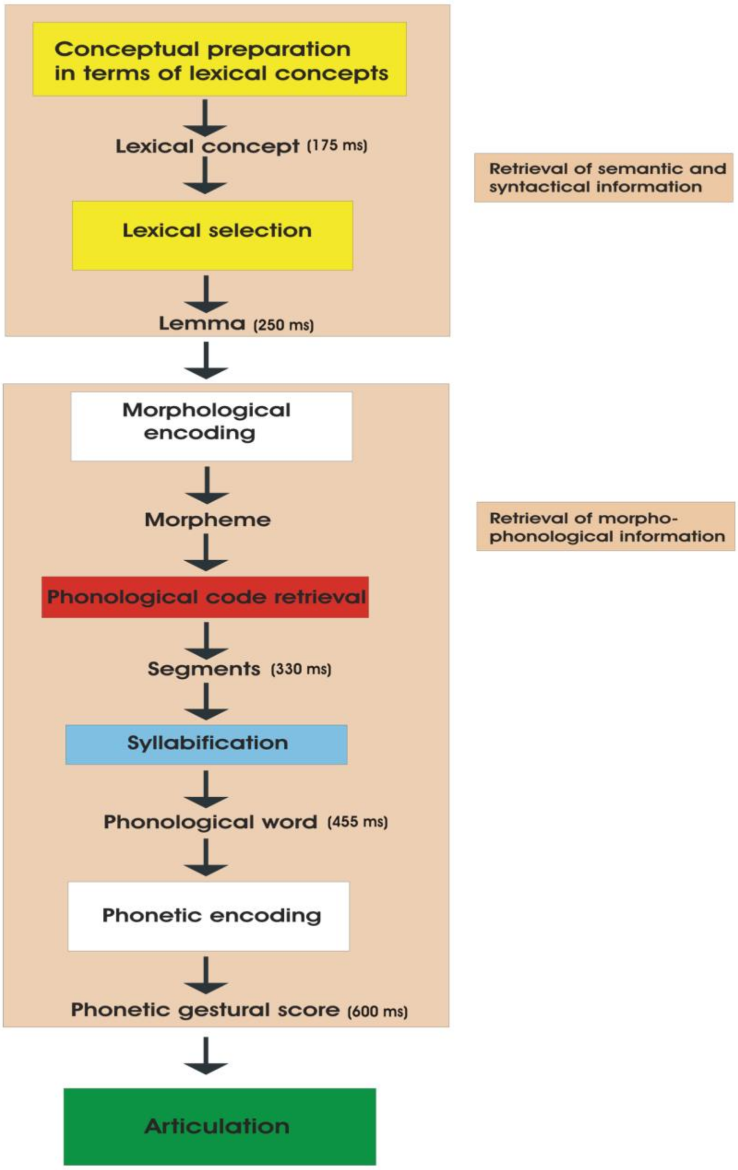
In order for a speaker to express a certain idea or topic, he needs to have a storage place containing the words of his/her language. This storage place is called the mental lexicon (Levelt 1989). Each item that is stored in this lexicon has four features. The first one is the meaning of the item. For example, the word ‘car’ denotes a ‘means of transportation’ or something similar. Second, its syntactic properties are specified, like category (in this case ‘noun’; other categories could be verbs, adjectives, conjunctions and so on), grammatical arguments (arguments that fulfil certain thematic roles) and so on. Third, a morphological specification of the item (for this example this would mean only the root form, i.e. there is only one morpheme) and last a phonological specification (syllable information). These four features can be split into two large parts; the first part containing the semantic and syntactic information belonging to an item, and the second part containing the form information (articulatory information).

The different stages preceding speech are based upon these different features (Figure 1.1. gives an outline of the different stages of speech production). (**1**) The first stage is called **conceptualization** and contains two sub-stages; (*i*) the first one is choosing a topic/item for expression (in terms of the model, this is called choosing a '*lexical concept*'). (*ii*) After a lexical concept has been chosen, its semantical and syntactic information will be retrieved (again, in terms of the model this is called *lemma retrieval*).

This first conceptualization stage is followed by (**2**) **form encoding**. This stage contains the retrieval of articulatory information and can be divided into three sub-stages. (*iii*) The first stage is morpho-phonological encoding which entails the retrieval of the word's morphological code (also called *morpho-phonological code retrieval*). For example, the word 'dogs' has two morphemes; the stem 'dog' and the added plural form 's'. Thus, two morpho-phonological codes need to be retrieved. (*iv*) This is followed by the second sub-stage, called *phonological encoding* proper. The word 'dogs' will then be divided into segments (/d/, /o/, /g/, /s/) and for each of these segments the phonological code will be retrieved and put together in a syllabic pattern. (*v*) The last stage is *phonetic encoding*, during which these syllables are turned into motor action instructions, leading to (**3**) **articulation** (Bock 1982; Dell 1986; 1988; Garrett 1975; Kempen and Huijbers 1983; Levelt 1989; 1999).

These different features of one item are connected, to make sure that a slightly different presentation of the item will also be recognised (for example 'carS', has the same basic meaning but a different syntactical and morphological structure).

Figure 1.1. A schematic representation of the speech production stages and the respective timing estimates.



1.4. ERPs related to speech production stages

In 1929, Hans Berger discovered that the electrical activity of the human brain could be measured by placing electrodes on the scalp, amplifying the signal and plotting the changes as voltage over time. The resulting diagram is called the electroencephalogram (EEG). Buried within the spontaneous oscillations that make up the EEG, neural responses to sensory, cognitive and motor events occur which can be extracted by means of averaging and filtering techniques. These specific responses are called event-related potentials (ERPs). The advantage of ERPs is their accurate timing information. Speech production for example, is achieved with amazing speed, going from the initial planning stage to articulation in just a few hundred milliseconds. If one intends to capture the neural events involved in speaking as they unfold in time, electrophysiological measures are a good method of choice.

An example of an intensively studied ERP component is the P300. This is a positive (hence P) deflection, peaking around 300 ms (hence 300) and it has originally been investigated in studies manipulating target probability. The amplitude of this component increases with a decreasing target probability (Picton, et al. 1992; Polich 2004; Pritchard 1981), but subsequent research has shown that the P300 amplitude varies as a function of multiple factors, among them the significance of the elicited stimulus, its subjective and objective probabilities, its targetness and so on (Johnson 1986). With regard to language processes, several components have been described:

The left anterior negativity (LAN) has been found in association with syntactic processing, occurring between 300 and 500 ms (Friederici, et al. 1996; Kluender and Kutas 1993; Münte, et al. 1993; Osterhout and Holcomb 1992). However, an earlier version of this component appears between 100 and 300 ms (Friederici 2002; 1993; Neville, et al. 1991) and is found to be responsive to word category violations (Friederici, et al. 1996; Hagoort, et al. 2003a; Münte, et al. 1993) and mismatches of gender, number, tense and case (Münte and Heinze 1994; Münte, et al. 1993). The N400, a negativity appearing between 300 and 500 ms, has been shown to be responsive to semantic mismatches (Kutas and Donchin 1980; Kutas and Van Petten 1994) and semantic, or discourse, integration processes (Brown and Hagoort 1993; Osterhout and Holcomb 1992; Van Berkum, et al. 1999).

A second component that reflects syntactic processing is the P600 (Hagoort, et al. 1993a; Osterhout and Holcomb 1993). This positivity, occurring between 500 and 800 ms, has been linked to syntactic (re) analysis and revision processes (Friederici 1995; Hagoort, et al. 1993b; Münte, et al. 1998), syntactical ambiguity (Osterhout, et al. 1994; Van Berkum, et al. 1999a), complexity (Kaan, et al. 2000) or, more recently, unification processes (Hagoort 2003a).

In the following, I will consider two components that have been used as temporal markers in language production experiments: the Lateralized Readiness Potential (LRP) and the N200. Whereas the former component is associated to response preparation (Kutas and Donchin 1974; Kutas and Donchin 1980), the latter negative deflection occurring at fronto-central sites is found for stimuli that require the inhibition of a motor response ('NoGo-stimuli') (Sasaki and Gemba 1993; Sasaki, et al. 1989). As such, both the LRP and the N200 are domain general, i.e. they are not specific indicators of language processes. The LRP component was first used by Van Turenhout et al. in two-choice go/no-go language production paradigms (1998; 1997). This kind of paradigm allows one to test the timing of two different kinds of processes (e.g. semantic and syntactic) in one trial. The first decision in this paradigm requires choosing whether to make a response with the left or the right hand ('hand decision'), while the second decision concerns whether the selected motor response should be executed or not ('go/nogo-decision). Whereas Van Turenhout et al. (1997; 1998) solely used the LRP to find timing differences between the different stages preceding speech production, Schmitt et al. (2000; 2001) measured the N200 component to pursue the same goal. For example, in Schmitt et al. (2000) the subject's task was (a) to make an animacy decision on a depicted object and (b) to determine whether the initial phonological segment of the target word was a vowel or a consonant. The instruction was, for example, to push a left button when the object was an animal and the right button when it was an object. However, to only respond only when the picture's name started with a vowel and subjects had to withhold their response when the picture's name started with a consonant. Subject's responses therefore reflected two decisions; a semantical and a phonological decision. The evaluation of the N200 latency in the different conditions (i.e., semantic information = go/nogo, phonological = hand, and vice versa) showed that semantical information became available approximately 90 ms earlier (380 ms) than phonological information (470 ms). Thorpe et al (1996) used a picture recognition task to show that activating a concept takes approximately 150 ms. However, withholding of a response, as in Schmitt et al. (2000) takes time to develop and therefore, we can assume that the time needed to activate a lexical concept is in between 150 and 200 ms.

A second study done by Schmitt et al. (2001) focused on the access of conceptual information. Subjects had to make decisions about the weight and about the (German) gender of a depicted object. In one case, the decision (go/nogo) was based upon weight information, and response hand (left or right) depended on the gender of the depicted object. In the reversed case subjects had to make a decision about the gender and the response hand was connected to the weight of the object. Latency differences on the N200 showed a delay of 73 ms when the decision depended on gender (i.e. syntactical information/ lemma retrieval). This difference in time was interpreted as the time needed to go from the accessed lexical concept to its lemma retrieval.

Investigating phonological encoding, in particular morpho-phonological encoding, Van Turenhout et al. (1998), using the go/no-go paradigm in a noun-phrase production task whilst looking at the LRP, found that a word's first phonological segment is available approximately 40 ms after lemma selection. Going further to phonological encoding proper, Van Turenhout et al. (1997) showed that syllabification processes take about 25 ms for each segment, meaning that the above example 'dogs' would take approximately 100 ms to syllabify.

In short, ERP studies have shown that there are time differences between the different types of information that are processed preceding language production. So far, accessing a lexical concept (lemma selection) during picture naming seems to occur 150-200 ms after picture onset. The second stage, lemma retrieval, seems to follow within 75 ms. Adding these would mean that the conceptualization phase ends approximately around 250 ms. The first stage of phonological encoding (i.e. morpho-phonological encoding) starts about 40 ms after lemma retrieval (at about 300 ms) and phonological encoding proper seems to take about 25 ms per segment (see Figure 1.1 for an overview of the temporal information related to each processing stage).

However, when looking at this temporal organization of word production, one has to take two things into account. First, a picture naming latency of 600 ms implies a rather simple task. Picture naming studies in an experimental setup tend to be quite easy and do not always reflect realistic situations. In other words, word naming latencies can be much longer than 600 ms, up to approximately 1200 ms depending on the experimental task (Indefrey and Levelt, 2004). Second, to give a clear overview of the timing of the different processes, this has been written in a serial matter. However, this does not mean that this is a serial process per se. As stated in the introduction, there is still a debate going on about the connections between the different stages and whether these are interconnected in a serial, cascading or parallel fashion. Taken together, this timing information is of critical importance to get a clear idea of how these processes are connected temporally. However, the exact timing information and conclusions about the nature of the connections need to be interpreted with caution.

1.5. fMRI studies related to speech production stages

fMRI refers to the use of Magnetic Resonance Imaging (MRI) to detect localized changes in blood flow and blood oxygenation level in the brain due to neuronal activity. This method is not used for gathering timing information, since changes in blood flow take some time. If we want to time quick processes, like language production for example, this method is to slow. However, it provides spatial information, i.e. it is able to reveal the locations in the brain that are involved in certain tasks.

fMRI studies investigating language processing have been extremely useful in gathering information about the neural networks associated with language. Indefrey and Levelt (2004) did a meta-analysis of speech production and comprehension studies and showed several areas that are involved in speech production. The studies that they used for the speech production meta-analysis included picture naming, word generation and word reading experiments. For the comprehension meta-analysis, studies were used that entailed (pseudo-) word listening tasks. By means of this meta-analysis, they looked at similarities and differences between comprehension and production and tried to relate the speech production model to the relevant neuroanatomical areas. This revealed that activation in the left middle temporal gyrus was associated with lemma retrieval. Further, semantic processing is said to be more distributed but mainly located in the left, middle and inferior temporal gyri (Indefrey and Levelt 2004; 2000).

The left posterior middle and the superior temporal gyri are said to be involved in phonological word-form retrieval since these areas were found activated when comparing word production versus non-word production (Indefrey and Levelt 2004; 2000). Syllabification processes appear to take place in the left inferior frontal gyrus (Broca's area) and the left mid-superior temporal gyrus (Indefrey and Levelt, 2000; 2004). Aleman (2005) and Scott and Johnsrude (2003) found phonological and phonetic processes to take place in the central and posterior temporal gyrus, and the superior temporal sulcus.

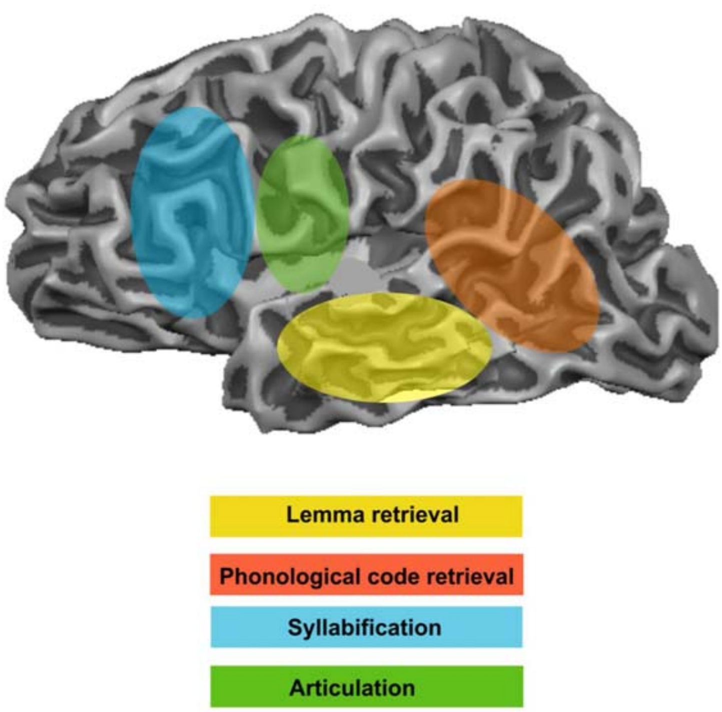
In sum, it appears that semantic and syntactical retrieval processes take place in the lower part of the temporal region, whereas phonological and phonetic processes seems to take place in the higher part of the temporal region as well as frontal areas. (Figure 1.2. displays a representation of the areas involved in speech production).

Hagoort (2005) proposes a more general language production and comprehension framework, the Memory-Unification-Control (MUC) model. This model is not referring to the different sub-stages of language production per se, but rather tries to look at more general processes that are involved in language. For example, the model contains a memory component that refers to the different kinds of language information that are stored in long-term memory and the retrieval of this information. The left temporal cortex plays an important role in these retrieval processes. Unification comprises the integration of lexical retrieved information into multi-word utterances. These processes seem to take place in the left inferior frontal gyrus (LIFG) and Broca's area.

The control component refers to the integration of online information and is associated with the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (DLPC), areas that are involved in verbal action planning and attentional control.

To sum up, lemma retrieval seems to take place in the left temporal region (middle and inferior temporal gyrus), as well as phonological retrieval processes (posterior and superior temporal gyrus) (Indefrey and Levelt, 2000; 2004). This finding is in concordance with the MUC model that talks about more general retrieval processes underlying language that take place in the left temporal region. The left frontal cortex appears to be involved in syllabification and integration processes.

Figure 1.2. A schematic representation of the brain areas involved in the different speech production processes.



1.6. Conceptualization

Going back to the first stage of the speech production models, i.e. conceptualization, we should remind ourselves that this entails choosing a certain topic and activating the corresponding semantic and syntactical information. Further, these processes are said to take place approximately in the first 350 ms (Jescheniak and Levelt 1994; Schmitt, et al. 2000; Thorpe, et al. 1996) and appear to be located in the left temporal region (Indefrey, et al. 2004; 2000; Maess, et al. 2002). But what exactly happens during this conceptualization phase? When a speaker has a certain communicational intention that he/she wants to convey to a listener, he has to take into account the world knowledge of the listener (also called common ground), one's own contributions to the conversation, but also the contributions that the listener has made or is expected to make in order to create the best understandable message. A so-called 'discourse-record' is created, an internal representation of all the things said during a conversation. Decisions about what to say and how to say it are made during the conceptualization phase. To be more specific, during macro-planning, an intention or goal is chosen, divided into sub-goals that are planned, ordered and specified for intended mood (e.g. declarative, interrogative, imperative) and content.

Its output is an ordered sequence of speech-act intentions (often shortened to speech acts, SA). These speech acts are further specified during the micro-planning phase, where they are assigned particular informational structures (e.g. what should be expressed as topical, focussed, or new information) and perspective. The output of this latter phase is called preverbal message (PM).

Note that these two processes do not necessarily have to be as separated and serial as is described here. It is very well possible that micro-planning already starts before macro-planning processes are completed. Both stages will be described in more detail below.

1.6.1. Macro-planning

As soon as a speaker wants to say more than a simple statement or remark, he is confronted with the linearization problem (Levelt, 1989). This means that he has to decide what to say first, what will come next and so on. This problem is solved by means of two sets of determinants; content-related and process-related determinants.

Content-related determinants are based on the principle of natural order, i.e. the order used corresponds to the chronological order. Looking at event structures, this means that the first event to happen in time is also the first to be mentioned in speaking. Natural order might be violated for reasons of 'topicalization', i.e. the speaker might utter the most important event at the beginning of the sentence. The use of temporal connectives 'before' and 'after' affords a speaker the freedom to choose which of two events in a sequence will be mentioned first in an utterance.

Importantly, these temporal connectives also inform the comprehender on the order of the upcoming events. 'After' indicates that events will be described in the actual order of occurrence, whereas 'before' signals the reverse order. (e.g. 'After I ate dinner, I did the dishes' or 'Before I did the dishes, I ate dinner').

An example of natural order in a different domain is the use of linear spatial structures. When describing a route to somebody, people use a 'source-to-goal spatial connectivity' strategy that expresses natural order as well; 'Turn right, walk until you see the church and when you are behind the church, turn right again'.

When there is no natural order and people have to describe multi-dimensional informational structures, process-related determinants are used. These are based on the principle of connectivity, meaning that one uses connections between different points in space to go from one location to the other (e.g. describing an apartment).

1.6.2. Micro-planning

When translating an intention into a preverbal message, there are four major aspects that are important to come to this level: accessibility, topicalization, assigning propositional format and perspective, and acknowledging language specific requirements (Levelt, 1989).

(1) First, the accessibility status of a topic needs to be checked. This means that a speaker has to have an idea how known a topic is for a listener. A topic can either be in-accessible ('new') or accessible ('already known'). If a topic is accessible, this can either be, because the topic already came up during the discourse or because speaker and listener have a common knowledge about the topic. For example, if the listener knows that Rome is the capital of Italy, this can either be because it was mentioned during the conversation or because this fact is in his general world knowledge. For accessible topics, a second distinction has to be made.

A topic has already been in discourse and one wants to refer to it again, or it is currently in the focus of the conversation (e.g. it is the main topic at that moment). Depending on the state of focus of the topic, a speaker will address this topic differently when one wants to refer to it. An example for introducing a new topic could be 'Yesterday, I went out with *A* colleague of mine'. If this topic has already been in discourse and one wants to refer to it again at a later point in time, this could be done by '*THE* colleague I was talking about came back from a holiday'. If this topic is in focus of discourse, one would refer to the same person as '*SHE* had been to Italy'. The example stated above shows reduction; speakers tend to reduce the size of referential expressions when a topic is repeated (i.e., use of pronouns instead of nouns).

During topicalization, a speaker has to make a decision about the importance of the referents he wants to talk about. The referent seen as the most important will get a priority treatment in grammatical encoding. For example, talking about the events 'having lunch' and 'getting fired', the latter clearly has more importance than the first event. Therefore, the second event will be put first and become subject of a sentence.

Perspective taking is about choosing relations and referent points between topics. An example of that would be to describe the interior of a house; one decides where to start the description and where to go from there. Last, acknowledging language specific requirements means that the speaker will automatically retrieve the conceptual information for the specific language spoken, such as temporal information (Levelt, 1989).

The understanding of connected discourse is highly dependent upon establishing links between topics and referents.

Examples are so-called role based links which are important when it comes to understanding something that is referring to an event mentioned previously.

1.7. Summary and Conclusions

The development of speech production research has shown that there are two main stages preceding speech; a first stage where semantic and syntactical information is retrieved and this is followed by the retrieval of form information. These two main stages can again be divided into several sub-stages. During the first sub-stage, conceptualization, a concept is activated and the corresponding semantic and syntactic information ('lemma') is retrieved. This stage is followed by the first sub-stage of form encoding, morpho-phonological encoding, during which morphological and phonological encoding proper takes place. This is followed by phonetic encoding and leading to the last articulation stage. Although the different speech production models agree on these different stages, there is still a debate going on whether these stages interact in a serial, cascading or parallel way.

In terms of timing of these stages, ERP studies have found that the different stages appear to have a different temporal order. The first stage, conceptualization, entails accessing a lexical concept and this seems to occur between 150-200 ms post-stimulus onset. This is followed by lemma retrieval (in approximately 75 ms), leading to a total of approximately 300 ms for the whole conceptualization stage.

Morpho-phonological encoding appears to take place about 40 ms after lemma retrieval and phonological encoding proper seems to take about 25 ms per segment.

fMRI studies that tapped into these different stages have revealed that different brain areas appear to be involved in the different stages. For example, retrieval processes (semantic, syntactic but also phonological) appear to take place in the left temporal cortex and the left frontal cortex is associated with integration processes.

Looking into conceptualization in more detail, a distinction can be made between macro- and micro-planning. During macro-planning, an intention is chosen and subsequently divided into sub-goals specified for intended mood and content. Its output is an ordered sequence of speech-act intentions (often shortened to speech acts, SA). During micro-planning, speech acts (SA) get assigned particular informational structures and perspective. The output of this latter phase is called preverbal message (PM).

Most language production research so far has focused on picture naming and word generation tasks, as is also shown by the ERP and fMRI studies revealing time and spatial information concerning conceptualization and form encoding processing.

As far as we know, macro- and micro planning have not been investigated in light of speech production yet. The present work therefore tries to gather more information about conceptualization in combination with language production, by looking in more detail into the two sub-stages macro- and micro planning.

1.8. Research Aims

The present thesis addresses the process of conceptualization in language production. In order to achieve a deeper understanding, the focus is on processes underlying macro-planning and micro-planning. During macro-planning, I investigated the linearization problem comparing 'before' and 'after' utterances. Concerning micro-planning, I looked at accessibility status comparing nominalization and pronominalization. ERP and fMRI were used in order to achieve insights into the temporal and neuroanatomical organization of the neural processes underlying macro-and micro planning.

The empirical part of the thesis is structured as follows:

Chapter 3: looked at macro-planning and linearization processes, in language production, using ERPs

Chapter 4: investigated linearization processes and macro-planning, preceding speech production, by means of fMRI

Chapter 5: examined micro-planning and accessibility processes, in language production, with ERPs

Chapter 6: considers micro-planning and accessibility processes, in language production, using fMRI

II. Language production and comprehension

Theories of word production and word comprehension have been developing in rather independent research traditions, although it should be clear that the two systems are intimately linked. This is also shown by picture interference paradigms where linguistic distracters affect the time course of word production (Glaser and Düngelhoff 1984; La Heij, et al. 1990; Lupker 1979).

During speech production, a mental concept is expressed. Words with appropriate semantic meaning are retrieved from the mental lexicon and processed for expression. During speech perception, the inverse process is performed and the final result of the comprehension process is the idea or concept of a given expression. Although intimately linked, there is also evidence from aphasia studies that two distinct processes underlie these two networks (Ferstl, et al. 1999; Linebarger, et al. 1983; Munhall 2001).

Most previous studies addressing the different language stages have focused on language comprehension (Brown, et al. 2000; Federmeier and Kutas 2001; Friederici 1995; Hagoort, et al. 2003b; Kaan, et al. 2000; Kutas and Federmeier 2000; Mecklinger, et al. 1995; Neville, et al. 1991; Osterhout, et al. 1994) mainly because the influence of speech on the ERP and fMRI signal is high. To keep speech production influences as little as possible and because the generation of longer utterances poses a second challenge in controlling for the underlying cognitive processes, language experiments investigating production have mainly used single word tasks like picture naming, word generation and word reading (for an overview of studies see (Indefrey and Levelt 2004; 2000)

Overt vocalization in ERP studies (Eulitz, et al. 2000; Liotti, et al. 2000) has shown that reliable and artifact-free ERPs can be generated in the interval between a stimulus and the respective vocalization of either picture naming or production of nominal phrases. Other researchers have rather used delayed vocalization procedures (Jescheniak, et al. 2002; Möller, et al. 2006) or have used button responses based on the covertly produced utterances (Schmitt, et al. 2000; Van Turenhout, et al. 1998) in order to avoid vocalization artifacts.

As for fMRI, several studies tapped into comprehension by means of violation paradigms (Friederici 1995; 2000; Hagoort 2003b; Hammer, et al. 2006) or by creating ambiguity in language processing (Brown, et al. 2000; Hammer, et al. 2005; Lamers, et al. 2006; Swaab, et al. 1998; Van Berkum, et al. 2003a). Some studies have tried silent word production (Binder 1995; Buckner 2000; Huang 2002) in comparison to overt production, but it appeared that silent speech does not activate the same brain areas as found during overt production (Barch 1999; Huang 2002; Palmer 2001).

There are a few studies that looked at overt speech production in combination with fMRI, either in terms of picture naming (Alario et al., 2006) or production of (SVO) sentences (Haller, et al. 2005; Kircher, et al. 2000). These studies showed that it is possible to minimize speech influences on the BOLD signal by means of several steps that will be discussed below.

Although language production should ideally be investigated by analyzing natural speech, overt vocalization leads to an increase in movement and artifacts due to the influence of speech.

These are two points that have to be considered thoroughly. The next section describes how the utterance of sentences was implemented in the thesis' ERP and fMRI experiments.

2.1. The present studies

Whilst tapping into conceptualization, we optimally used the timing difference between this stage and the actual utterance.

For the ERP experiments, this looked like follows; since we were interested in a time-interval of 600 ms triggered to the beginning of the conceptualization time-window, speech utterances did not influence this time window because (i) the length of the utterance was controlled for by instructing subjects to use the present tense for all sentence parts. This was also done to minimize variability in the utterance structures. (ii) Additionally, a stimulus cue was used to indicate that speech time was over. This cue was also used during the practice sessions to familiarize subjects with the amount of time they had for speaking. (iii) Further, the influence of the utterance on the consecutive trials was minimized by adding 500 ms trial time after the response time was over. (iv) Last, speech onset was checked by collecting RT data and by the use of speech prompts at the moment RTs were too quick (in case of the micro-planning ERP experiments).

For the fMRI experiments, control of the length of the utterances was identical to the ERP experiments. Further, the influence of speech on the consecutive trials was minimized by prolonging the trial time to 20 sec, adding approximately 15 sec after stimulus presentation and response.

Speech onset times were controlled by use of a camera that was aimed at the mouth. This method was not specific enough to collect RTs but gave an accurate utterance onset.

Prior to all measurements, subjects were instructed to move as little as possible and they received three practice trials in order to familiarize them with the stimulus material, the timing of presentation and the timing of speech. A detailed explanation about the procedure preceding the experiments can be found in the respective method section of each experiment.

During the measurement proper, it was important that subjects moved as little as possible and they were carefully instructed to achieve this. Since ERP has a high temporal resolution, the effect of movement on the signal is immediately visible and over at the moment overt responses finish. Speech reflects itself as muscle contractions on the ERP signal and since it has a different frequency than the ongoing ERP signal (the main signal is being measured with a frequency band of 0.5 until 30 Hz whilst muscle contractions have a frequency around 100 Hz), it can be subtracted from the main signal by means of filtering.

In sum, the high temporal resolution of ERPs leads to short-term effects of speech on the ERP signal and maximally separating the target window from the response window is therefore a reliable method to gain artifact-free data. However, overt responses in the fMRI scanner can cause repositioning of the jaw, head and tongue and this does not only lead to distortions but can also cause long-term effects like misregistration in the time series MR images (Barch, et al. 1999; Birn, et al. 1998; 1999a; Huang, et al. 2002).

There are several ways to solve this problem as best as possible. (i) First, one also uses the temporal delay of the BOLD signal to separate the window of interest as much as possible from the task performance window. This difference in temporal delay between motion induced changes and the BOLD response can then be used by ignoring the images made during motion. (ii) Additionally, if the overt speech time is kept short, it can be separated by periods of time sufficiently long to allow for full evolution of the hemodynamic response (Birn, et al. 1999a). During overt speech, muscles of the mouth, tongue and jaw move. This does not only lead to distortions in the BOLD signal but also to brief MR signal intensity changes in the moving muscles and in brain areas closely located to those muscles (i.e., the frontal areas). (iii) However, due to the time difference between overt vocalization and the BOLD signal, these changes occur earlier then the BOLD signal changes within the brain. (iv) Additionally, visual inspection shows that the BOLD response related to movement looks different in shape and time course since it has a sharper and more abrupt peak.

During the measurement, it was important that subjects moved as little as possible. Therefore, head movement was restricted by the use of cushions, placed around the head of the subjects. Further, misregistration in the time series images can be corrected by alignment, a step that is taken during preprocessing. Further details on preprocessing and data analysis will be described in the respective method-sections of each experiment.

III. Macro-planning and ERPs

Abstract

During conceptualization, ideas are transferred into linguistic representations.
The first phase, macro planning, contains choosing an idea/intention ('what do I want to say') and the linguistic ordering of this idea within a sentence. The linearization problem that occurs here (i.e., choosing what to say first, what will follow and so on) is usually solved by using a chronological order strategy. This means that an event that occurred first in time is also mentioned first in speaking. We investigated this linearization process by letting subjects create sentences containing a chronological order and sentences where this strategy was violated. This resulted in subjects producing utterances that started with the word 'After' (containing a chronological order) and 'Before' (sentences with an unnatural order).
Subjects saw a male or female face, followed by two objects combined with the numbers '1' and '2'. The task was to produce a sentence as quickly and accurately as possible, describing the male/female using the objects with a natural ('after') and unnatural ('before') time sequence. This time sequence was indicated by the numbers.
The aim of this study was to get more insight in the conceptualization process of linearization, and it was expected that the creation of an unnatural order would lead to more conceptualization processing.

3.1. Introduction

As soon as a speaker wants to say more than a simple statement or remark, he is confronted with the linearization problem (Levelt, 1989). This means that he/she has to decide what to say first, what will come next and so on. This problem can be solved by using content-related determinants. These determinants are based on the principle of natural order, i.e. the order used corresponds to the chronological order. Looking at event structures, this means that the first event to happen in time is also the first to be mentioned in speaking. Natural order might be violated for reasons of 'topicalization', i.e. the speaker might utter the most important event at the beginning of the sentence.

The use of temporal connectives 'before' and 'after' affords a speaker the freedom to choose which of two events in a sequence will be mentioned first in an utterance. Importantly, these temporal connectives also inform the comprehender on the order of the upcoming events. 'After' indicates that events will be described in the actual order of occurrence, whereas 'before' signals the reverse order. (e.g. 'After I ate dinner, I did the dishes' or 'Before I did the dishes, I ate dinner').

Research in the field of discourse semantics investigating what kind of information the temporal connectives 'before' and 'after' entail found that they trigger presuppositional effects (Heinämäki 1974). For example, the sentence 'I went on a holiday after I won the lottery' presupposes a causal relation between the two events in the sense that without the money, there would not have been a holiday (Schilder 2001). This implies that the temporal connectives *before* and *after* can not solely be seen as markers of temporal relationships. Moreover, the temporal relation created by *after* entails that the subordinate clause is true while *before* allows for the subordinate clause to be either true or false. If the subordinate clause is interpreted as false, or non-veridical, it conveys the meaning that the earlier event prevented the latter one from happening. The decision whether the subordinate clause is true or false is based on contextual or world knowledge. Further, Tenbrink and Schilder (2001) suggested that both *before* and *after* can express a narration (e.g., the event described second is a consequence of the first event), but in case of a *before* initial sentence, the main clause temporarily precedes the situation referred to by the before-clause. Thus, the usual order of events in narration is inverted.

This implies that *before* initial sentences are more difficult since they express an inverted narration relation between events. Language acquisition studies in children report divergent results when it comes to processing of temporal connectives. Some studies show that children have more difficulty acquiring 'before' than 'after' (Clark 1971; Feagans 1980), but there are also studies that report no differences between these temporal connectives (Amidon and Carey 1972). These divergent results can partly be explained by the differences in cognitive demands of the tasks being used. For example, Stevenson and Pollitt (1987) tested the understanding of temporal terms of English children aged 2 to 5 by letting them act out situations described by sentences containing the words 'before' and 'after'. They used three different tasks that differed in cognitive load and they found that children's performance improved when the cognitive load of the task was reduced. Further, children showed a tendency to act out only the first clause of before sentences. This implies that they do not understand the reversed temporal relation between events that is depicted by *before* sentences and the authors concluded that the children had greater difficulty understanding 'before' in comparison to 'after' sentences (see also Partee (1984)).

Similarly, Parkinson patients have also been shown to make more errors for sentences starting with 'before', since they tended to understand 'before' sentences as if they had started with 'after' (Natsopoulos, et al. 1991). In a related study by the same authors (Natsopoulos, et al. 1993), Parkinson patients also failed to understand so-called object-relative clauses (in which the subject of the main clause serves as the object of the relative clause).

These sentences were interpreted as subject-relative clauses, i.e. the subject of the main clause was also assumed to be the subject of the relative clause. Because of fewer filler/ gap positions in subject relative clauses, these sentences are less demanding on working memory. Taken together, because of their limitations in working memory, these studies suggest that Parkinson patients use semantic rather than syntactic information to guide understanding. Thus, it appears that the understanding of unnatural order sentences leads to more working memory processing.

The role of working memory in the processing of temporal connectives was investigated by means of an ERP study, done by Münte and colleagues (1998). During this study, participants read sentences that started with the temporal connectives 'Before' and 'After'. The sentences appeared one word at a time whilst EEG was recorded (e.g.; Before/After the psychologist submitted the article, the journal changed its policy) 'Before' sentences differed from 'After' sentences by a ramp-like negativity which started around 300 ms after onset of the sentence initial word and lasted for the entire sentence. This before/after-difference was greater for those participants' with better individual working memory capacity, indicating an immediate interaction (already at 300 ms after presenting before/after words) between working memory and linearization of conceptual events. The authors concluded that sentences containing an unnatural order of events are more demanding on working memory in comparison to natural order sentences, possibly leading to different discourse representations for the two types of sentences.

In sum, these studies seem to show that the temporal connective 'before', which reflects an unnatural order of events, is more difficult to understand than 'after', the temporal connective that reflects a natural, chronological order of events. This is confirmed by the ERP results that show an increased demand on working memory resources when an unnatural order was presented.

The present study addresses the use of temporal terms in production. We investigated linearization by letting subjects create sentences containing a chronological order, starting with the word 'After' and sentences where this strategy was violated (sentences with an unnatural order, starting with the word 'Before'). Subjects saw a male or female face, followed by two objects combined with the numbers '1' and '2'. The task was to produce a sentence as quickly and accurately as possible, describing the male/female using the objects, with a natural ('after') and unnatural ('before') time sequence. This time sequence was indicated by the numbers. As we supposed that the two conditions differ in working memory load, we expected to find ERP differences related to this fact (paralleling the results of Münte et al 1998, in the comprehension domain).

3.2. Methods Experiment 1

3.2.1. Participants

Twenty-one right-handed, neurologically healthy subjects aged between 20 and 28 (mean age 24.1, 9 women) with normal or corrected to normal vision and German as their native language gave informed consent to participate in this study. Fifteen subjects were used for the final ERP analyses; six subjects were rejected due to more than 25 % blinking and movement artefacts.

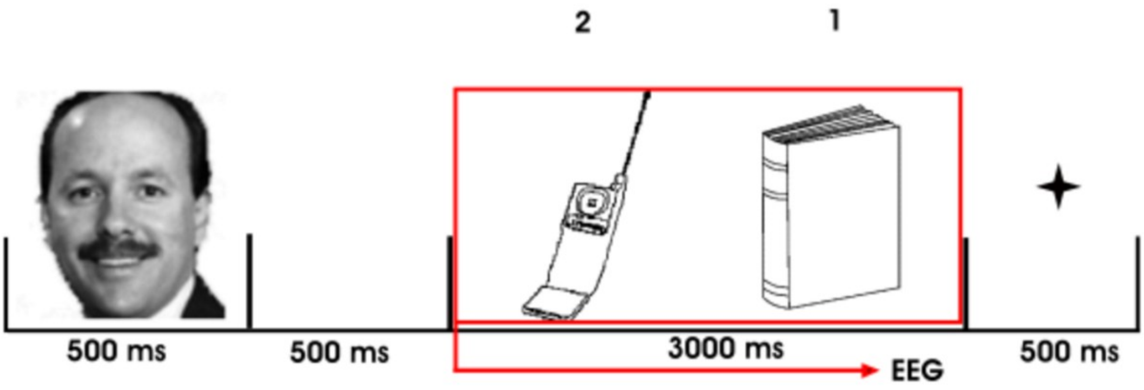
3.2.2. Stimuli

A total of 50 black and white object line-drawings taken from various sources (picture data base of the Max-Planck Institute for Psycholinguistics, Nijmegen; Snodgrass and Vanderwart, 1980) were used. Pictures were adapted with Corel Draw version 11.0 to meet the criteria of the same resolution (300 x 300 dpi), size (33 x 33 mm) and colour combination (black on white background). The object pictures were combined into pairs such that no semantic and phonological overlap between the words denoting the objects on the two pictures occurred. They were presented with a total of 50 male and 50 female faces in such a way that each object pair was presented twice in one condition (counterbalanced for the position of the pictures). This resulted in a total of 100 picture pairs per condition and 200 picture pairs for the entire experiment.

3.2.3. Procedure

Each trial comprised one face and a pair of objects combined with the numbers '1' and '2'. The male/female picture was presented for 500 ms, followed by a 500 ms blank interval. This was followed by the object pair combined with the numbers, presented for 3000 ms (see Figure 3.1 for an example of one single trial). The instructions were such that subjects had to produce a sentence describing the depicted person using the objects in a certain order. E.g., if the subject had seen the pair 'female face / couch and car', with the number 1 above the first object and the number 2 above the second object, the correct German utterance for a natural order would have been: 'Nachdem die Frau sitzt, fährt sie' (In English; 'After the woman sits (on the couch), she drives (a car)'; information in parentheses for clarification only). Likewise, if the number '2' was above the first object and the number '1' above the second object, the appropriate German utterance for an unnatural order would then be 'Bevor die Frau sitzt, fährt sie' (in English; 'Before the woman sits, she drives (a car)'). At the end of each trial, a fixation-point (presented for 500 ms) prepared subjects for the next trial. In order to optimally match the two types of utterances, subjects were instructed to use an identical sentence structure (except for the initial word). They always had to produce both sentence parts in present tense to minimise variability among the answers and to keep overt production time as short as possible. Additionally, subjects were instructed to utter the required sentence as soon as and as correctly as possible.

Figure 3.1. A single trial example. EEG was triggered by the onset of the pictures, indicated by the red block.



After the application of the EEG electrodes, subjects were seated in a sound-proof cubicle and received detailed explanations about their task during the experiment. They received three practice runs before the actual experiment started. During the first practice run, subjects saw the pictures of the objects with the corresponding verb and they had to learn the verbs to the objects. The second practice run then showed the same pictures without presentation of the verbs and subjects had to name the pictures out loud (with the learned verb). For these two practice sessions, subjects could take as much time as required and they had to perform errorless before continuing with the last practice session. The last practice session entailed example trials of the experiment itself, so that subjects could familiarize themselves with the timing of the stimuli. Subjects were told to sit as still as possible, and to blink only during the presentation of the fixation-point or while they were speaking.

3.2.4. Data acquisition and analysis

EEG was registered using tin electrodes mounted in an 32- channel electrode cap (FP1, FP2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, Fpz, Fz, Cz, Pz, Fc1, Fc2, Cp1, Cp2, Po3, Po4, Fc5, Fc6, Cp5, Cp6, positions of the 10/20 system) and a Synamps amplifier (NeuroScan Inc., Herndon, VA). Two additional electrodes were placed at the left and right mastoid for referencing. The electrode placed on the left mastoid was used for online referencing. Data were re-referenced off-line to the mean of the activity at the two mastoid electrode sites. Vertical eye movements were measured with a bipolar montage comprising electrodes placed above the left eyebrow and below the left orbital ridge. Horizontal eye movements were measured with two electrodes placed at the left and right external canthi. EEG-data were recorded continuously (time-constant 10 seconds, filter settings 0.5 to 30 Hz) with a sampling rate of 250 Hz. Electrode impedances were kept below 5 kΩ. The EEG was averaged for each picture-pair for epochs of 1024 ms including a 300 ms pre-stimulus baseline. The waveforms were measured in two time windows; 200-250 ms and 250-300 ms, chosen after visual inspection of the signal. For each time-window, mean amplitudes were measured at midline, temporal, and parasagittal sites (the exact electrode sites for each factor are mentioned in Table 2.4.). Factors were order (natural versus unnatural), anterior/posterior (5 levels for temporal, 7 levels for parasagittal, 3 levels for midline) and hemisphere (left versus right, the factor was not used for midline analyses).

Statistical testing was conducted using repeated measures analyses of variances (ANOVA), with a correction of degrees of freedom for non-sphericity (Greenhouse-Geisser algorithm) where necessary.

3.3. Results Experiment 1

3.3.1. Behavioural Results

Voice onset latencies (VOL) were collected by means of a voice key (Presentation, version 9.10). The responses of the fifteen subjects that also contributed to the ERP analysis were included in the analysis. There was a significant difference in onset time for the natural order condition (mean VOL = 1214 ms, SD = 165) versus the unnatural order condition (mean VOL = 1293 ms, SD = 189) ($T = -3.38$, $p < .004$).

3.3.2. Electrophysiological results

The grand average waveform time-locked to the picture onsets shows that the conditions start to diverge around 0 ms (see Figure 3.2.). The first peak, a negativity, peaks around 120 ms and is followed by a positivity peaking around 190 ms. A third peak, a frontal negativity, is found in time window 200-250 ms and this was followed by a later parietal component in the time window 250-300 ms.

The N1-P2 complex, normally occurring after visual stimulation, did not show any significant differences between the two conditions.

Time window 200-250 ms

A fronto-central analysis showed a significant main effect for the Factor order on a negativity that was higher for the after condition (see Figure 3.2 for the effect on the electrodes and Figure 3.3 for the topographical distribution of this effect).

Time window 250-300 ms

A main effect of order was found on midline and temporal electrodes. Parasagittal sites showed a main effect of order on centro-parietal electrodes. The positivity on these electrodes was larger for the before-condition in comparison to the after-condition (see Table 3.1 for a full overview of all significant effects in both time windows) Figure 3.2 shows the effect on separate electrodes and Figure 3.3 displays the topographical distribution.

Table 3.1. Comparisons of before versus after for the two time-windows. Given are the F-values (dF = 1,14)

	200-250 ms	**250 – 300 ms**
Parasagittal		
(F7/8,Fc5/6,T7/8,Cp5/6,P7/8)		
Centro-parietal (Cp5,Cp6,P7,P8)		
Order		5.37*
Temporal		
(F3/4,Fc1/2,C3/4,Cp1/2,P3/4,Po3/4,O1/2)		
Order		9.15***
Fronto-Central (F3,Fc1,F4,Fc2)		
Order	6.54*	
Centro-parietal (C3,C4,Cp1,CP2)		
Order		5.71*
Parieto-occipital (P3,P4,Po3,Po4,O1,O2)		
Order		7.90**
Midline(Fz,Cz,Pz)		
Order		7.51*

*** p < .001
** p < .01
* p < .05

Figure 3.2. Grand average ERPs at selected scalp sites time locked to the onset of the pictures which prompted the utterance. The after condition gave rise to a more negative waveform starting at about 200 ms (depicted in the blue area), followed by a centro-parietal positivity for before sentences around 300 ms (depicted in the pink area).

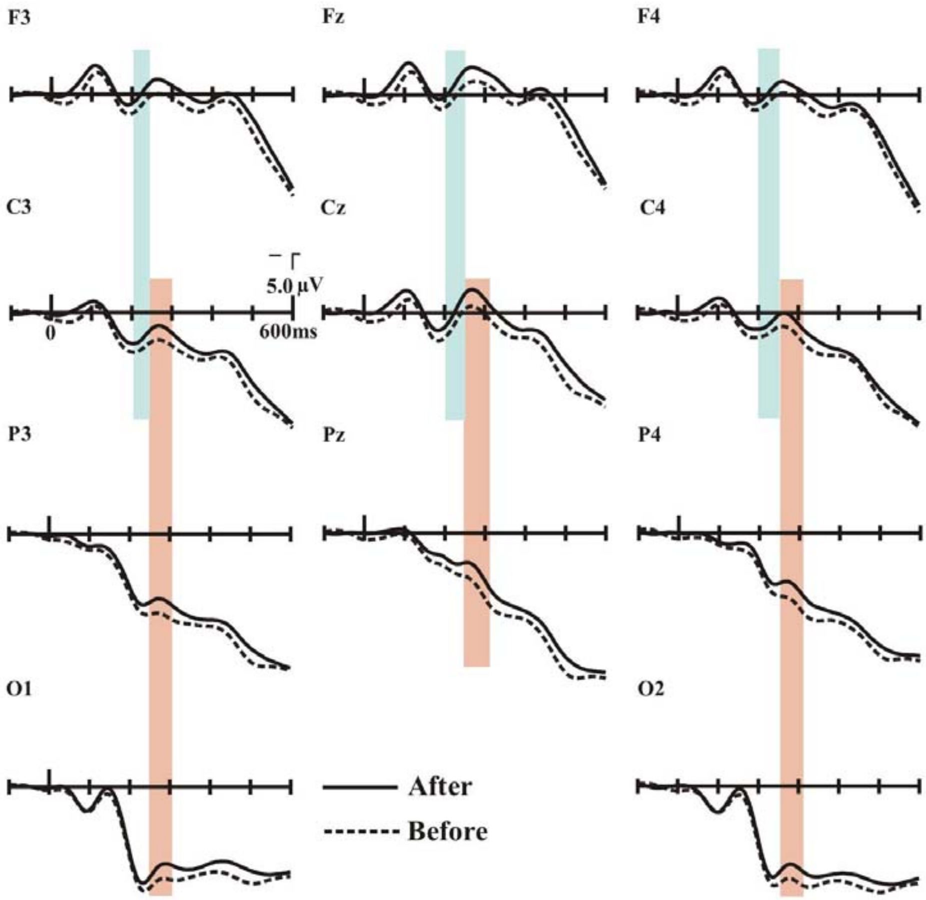
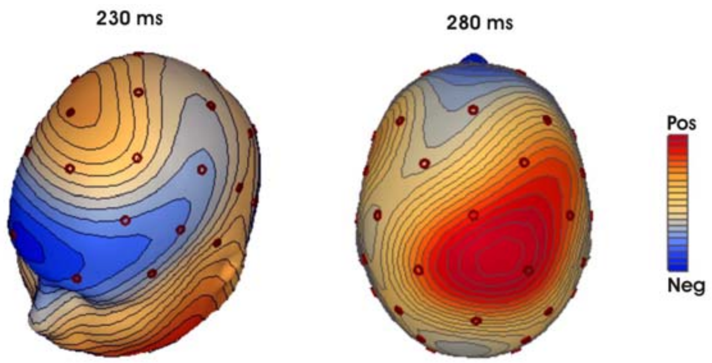


Figure 3.3. Spline interpolated isovoltage maps of the difference between the after and before condition. During the first phase a frontal distribution is evident, while around 300 ms a centro-parietal distribution emerges (min/max scaling: -0.63 to 0.63 µV at 230 and 280 ms).



3.4. Discussion Experiment 1

Voice Onset Latencies were later for unnatural order sentences in comparison to the production of a natural sequence of events. This suggests that 'unnatural' before-sentences are more difficult to produce than natural after-sentences. This parallels the results found by comprehension studies showing that 'before' sentences are more difficult to comprehend than 'after' sentences (Stevenson and Pollitt, 1987; Natsopolous et al., 1991).
Further, we found differences between the two conditions on two components, a fronto-central negativity in the time window 200-250 ms for the after condition, followed by a centro-parietal positivity for before sentences in the time window 250-300 ms.

When looking at the negativity, one could interpret this effect in terms of modulation of working memory, a result found in language comprehension studies before (King and Kutas 1995; Mecklinger, et al. 1995; Müller, et al. 1997). Also, Münte et al. (1998) found a difference in the understanding of temporal terms in relation to working memory as well. They found a greater left frontal negativity for 'before' sentences in comparison to 'after' sentences, revealing largest differences for subjects with high scores for working memory span. They concluded that this left frontal negativity represented an immediate interaction between working memory and linearization of conceptual events. In other words, sentences containing an unnatural order of events are more demanding on working memory. If we interpret the amplitude difference on the frontal component in the present study in terms of the cited comprehension study, this would imply that creating a natural order would be more difficult than creating an unnatural order, an explanation that feels counterintuitive at first glance, because it is supposed that the natural-order condition would be the more natural and therefore easier and less demanding on working memory. I will come back to the direction of this effect in the general discussion part of this chapter.

Further, we found a parietal positivity between 250 and 300 ms for the before condition. Its distribution and polarity suggest that this may be an instance of the P300. The P300 is a well-known component often found in tasks investigating attention devoted to a stimulus, stimulus salience, task relevance, objective and subjective probability among a stimulus sequence, or the amount of resources needed to process a stimulus (Donchin, 1981; Johnson, 1986; Kutas et al., 1977; Münte et al., 2000; Verleger, 1988). Intracranial recordings point to wide-spread neural generators of this component (Clarke et al., 1999a; Clarke et al., 1999b) and it is quite likely that these different generators support different cognitive operations and might be active in different combinations in a task-dependent fashion. Seeing that 'before' sentences (as the more complex sentences in our study) are likely to consume more processing resources, one would predict a greater positivity following the P300 framework. However, a second possibility for finding a component that has often been found in saliency and attention research is the use of the numbers during the experiment. If the use of the numbers led to a visual decision about what order to produce, instead of a linguistic one, we would simply be measuring cued visual attention.

In order to make sure that this was not the case, a second experiment was designed containing the same task but different stimulus material.

3.5. Experiment 2

Abstract

During this study, only object pictures were used and they were presented sequentially. Instead of numbers, a coloured fixation cross followed the object pictures to cue the right utterance. The task was the same as for the first experiment; subjects had to produce a sentence, describing the use of the objects in a chronological/natural ('after') and unnatural ('before') order. Since faces were not used during this study, subjects were instructed to produce sentences in which they themselves used the objects.
The aim of this study was to see whether the centro-parietal component found in the first study could be replicated with a different paradigm. If this was the case, we would expect to find the same direction of the effect, i.e. a higher positivity for the unnatural order condition.

3.6. Methods Experiment 2

3.6.1. Participants

Thirty-two right-handed, neurologically healthy students aged between 20 and 32 (mean age 23.3, 23 women, 9 men) with normal or corrected to normal vision and German as their native language gave informed consent and were paid for their participation. Subjects with more then 25 % loss of trials caused by blinking or movement artefacts were excluded from further analysis. In this study, artefacts were mainly caused by subjects not being able to sit still while talking, or most importantly, by movements prior to vocalization, i.e. in the time-window of interest related to speech planning prior to articulation. It was not uncommon for subjects to move their head or to blink immediately before they started producing an utterance. It turned out that some participants could not control these movements. Therefore, to ensure clean recordings during the conceptualization window, we had to exclude 15 subjects, leaving 17 subjects for the final analyses.

3.6.2. Stimuli

A total of 75 pairs of black and white line-drawings were taken from the same sources (we used the same 50 objects from the first study and added 25 more). Pictures were edited in the same way as reported above, only presented on a black background, and again combined into pairs such that no semantic and phonological overlap occurred.

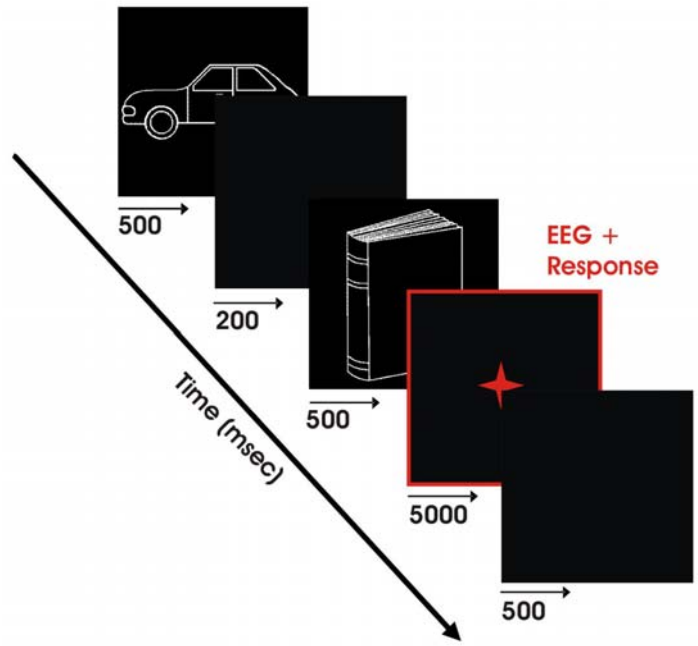
Each picture pair was presented twice in each condition (before/after) with the position of the pictures rotated. This resulted in a total of 150 picture pairs per one condition and 300 picture pairs for the entire experiment.

3.6.3. Procedure

Each trial comprised the following sequence: The first object picture was presented for 500 ms, followed by a blank screen for 200 ms. This was replaced by a second object picture, presented also for 500 ms, followed by a colored fixation cross with a duration of 5000 ms to allow for overt response (see Figure 3.4. for an example of a single trial). At the end of each trial, a blank screen was shown for 500 ms which prepared the subjects for the next trial. The instructions were the same as for the first experiment, namely to assume that action 1 belonging to object 1 occurred first, while action 2 associated with object 2 happened subsequent to action 1. The only difference was, due to removal of the faces, that subjects created sentences in which they themselves performed the actions depicted by the objects. The color of the fixation cross (red or yellow) specified whether participants generated the event description by means of a (natural) 'after' or an (unnatural) 'before' sentence.

For example, subjects saw the object 'book' and then the object 'couch', followed by a red fixation cross. The instructed, correct German utterance for a natural order sentence would then be 'Nachdem ich lese, sitze ich' (in English; 'After I read (a book), I sat (down on the couch)'). The same objects followed by a yellow fixation cross, would require the utterance 'Bevor ich sitze, lese ich' (in English; 'Before I sat (down on the couch), I read (a book)'). Again, subjects were instructed to use an identical structure for both sentences (except for the initial word) and they had to produce both sentence parts in the present tense. The color of the fixation cross was counterbalanced over subjects. And, subjects were instructed to utter the required sentence as soon and as correct as possible. After the application of the EEG electrodes, we followed the same procedure used during the first experiment. They received three practice runs, they were told to sit as still as possible and to blink only during the presentation of the fixation-point or while they were speaking.

Figure 3.4. A single trial example. EEG was triggered to the onset of the fixation cross, indicated by the red arrow



3.6.4. Data acquisition and analysis

The acquisition of the data was exactly the same as the first experiment. During recording, electrode impedances were kept below 5 kΩ. EEG was averaged time-locked to the onset of the fixation cross for epochs of 700 ms including a 100 ms pre-stimulus baseline. Only single trials free of blink and movement artefacts were included in the averages. To quantify the ERP effects, mean amplitudes were measured at midline (Fz, Cz, Pz), parasagittal (F3/4, Fc1/2, C3/4, Cp1/2, P3/4, Po3/4, O1/2), and temporal (F7/8, Fc5/6, T7/8, Cp5/6, P7/8) sites in an early (180-230 ms) and a later (350-400 ms) time-interval relative to a baseline (-100 to 0 ms). The two time windows were chosen after visual inspection of the signal. Factors were order (natural versus unnatural), anterior/posterior (5 levels for temporal, 7 levels for parasagittal, 3 levels for midline) and hemisphere (left versus right, the factor was not used for midline analyses). Statistical testing was conducted using repeated measures analyses of variances (rANOVA), with a correction of degrees of freedom for non-sphericity (Greenhouse-Geisser algorithm) where necessary.

3.7. Results Experiment 2

3.7.1. Behavioural Results

Voice onset latencies (VOL) were collected by means of a voice key (Presentation, version 9.10). The responses of the seventeen subjects that also contributed to the ERP analysis were included in the analysis.

There was no significant difference in onset time for the natural order condition (mean VOL = 1362 ms, SD = 29.6) versus the unnatural order condition (mean VOL = 1359 ms, SD = 23.2) (T = -.058, p = .95).

3.7.2. Electrophysiological results

The grand average ERPs were time-locked to the fixation cross and the two conditions start to diverge around 180 ms, with the before condition being more positive than the after condition (see Figure 3.5). The N1-P2 complex, normally occurring after visual stimulation, did not show any significant difference between the two conditions.

Time window 180-230 ms

Reliable differences between before and after sentences were revealed by main effects of the Factor order for parasagittal and temporal electrode sites (see Table 3.2. for an overview of the significant effects in this time window). No reliable interactions were obtained between order and the topographical factors. However, the effect is largest on fronto-central electrodes. Figure 3.5 shows the effect on several electrodes. The topographical map showing the fronto-central distribution of the effect is depicted in Figure 3.6.

Time window 350-400 ms

For the later time-window the main effect of order did not reach significance. A significant order by anterior/posterior interaction for the parasagittal and temporal sites reflected a posteriorly distributed difference between before and after sentences were present (see Table 3.2 for an overview of all the significant effects in this time window). Figure 3.5 shows the effect on selected electrodes, Figure 3.6 the corresponding topographical map.

Table 3.2. Comparison of before vs after utterances on the frontal and the parietal component. Given are the F-values. Abbreviations: Ant = Anterior-Posterior Factor.

	Df	**180- 230 ms**	**350 – 400 ms**
Parasagittal (F7/8,Fc5/6,T7/8,Cp5/6,P7/8)			
Order	1,16	6.22*	
Order x Ant	4,64		7.12**
Temporal (F3/4,Fc1/2,C3/4,Cp1/2,P3/4,Po3/4,O1/2)			
Order	1,16	9.09**	
Order x Ant	2,32		9.96*
Midline(Fz,Cz,Pz)			
Order	1,16	4.83*	

*** p < .001
* * p < .01
* p< .05

To test whether indeed the early and late portions of the before/after differences had different distributions we determined the mean amplitude of the after minus before difference waves in the 180-230 ms and 350-400 ms time-windows for all 29 scalp electrodes. These values were subjected to the vector normalization procedure described by McCarthy and Wood (1985) and then entered into an ANOVA with time-window (early vs. late) and electrode site (29 levels) as factors. A significant interaction between time-window and site ($F(28,448)=3.06$, original $p<0.0001$, Huynh-Feldt corrected: $p=0.038$) indicated that the difference between condition had indeed a different distribution in the two time-windows.

Figure 3.5. Grand average ERPs at selected scalp sites time locked to the onset of the fixation cross that prompted the utterance. The after condition gave rise to a negativity around 200 ms (depicted in the blue area), followed by a centro-parietal positivity for before around 400 ms (depicted in pink).

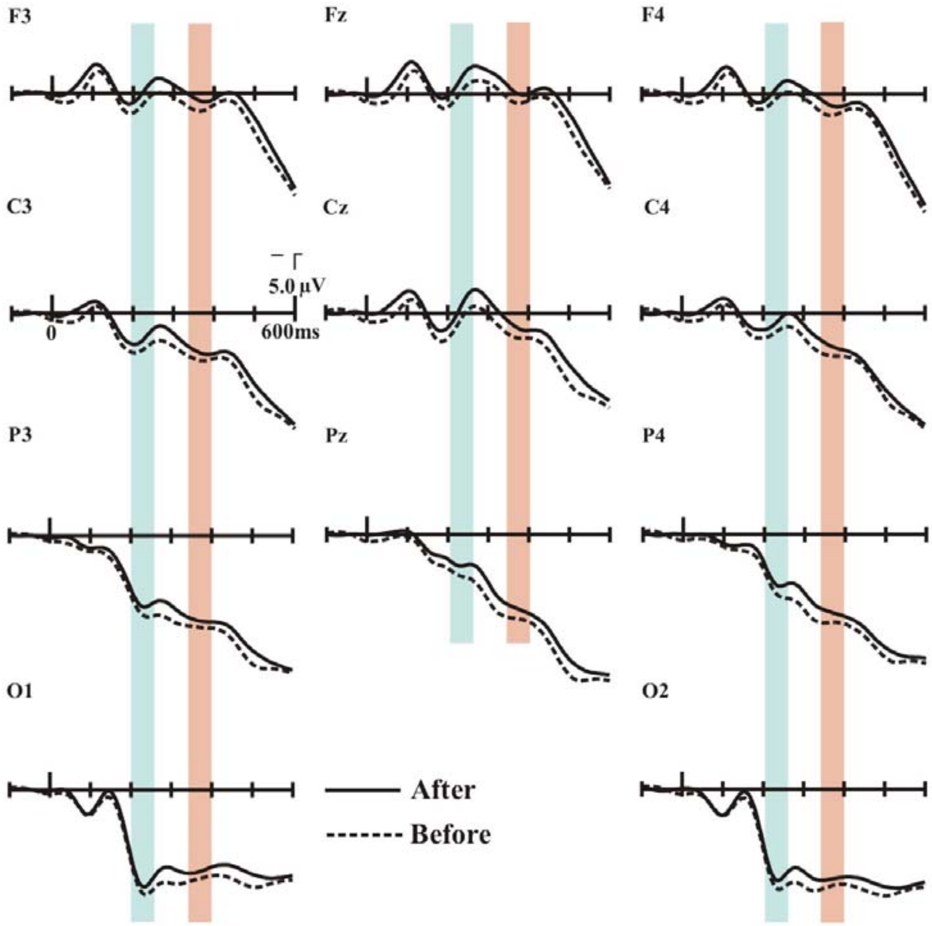
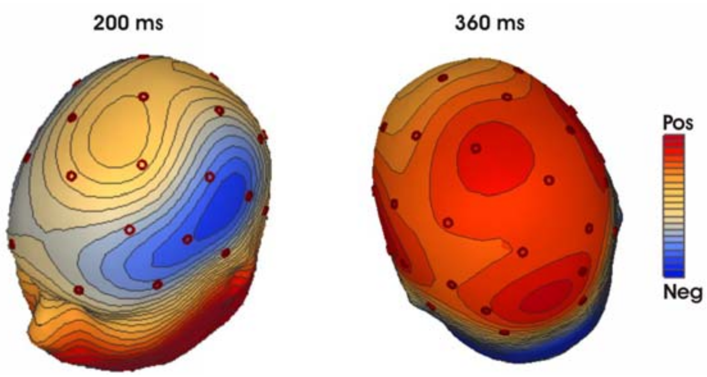


Figure 3.6. Spline interpolated isovoltage maps of the difference between the after and before condition: During the first phase a fronto-central distribution is evident, while beyond 350 ms a clear parieto-occipital maximum emerges (min/max scaling: -0.24 to 0.24 µV at 196 ms; -0.98 to 0.98 µV at 360 ms).



3.8. Discussion Experiment 2

The observed lack of effects for voice-onset latency (VOL) is counterintuitive at a first glance as we expected longer latencies for a more difficult planning in the before case as in experiment 1. The lack of VOL differences found in the present study may be related to a ceiling effect or a strategy to delay naming until the entire utterance plan is available. Note that VOL measures the end of an entire information processing cascade. Strategic effects and execution are included next to the process of interest, i.e. the conceptual planning.

The ERP results of the present study show differences between sentences in which a sequence of events is uttered in chronological, 'natural' order (sentences beginning with 'after') and reversed, 'unnatural' order ('before'-sentences). The earlier portion of the difference between before and after sentences has a fronto-central distribution within the 180-230 ms time-window and is more negative for the after condition. In terms of working memory, this would mean that the natural order condition requires more working memory load in comparison to the unnatural order. I will come back to the direction of this effect in the general discussion below. The parietal positivity, found in the time window 350-400 ms, resembles a P300 component in distribution and time window. Further, it looks similar to the component found in the first study, showing a higher positivity for before versus after sentences.

3.9. General Discussion

The two studies reported here show divergent results on the reaction times. Whereas the first study revealed significantly longer reaction times for an unnatural order utterance, this result has not been found during the second study. A possible explanation for this difference lays in the difficulty of the second study. Subjects participating in the second study reported this to be a difficult experiment. During the first study, the object pictures were presented simultaneously, whereas a sequential presentation was chosen for the second study. Additionally, during preparation of the response objects were still visible for the first study, whilst they were only presented for 500 ms each during the second study. This made the second experiment more difficult then the first one, which might have led to a ceiling effect in the reaction time data of this experiment. The higher number of subjects tested for the second experiment can be explained by the same reason. During the second experiment, subjects tended to move more at or slightly before the actual utterance onset time. These movements occur more frequently when the difficulty of a task increases and since they are often unconscious (e.g. blinking at the moment one starts talking, or moving the head in a forward manner), subjects that were not able to control for these movements were discarded.

Both macro-planning studies show the same pattern of ERP results, namely a fronto-central negativity followed by a centro-parietal positivity.

Fronto-central negativity: The frontal negativity found during these studies resembles working memory activation found in several studies investigating comprehension of spoken (Müller, et al. 1997) and written (King and Kutas

1995; Mecklinger, et al. 1995) sentences with various syntactic structures (Subject Object (SO) and Subject Subject (SS) relative clauses). The three studies cited here revealed an anterior negativity for the more complex SO sentences, a result interpreted in terms of more working memory demands for the understanding of more complex sentence structures. A similar result has been reported by Münte and colleagues (1998), who showed interaction between working memory and linearization processes in the understanding of temporal terms on a frontal negativity for the more difficult, unnatural order sentences. Frontal activation has been associated with verbal working memory processes before (Posner and Petersen 1990), a finding also confirmed by functional neuroimaging and patient studies (Mesulam 1998).

When we look at the negativity found in the first study described here, it shows a higher negativity for the natural order sentences. This would imply that working memory demands are higher during the production of an unnatural order sentence. The direction of this effect can be explained by taking a closer look at the experiment itself. In both conditions, subjects saw a male or female face followed by two simultaneous presented objects combined with the numbers '1' and '2'. During this experiment, there were two factors that influenced the production of order. First, the 'feeling of natural order', created due to the fact that reading usually occurs from left to right. Subjects automatically developed the feeling that the left object was the first to occur in time simply because it is processed first. Second, the use of the numbers, indicating what kind of order the subjects had to produce.

During the natural order condition, the 'feeling of order' was confirmed by the use of the numbers, leading to the preparation of a natural order sentence. The unnatural order condition however, had a reversed presentation of the numbers ('2' above the first picture and '1' above the second picture) although the 'feeling of order' was identical to the natural order condition. In other words, subjects were forced to create an unnatural order although the feeling of order was still intact. This led to an incomplete violation of the natural order strategy during the unnatural order condition. The natural condition might therefore appear to be 'more difficult' in terms of working memory demands because this condition reflects the natural process of preparation of an order whereas the unnatural order condition possible does not. This is what becomes reflected on the working memory component.

The second study also shows a greater negativity for the natural condition on this fronto-central component. However, the direction of this effect is not caused by incomplete violation of the natural order strategy. This strategy was violated completely since subjects started the utterance with the last presented object in the unnatural order condition. However, since the object pictures were presented sequentially during this study, the presentation of the first picture needed to be kept in mind longer when subjects had to create a natural order sentence. This is contrary to the production of the unnatural order that started with the utterance of the last presented object.

In sum, in order to utter a natural order sentence, subjects had to go back two steps to start with the first presented object and this process demands more working memory load.

Taken together, both experiments show a higher negativity for the natural order sentences, a finding that can be explained in terms of working memory load.

Centro-parietal positivity: The distribution and polarity of the component found during both studies suggest that this may be an instance of the P300 or P3b. The P300 is a well-known component often found in tasks investigating attention devoted to a stimulus, stimulus salience, task relevance, objective and subjective probability among a stimulus sequence, or the amount of resources needed to process a stimulus (Donchin, 1981; Johnson, 1986; Kutas et al., 1977; Münte et al., 2000; Verleger, 1988). Currently, there are two different opinions about what the amplitude of the P3 reflects exactly. The first approach describes the amplitude of the P300 as an indicator for adaptation processes when new or unexpected information has to be processed (Donchin and Coles 1988). The second approach explains P300 activation in terms of closure processes that occur at the moment expectations regarding target stimuli are met (Verleger 1988). Whereas the first theory states that new/unexpected information leads to higher P300 amplitude, the second theory assumes the opposite by saying that it reflects a response to expected stimuli.

What binds these two approaches is that both of them assume that the P300 reflects attentional processes of some sort. Looking back at the results found in the present studies, this would indicate that the production of an unnatural order sentence requires more resources then natural order utterances. However, intracranial recordings point to wide-spread neural generators of this component (Clarke et al., 1999a; Clarke et al., 1999b) and it is quite likely that these different generators support different cognitive operations and might be active in different combinations in a task-dependent fashion. Seeing that 'before' sentences (as the more complex sentences in our study) consumed more processing resources, one could argue by extension that conceptualization in this case takes up more resources. Thus, whereas there was insecurity about the influence of the numbers on the linguistic task during the first experiment, the second experiment that contained exactly the same stimulus material for both conditions (only object pictures) clearly showed that the replicated effect was not influenced by attention processes.

Another point to mention is that the P300 effect has been found in a different conceptualization experiment done in our laboratory as well. This study focussed on process-related strategies and manipulated the complexity of utterances describing the direction of an arrow in a network of geometrical forms (easy: downwards, medium: downwards to the triangle, complex: downwards to the grey triangle) (Marek et al., in press). As mentioned in the introduction, process-related strategies are used when content-related information (e.g. differences in time between events) is not available.

In this case, medium and complex utterances were associated with a parietal positivity when compared with the "easy" condition. It thus appears that the amplitude of the P300 varies as a function of conceptualization difficulty.

Taken together, the results from these two macro-planning studies seem to indicate that this P300 component reflects conceptualization difficulty, or in other words, the amount of resources involved in conceptualization processes.

In the language comprehension literature another positivity with a parietal maximum features prominently is the P600 (or syntactic positive shift). This is elicited by a broad range of syntactic anomalies, such as phrase structure violations, morphosyntactic violations, case violations or unpreferred continuations of temporarily ambiguous sentences. Hence, this component is said to reflect syntactical reanalysis or revision processes (Friederici 1995; Hagoort, et al. 1993; Münte, et al. 1998), syntactical ambiguity (Osterhout, et al. 1994; Van Berkum, et al. 1999a), complexity (Kaan, et al. 2000) or, more recently, unification processes (Hagoort 2003). There has been a debate whether this P600 is language specific or whether it is related to the P300 and indicating stimulus saliency or probability effects (Coulson, et al. 1998a; Gunter, et al. 1997). However, we did not introduce any violations. Further, subjects created syntactically equal sentences in both conditions (the only thing that differed was the temporal connective), an interpretation of the current findings within a syntactical framework does not seem fruitful.

However, it can not be ruled out completely that, although subjects were forced to utter syntactical equally sentences, they prepared an utterance that was more syntactical natural. In that case, it could be that syntactical integration processes do play a role.

Taken together, both experiments show a higher positivity for the unnatural, before condition on a centro-parietal component. This effect can be explained in terms of conceptualization difficulty. However, a second possibility that can not completely be dismissed is that there might be some syntactical integration processing going on.

IV. Macro-planning and fMRI

Abstract

The experimental setup of the experiment was the same as the second ERP experiment; a sequence of two objects was followed by a coloured fixation cross. Subjects had to produce a sentence describing the use of the objects in a natural ('after') and unnatural ('before') order.
The aim of this study was to gather information about neuroanatomical areas underlying conceptualization processes, and more specifically linearization process. It was expected to find an enlarged BOLD signal for the unnatural order condition in speech production related areas.

4.1. Introduction

To my knowledge, no study so far has looked at linearization processes by means of fMRI. Therefore, I will turn to speech production models and a meta-analysis study done by Indefrey and Levelt (2004) that tried to get more insights into brain areas related to speech production. Further, I will describe some production studies that tapped into different speech production stages.

Indefrey and Levelt (2004) did a meta-analysis of speech production and comprehension studies and showed several areas that are involved in speech production. The studies that they used for the speech production meta-analysis included picture naming and word generation experiments. By means of this meta-analysis, they looked at similarities and differences between comprehension and production and expanded their speech production model with the relevant neuroanatomical areas. This revealed that activation in the left middle temporal gyrus was associated with lemma retrieval. Although lemma retrieval is part of the more general conceptualization stage, Maess et al. (2002) showed that this region is rather activated during lemma retrieval than during conceptual processing per se.

They found this result during a MEG study where subjects performed in a semantic interference task. Subjects had to name items that either belonged to the same semantical category or to a different one. Naming semantically related items lead to longer RTs, an effect explained as the 'semantic context effect'. This context effect states that naming several items from one semantical category leads to competition because their corresponding lemmas compete for selection. This process affects selection latency and response times. The Maess et al. (2002) study showed the typical RT-effects of a semantic interference study. Moreover, the MEG results indicated that the area underlying this semantic interference effect was the left temporal region. The left posterior middle and the superior temporal gyri are said to be involved in phonological word-form retrieval, since these areas become activated during word production versus non-word production (Indefrey and Levelt 2000), a result also found in the meta-analysis (Indefrey and Levelt, 2004). Sub-lexical phonological encoding (syllabification processes) has been found in the left inferior frontal gyrus (Broca's area) and the left mid-superior temporal gyrus (Indefrey and Levelt, 2000; 2004).

To sum up, parts of the conceptualization stage, lemma retrieval seems to take place in the left middle temporal region, whereas phonological code retrieval appears to be located in the superior temporal region (Indefrey and Levelt, 2000; 2004).

There are a few neuroimaging studies that looked at sentence production (Alario, et al. 2006; Haller, et al. 2005; Indefrey, et al. 2001a; Kircher, et al. 2000).

Kircher et al. (2000) let subjects describe Rorschach inkblots in the scanner whilst measuring speed of word production. This rate of production was positively correlated with the degree of signal change in the superior temporal lobe and the supramarginal gyrus. The authors concluded that these areas might be involved in lexical retrieval.

A speech production study that focused on syntactic encoding required subjects to create three different kind of sentences (Indefrey, et al. 2001a). Subjects saw a set of coloured two-dimensional geometric objects that made two specific actions; either they moved next to the other object or they launched the other object. They were asked to describe these actions in three different ways; (1) in a full sentence, (2) with a sequence of noun phrases that had local syntactical structure but did not have a sentence-level syntactical structure and (3) with a sequence of single words that did not have a syntactic relationship at all. Comparing full sentences to sequences of words without a syntactic relationship lead to activation close to Broca's area (the left anterior Rolandic operculum) in the frontal cortex. The authors concluded that this area is involved in the syntactic integration of words into phrases and sentences.

A second study tapping into syntactical processing was done by Haller et al. (2005). Subjects had to produce simple SVO sentences whilst manipulating the demands on syntactic production. This was done in three different ways; subjects had to syntactically complete sentences (rearranging word order, declination of the verb), read words aloud and read sentences aloud. Results showed higher activation in the left inferior frontal gyrus/Broca's area when syntactic demands were higher.

Within this area, BA45 was stronger activated than BA 44 during the task. The same pattern of activation was found in the right inferior frontal gyrus and this led the authors to conclude that Broca's area, more specifically BA45, is highly involved in syntactical processing.

Another study tapping into speech production was done by Alario et al. (2006). They did two experiments in which familiarity, complexity and degree of external guidance in language production was manipulated. During the first experiment, subjects saw words and either had to read or repeat them (comprehension versus production) whilst familiarity (words versus pseudo-words) and complexity (mono/bi-syllabic words versus tri/quadric-syllabic items) were manipulated. Overall speech production results showed activation in the medial frontal cortex (pre-SMA) bilaterally, the precentral cortex, Broca's area and its corresponding right hemisphere region. Further, they also found activation in the posterior part of the superior temporal gyrus. Manipulation of familiarity and complexity were visible in the pre-SMA and the lateral frontal cortex. A second experiment, manipulating external guidance, replicated the speech production activation pattern from the first experiment, areas being defined as part of the speech production network (Indefrey and Levelt, 2000; 2004). In sum, Kircher et al. (2000) revealed that lexical retrieval is associated with left temporal region activation, a result also shown by Maess et al. (2002). Further, different levels of syntactical processing lead to activation in the left and right inferior frontal gyrus (Indefrey et al., 2001; Haller et al., 2005). Syllabification processes were found in the frontal cortex as well (Alario et al., 2006)

The present study investigated the use of temporal terms in production by focussing on linearization. Subjects had to create sentences containing a chronological order, starting with the word 'After', and sentences where this order was violated (sentences with an unnatural order, starting with the word 'Before'). They saw two sequentially presented objects, both for 500 ms, followed by a coloured (4 sec) and a white fixation cross (14 sec). The task was to produce a sentence as quickly and accurately as possible, describing the use of the objects in a natural ('after') and unnatural ('before') time sequence. It was expected to find activation for a before versus after contrast in speech production related areas, especially the left temporal lobe that is said to be involved in lemma retrieval.

4.2. Methods

4.2.1. Participants

Fifteen right-handed, neurologically healthy participants aged between 21 and 29 (mean age 23.8, 8 women) with normal or corrected to normal vision and German as their native language gave informed consent and were paid for their participation.

4.2.2. Stimuli

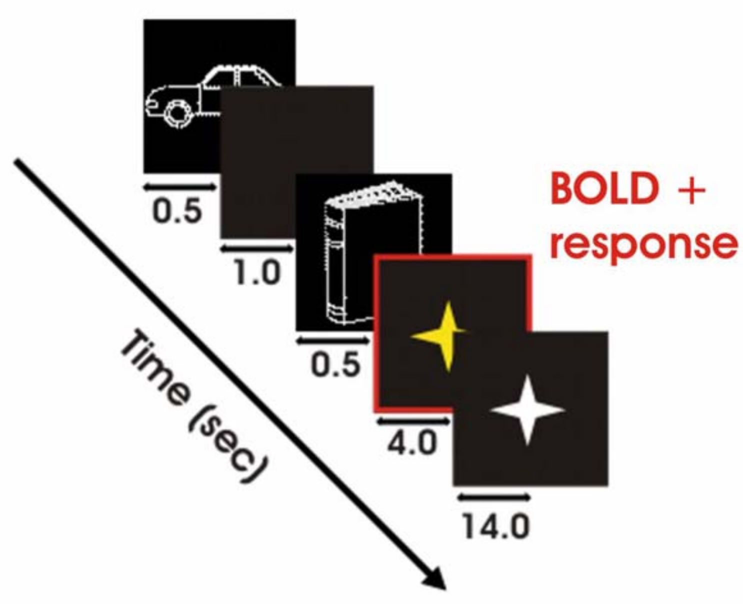
A total of 40 black and white line-drawings were taken from the earlier experiment. Pictures were exactly the same as the one used for the last EEG experiment.

Each picture pair was presented twice in each condition (before/after), the position of the pictures rotated to counterbalance for location so that a total of 40 picture pairs per condition were used and 80 picture pairs for the entire experiment.

4.2.3. Procedure

Each trial in this slow event-related design comprised the following sequence: The first object picture was presented for 500 ms, followed by a *blank screen for 500 ms.* This was replaced by a second object picture, presented also for 500 ms, followed by another blank screen (500 ms) and a colored fixation cross with a duration of 4000 ms to allow for overt response (see Figure 4.1. for an example of a single trial). This colored fixation cross was replaced by a white fixation cross to indicate that overt response time was over. This white fixation cross lasted for 14 s, after which the next trial was presented. Differences in timing between the fMRI experiment and the last ERP experiment on the presentation of the colored fixation cross was deliberately chosen to minimize speech influences on the BOLD signal. For the same reason, the presentation of the white fixation cross following the coloured cross was prolonged to 14 seconds.

Figure 4.1. Example of one single Trial. BOLD signal was measured at the presentation of the fixation cross, indicated by the red square.



Instructions were the same as for the last ERP experiment namely to assume that action 1 belonging to object 1 occurred first, while action 2 associated with object 2 happened subsequent to action 1. The color of the fixation cross (red or yellow) was counterbalanced between subjects and it indicated whether participants generated the event description by means of a (natural) ‘after’ or an (unnatural) ‘before’ sentence. For example, subjects saw the object ‘book’ and then the object ‘couch’, followed by a red fixation cross. The instructed, correct German utterance for a natural order sentence would be ‘Nachdem ich lese, sitze ich’ (in English; ‘After I read (a book), I sat (down on the couch)’). The same objects followed by a yellow fixation cross, would require the unnatural utterance ‘Bevor ich sitze, lese ich’ (in English; ‘Before I sat (down on the couch), I read (a book)’).

To minimize variability among the answers and to keep overt production time as short as possible, subjects were instructed to use an identical structure for both sentences (except for the initial word) and to produce both sentence parts in the present tense. Lip movements were recorded with a camera to monitor speech errors and to be able to check speech onset moments. The speech onsets were not used for the calculation of reaction times because the camera recordings were not sensitive enough. It was rather used as an extra check for speech influences on the BOLD signal. Subjects were instructed to utter the required sentence as soon and as correctly as possible. Outside the scanner subjects received the same three practice runs that were used during the EEG experiments.

4.2.4. Data Acquisition and Analysis

Images were obtained using a 3 Tesla Siemens Magnetom Trio Scanner (Siemens Medical Systems, Erlangen, Germany) and an eight channel head coil. High-resolution, anatomical images were acquired (MP-RAGE, TR = 2500 ms, TE = 1.68 ms, 192 sagittal slices, in-plane resolution 1 x 1 mm^2, slice thickness 1 mm, FOV = 256 mm, matrix size 256 x 256, flip angle 7 º). BOLD dependent functional magnetic resonance images covered the entire cortical volume (30 slices oriented parallel to the AC-PC line, specified with a midsagittal scout image; TR = 2000 ms, TE = 30 ms, FOV = 220 x 220, flip angle 80 º, matrix size = 64 x 64; in-plane resolution 3.5 x 3.5 mm^2, slice thickness 3.5 mm, inter-slice gap 0.35) using an echo planar imaging sequence.

One functional run lasted approximately seven minutes, consisted of 210 volumes of which the first four were skipped to avoid T1 saturation effects. In total, there were four runs.

Subjects were placed in the scanner and cushions were used to reduce head motion. The presentation of the visual stimuli was volume triggered. Stimuli were presented on a screen positioned at the head end of the magnet bore and subjects viewed the screen through mirror glasses. Overt responses were recorded with an eye-tracking camera aimed at the mouth.

Functional and anatomical images were analyzed with Brainvoyager QX software (Brain Innovation, Maastricht, The Netherlands).

Functional runs were corrected for slice scan time (sinc interpolation), 3D head motion (using trilinear/ sinc interpolation, within and between runs) and for linear trends and low-frequency drifts (high-pass filter of 3 cycles per time point). Functional data were then aligned to the anatomical images and normalized into the standard coordinate system Talairach space (Talairach and Tournoux 1988), followed by spatial smoothing with an 8 mm FWHM Gaussian kernel. A polygon mesh of each cortical hemisphere was obtained by segmenting and tessellating the white/grey matter boundary (Kriegeskorte and Goebel 2001). This boundary was used to create anatomical masks plus 1,5 mm minus 1,5 mm defining grey matter. Thus, only grey matter was included in further processing. Percent signal change was estimated using a mixed-effects general linear model (GLM) with three predictors (‘before’ sentences, ‘after’ sentences and object pictures). Onset times for regressors were determined by the time the respective fixation cross appeared on the screen. Duration of each event was 4 seconds.

Regressors were convolved with a simple gamma function (Boynton, 1996). A random effects GLM (general linear model) was specified for the predictors (1) ‘before’ sentences, (2) ‘after’ sentences and (3) object pictures. Significant differences between the two order conditions were assessed by means of contrast (t) maps. Multiple comparisons threshold was not controlled by the False Discovery Rate (FDR) t-value. Reported activations are based on group statistics.

4.3. Results

When looking at the differences between the two conditions, we found an enlarged BOLD response for the before versus after condition in the left middle temporal gyrus (LMTG, BA21) ($T = 4.00$, $p < .001$) (Figure 4.2).

Lowering the threshold ($T = 2.80$, $p < .014$), we also find this contrast in the left (BA45) and the right (BA47) inferior frontal gyrus (Figure 4.2).

Table 4.1. Mean Talairach coordinates of areas of interest (mm ± SD) as defined by Talairach and Tournoux (1998; x: left-right; y: anterior-posterior origin in anterior commissure; z: inferior-superior) Abbreviations: MTG: middle temporal gyrus; IFG: inferior frontal gyrus.

Area	*X*	*Y*	*Z*
Left MTG	-58	-33	-1
Left IFG	-47	29	3
Right IFG	46	30	1

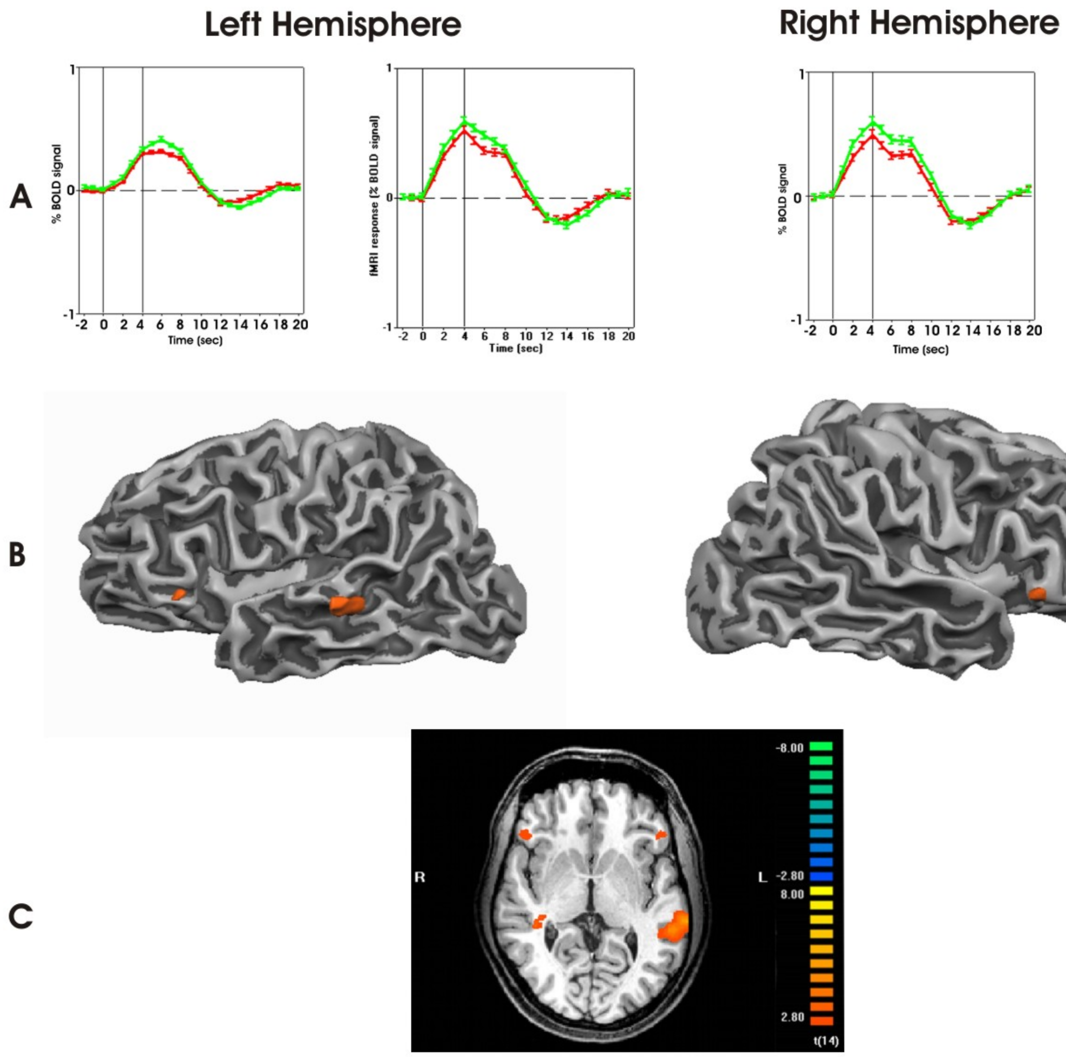


Figure 4.2. (**A**) Event-related average time course of the BOLD response for the area LMTG in the left panel, for the LIFG in the middle panel and for the RIFG in the right panel (green: before condition; red: after condition).
(**B**) Activated voxels as revealed by GLM analysis for the before condition in the left MTG and the IFG (left panel) and in the right IFG (right panel).
(**C**) Activated areas superimposed on an axial slice of a standard brain transformed into Talairach space. The strongest activation was found in the LMTG (BA21). The left side of the image is the right side of the brain.

4.4. Discussion

The present study showed activation for the contrast before versus after-sentences in the left middle temporal gyrus (BA 21) and a bilateral activation pattern in the inferior frontal gyrus (BA 45 left, BA 47 right), areas that have been found in speech production studies before (Alario, et al. 2006; Indefrey and Levelt 2004; 2000). The left middle temporal region has been found in lexical retrieval processes in production (Maess et al., 2002; Kircher et al., 2000). The inferior frontal cortex showed activation for the same contrast as well, both in the left and in the right hemisphere. The left inferior frontal gyrus has been found in speech production before, during syntactical integration processes (Indefrey, et al. 2001a).

In terms of speech production, the activation pattern in the LMTG could than be explained by more retrieval processes for the unnatural order condition whereas the LIFG would display more syntactical integration processing for an unnatural order.

Besides syntactical processing, the LIFG has also been linked to verbal working memory in terms of integration processes (Hagoort, 2005; Martin 2003) again in a syntactical context (Haller, et al. 2005; Indefrey, et al. 2001a; Kolk 1995), but also in a task-independent context of maintenance and processing of stimuli (Indefrey, et al. 2001b).

Comprehension studies that compared the understanding of simple and complex sentences have revealed an interaction between complexity and activation in the left inferior frontal cortex (BA44/45) (Caplan, et al. 1998; Just, et al. 1996; Stromswold, et al. 1996).

But also comparing sentences on the level of semantics (do two sentences have the same meaning) revealed activation in the inferior frontal cortex (BA 45/47) (Fiebach, et al. 2001). Since both tasks required the two sentences to be held in memory, it is clear that memory processes play a role in both types of sentences. Moreover, activity in the inferior frontal cortex appears to be influenced by memory processes rather than syntactic or semantic processes only.

Anterior and posterior temporal activity has also been found during semantical and syntactic sentence processing tasks (Dapretto and Bookheimer 1999; Just, et al. 1996; Ni, et al. 2000), often accompanied by inferior frontal gyrus activation (Dapretto and Bookheimer 1999; Kuperberg, et al. 2000; Ni, et al. 2000).

Taken together, comprehension studies addressing understanding of sentences reveal a network that includes the left inferior frontal cortex and left temporal areas. Whereas the LIFG is said to be more involved in the underlying memory processes, the temporal areas would then display lexical processing and the activation of syntactic and semantical information (Friederici 2002; Kaan and Swaab 2002).

A third result in the present study was an enlarged BOLD signal for the unnatural order condition in area BA47, in the right inferior frontal gyrus (RIFG). Speech production studies have found a bilateral activation pattern in the IFG before (Haller et al., 2005; Alario et al., 2006). Comprehension studies have found activity in the left BA47 whilst tapping into semantic aspects of language processes (Abdullaev and Bechtereva 1993; Abdullaev and Posner 1998; Dapretto and Bookheimer 1999).

Although right hemisphere activation during language processing is still under debate, recent neuroimaging studies have suggested that the right inferior frontal gyrus comes into play during auditory sentence comprehension and processing of sentence melody (Friederici 2002; Meyer, et al. 2000; Poldrack, et al. 2001).

Taken together, the activation pattern of the present study is in line with the brain areas found in several speech production studies before (Haller, et al. 2005; Indefrey, et al. 2001a; Kircher, et al. 2000). Further, comprehension studies investigating the understanding of sentences revealed a network of the left inferior frontal cortex and middle and superior temporal areas that are involved in semantical and syntactic processing. The right inferior frontal cortex is said to be involved in processes concerning sentence melody and auditory sentence processing.

In summary, this pattern of results suggests that the preparation of an unnatural order sentence requires more semantical and syntactic processing, both in terms of working memory processes that take place in the frontal cortex, and in terms of retrieval or activation of semantical and syntactic information in the temporal region.

V. Micro-planning and ERPs

Abstract

During micro planning, ideas are translated into preverbal messages by means of accessible concepts. A topic can either be un-accessible ('new') or accessible ('already known') for a listener. A speaker may use several strategies to indicate to a listener that a topic is already known. One of these is reduction; speakers tend to reduce the size of referential expressions when a topic is repeated. We investigated this by letting subjects create utterances where two new topics were introduced (nominalization) and sentences where one topic was introduced and repeated (pronominalization). Subjects saw a picture pair of a male/female face and an object, followed by a speech prompt. Then, a second picture pair was presented followed by a second speech prompt. The task was to produce two short sentences at the two commands, describing the man/woman using the object, either with nominalization or pronominalization. During nominalization, two different faces were presented while during pronominalization the same face appeared twice.

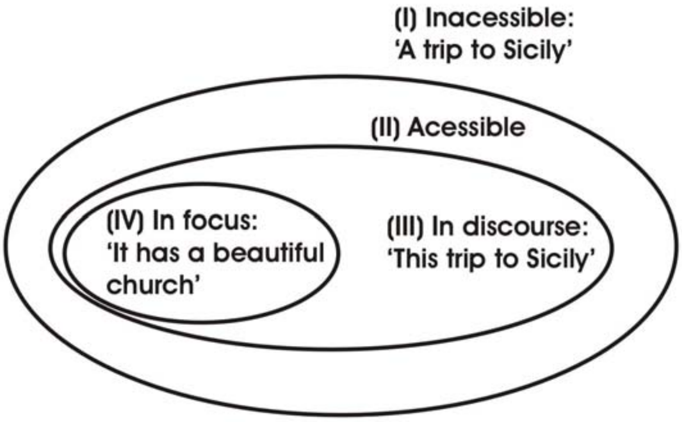
The aim of this study was to gain insight in the conceptualization process of accessibility, and it was expected to find more conceptualization processing during the production of pronouns.

5.1. Introduction

When going from an intention to a preverbal message, accessibility status is one out of four major aspects that are important to reach this stage (Levelt, 1989). During discourse, it is important that a topic is equally accessible for the speaker and the listener. To achieve this goal, the speaker attaches some sort of index or value to each referent in a message to indicate the amount of accessibility. For example, the use of 'the' boat, instead of 'a' boat is an indication that this topic has come up before and is therefore better accessible than a new topic. There are several levels of accessibility; a topic can be (I) completely new and inaccessible. This state of accessibility refers to topics that have not been mentioned before. For example, with the sentence 'Yesterday, I came back from **a** trip to Sicily' a new topic is introduced.

(II) A topic has a certain degree of accessibility. This can either be because (a) the listener can infer the referent, or (b) the speaker assumes that this is part of the listener's world knowledge. For example: a speaker talks about his holiday on an island. When he explains that he got sick on the way to the island, he does not explicitly need to refer to the vehicle that brought him there. Everybody knows that an island is surrounded by water, and this fact makes it unnecessary to explicitly mention that a boat is a way to reach an island. An example for (b) is talking about THE pope. This is a topic that does not need to be introduced explicitly in order for the listener to understand who the speaker talks about. Further, we can distinguish between two levels of accessibility within discourse. (III) First, when a topic has already been in discourse and a speaker wants go back to the same topic once more. An example of this would be the sentence '**This** trip to Sicily I mentioned…and so on'. (IV) Second, when a topic is in the focus of the conversation, e.g. it is the main topic at this moment. A topic is fully accessible and a remark like '**It** has a beautiful church' is sufficient for the listener to know that, by means of 'it', the speaker is referring to the island again. These four dichotomies are not orthogonal, but rather embedded in the way that is represented in Figure 5.1 below.

Figure 5.1. Representation of the four different levels of accessibility. The examples are explained in the text.



These examples show that, depending on the state of focus of the topic, a speaker will address this topic differently. The more accessible a topic is, the more a speaker reduces the amount of expressions used to refer to this topic. This is called reduction (Clark and Wilkes-Gibbs 1986; Krauss and Weinheimer 1964) and an example of this strategy is the use of pronouns; at the moment a topic, or in this case a person, becomes more accessible, the amount of referential expressions is reduced. For example, New/in-accessible: 'Yesterday, I met A new colleague', accessible-in discourse: 'THIS colleague's name is Brian', accessible-in focus: 'HE comes from England'. However, the use of this reduction strategy implies that a pronoun must correctly relate to its corresponding antecedent that has been mentioned at a different time point. In order to do so, a pronoun must be correctly linked to an antecedent in terms of semantics and syntax, a process called co-reference.

Garrod and Terras (2000) introduced a two-stage process for pronoun comprehension containing bonding and integration. First a loose, superficial attachment between a pronoun and its antecedent is made, based upon syntactical information like gender (bonding). This is followed by committing to a full referential interpretation of the pronoun by checking semantic and syntactical information (integration) (Garrod and Sanford 1990; McKoon and Ratcliff 1981; Sanford, et al. 1983).

Looking at production, Schmitt et al. (1999) investigated lexical access in pronoun production by proposing a four-step model of pronoun access in German. During the first step, a communicative intention is translated into a preverbal message by marking topics as old or new information and consequently, referring to them by pronouns or nouns. This first step is followed by lexical selection (retrieval of syntactic information from the mental lexicon), automatically activating gender and pronoun information, the last two steps of the model. When selection of a German pronoun is taking place, access of gender is necessary because the pronoun must fit with the gender of the antecedent. The model states that selection of a pronoun, due to a discourse-depending switch, leads to a gate in the connection between the lexical gender and the corresponding pronoun node. If the accessibility status of a topic is 'in focus', this gate will be open and can give access to pronoun information. If, on the other hand, the accessibility status of a topic is 'not in focus', this gate will be closed and only noun information can be accessed.

Schmitt et al. (1999) tested the model by looking at the different types of linguistic information needed in order to produce a correct pronoun, studies also done by Meyer et al. (1999) and Jescheniak et al. (2001). For example, Jescheniak and colleagues (2001) did four experiments in which they looked at lemma and phonological form information of a noun when its pronoun had to be produced. First, they looked at lemma information and investigated whether the lemma belonging to a noun becomes reactivated at the moment of pronoun production. They found that presentation of a semantically related distractor leads to inhibition in production of both the noun and the pronoun. The authors concluded that this inhibition process could only occur if a noun's lemma is reactivated at the moment its pronoun is produced. When presenting a phonologically related distractor however, an inhibition effect was only found in the noun condition and no measurable effect was found in the pronoun condition. This would suggest that there is dissociation between semantic and phonological processing and that only lemma information is needed in order to produce a pronoun. These results are in line with a Go/Nogo study done by Van Turenhout et al. (1998), showing that grammatical information (gender) can be processed independently from phonological information.

In sum, there are several studies that tried to explain what kind of linguistic information is needed to establish co-reference between a pronoun and an antecedent. Experiments using semantical and phonological distractors presented with nouns and pronouns showed that in order to produce a pronoun, lemma information is needed. Phonological information seems not to be necessary for the production of a pronoun.

ERP studies that focussed on the same question by looking at the integration processes underlying pronoun resolution yielded the same result. Lamers et al. (2006) report studies where gender information was manipulated in both German and Dutch sentences by means of a violation paradigm. Subjects read sentences that were presented word by word whilst answering simple yes/no questions (by means of button presses) that were unrelated to the aim of the studies. Sentences containing a gender violation (‘*The friend* (male) was invited, therefore they counted on *her*’) showed a higher amplitude on the N400/P600 complex, indicating that both semantic and syntactic integration processes are involved in pronoun resolution, a result also found by Schmitt et al (2002) and Navarrete et al. (2006).

The present studies focused on accessibility status during conceptualization. We investigated this by letting subjects create utterances where either a topic was new and in-accessible (nominalization) or sentences where a topic was in focus (pronominalization). Subjects saw a male/female face combined with an object picture, followed by a speech prompt. A second picture pair was presented and followed by a speech prompt. The task was to produce two short sentences upon the prompt, describing the male/female person using the object. If the second picture pair contained the same face, subjects were instructed to use a pronoun for the second utterance. If they saw a new face, they were instructed to utter a noun. It was expected to find more conceptualization processing for pronoun production, because more conceptualization resources are thought to be needed to build co-reference during pronominalization.

However, since ERP studies looking at pronoun integration processing tapped into comprehension and did this by means of violation paradigms, we did not expect to find differences in accessibility on the components described above. Moreover, we expected a similar looking P300 component, also found during the macro-planning experiments, because of the following reasons; first, we tapped into conceptualization processes in a natural setting, i.e. without the use of violations or ambiguity. Second, we also measured conceptualization processes in language production.

5.2. Methods Experiment 1

5.2.1. Participants

Seventeen right-handed, neurologically healthy subjects aged between 20 and 28 (mean age 24.1, 9 women) with normal or corrected to normal vision and German as their native language gave informed consent to participate in this study. Fifteen subjects were used for the final analysis, two subjects were excluded because of excessive eye-blinks and artefacts.

5.2.2. Stimuli

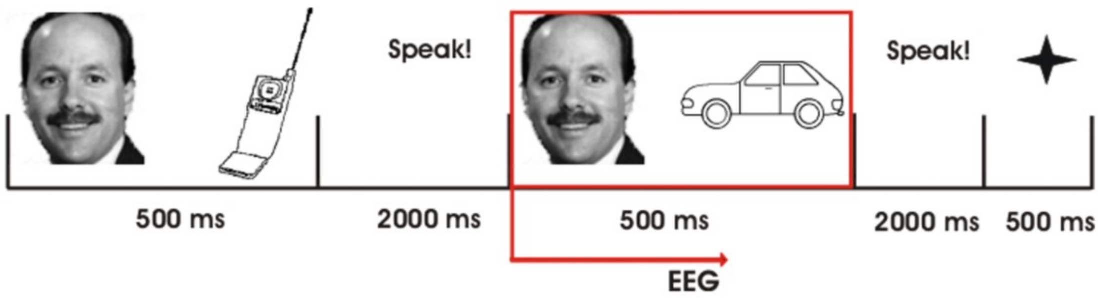
50 male and 50 female faces were combined with 50 object pictures. The object pictures were taken from the picture data base of the Max-Planck Institute for Psycholinguistics, Nijmegen (Snodgrass and Vanderwart 1980). Pictures were edited with Corel Draw version 11.0 to have the same resolution (300 x 300 dpi), size (33 x 33 mm) and colour combination (black on white background).

Pictures that were presented in one trial were checked for semantic and phonological overlap between the words denoting the objects. Stimuli were presented in picture pairs; the face of a male/female person (left) was combined with the line drawing of an object (right). The picture pairs were presented in the middle of the screen against a white background and visual input was kept constant over all conditions. Each trial comprised two face/object pairs and each pair was presented twice in each condition (with the position of the pictures rotated), coming to a total of 100 trials per condition and 200 trials for the whole experiment.

5.2.3. Procedure

The first picture pair was presented for 500 ms, after which subjects got a 2000 ms interval to produce an utterance describing the pair (initiated with the command ‘sprechen’, i.e. ‘speak’ in English). Next, the second pair was presented for 500 ms, after which subjects had again 2000 ms for the production of an utterance. For the second pair a new object was combined either with the same face as presented in pair one or with a new face (always of the other sex, subjects never saw two different males or females). At the end of one trial, a fixation-point was shown for 500 ms which prepared the subjects for the next trial (Figure 5.2. shows an example of a single trial).

Figure 5.2. An example of a single trial. EEG is triggered to the onset of the second picture pair, as indicated by the red square.



The instructions were such that subjects had to produce two sentence pairs describing the depicted person using the object. E.g., if the subject had seen the pair 'female face / book', an appropriate utterance would have been: 'Die Frau liest (ein Buch)' (in English 'The woman reads (a book)'; information in parentheses for clarification only). If a new face was presented for the second pair (e.g., pair "man / car"), the correct utterance would be: 'Der Mann fährt (ein Auto)' (in English: 'The man drives (a car)'). If however, the face of the first pair had been repeated, the appropriate pronoun had to be used (e.g., pair "woman / car"): 'Sie fährt (Auto)' (in English: 'She drives (a car)'). In order to optimally match the two types of utterances, subjects were instructed to use an identical sentence structure. They always had to produce both sentences in present tense to minimise variability among the answers and to keep overt production time as short as possible. Especially, they were instructed to keep the grammatical structure for both sentences exactly the same.

After the application of the EEG electrodes, subjects were seated in a sound-proof cubicle and received detailed explanations about their task during the experiment.

Prior to the experiment proper, they received three practice runs. During the first practice run, subjects saw the pictures of the objects with the corresponding verb and they had to learn the verbs to the objects. The second practice run then showed the same pictures without presentation of the verbs and subjects had to name the pictures out loud (with the learned verb). For these two practice sessions, subjects could take as much time as required and they had to perform errorless before continuing with the last practice session. The last session entailed example trials of the experiment itself, so that subjects could familiarize themselves with the timing of the stimuli. Subjects were told to sit as still as possible, and to blink only during the presentation of the fixation-point or while they were speaking.

5.2.4. Data acquisition and analysis

EEG was recorded with tin electrodes mounted in an electrode cap at standard positions of the 10/20 system (FP1/2, F3/4, C3/4, P3/4, O1/2, F7/8, T7/8, P7/8, Fpz, Fz, Cz, Pz, Fc1/2, Cp1/2, Po3/4, Fc5/6, Cp5/6). Two additional electrodes were placed at the left and right mastoid for referencing. The electrode placed on the left mastoid was used for online referencing. Data were re-referenced off-line to the mean activity of two mastoid electrode sites. Vertical eye movements were measured with a bipolar montage comprising electrodes placed above the left eyebrow and below the left orbital ridge. Horizontal eye movements were measured with two electrodes placed at the left and right external canthi. EEG-data were recorded continuously (time-constant 10 seconds, low-pass filter settings 0.5 to 30 Hz) with a sampling rate of 250 Hz.

Electrode impedances were kept below 5 kΩ. EEG was averaged time-locked to the onset of the fixation cross for epochs of 700 ms including a 100 ms pre-stimulus baseline. Only trials free of blink and movement artefacts were included in the averages. To quantify the ERP effect, mean amplitudes were measured at midline (Fz, Cz, Pz), parasagittal (F3/4, Fc1/2, C3/4, Cp1/2, P3/4, Po3/4, O1/2), and temporal (F7/8, Fc5/6, T7/8, Cp5/6, P7/8) sites in the time-intervals 200-300 ms and 300-500 ms, relative to a baseline (-100 to 0 ms). These were subjected to repeated measures ANOVA. Factors were pronominalization (nouns versus pronouns), anterior/posterior (3 levels for midline, 5 levels for temporal, 7 levels for parasagittal) and hemisphere (left versus right, this factor was not used for midline analyses). The Huynh-Feldt correction for inhomogeneities of covariance was used when appropriate. We report the corrected p-value in conjunction with the original degrees of freedom.

5.3. Results Experiment 1

The grand average ERPs time-locked to the presentation of the second picture pair shows that the two conditions start to diverge around 220 ms, with the pronoun condition being more positive than the noun condition (see Figure 5.3). This effect is visible on all electrodes but appears to be earlier at frontal sites. At posterior sites, it emerges around 280 ms.

The N1-P2 complex, normally occurring after visual stimulation, does not show any significant differences between the two conditions.

Time window 200-300 ms

Parasagittal and midline electrodes show a main effect of the Factor pronoun (for a full overview of all significant results, see Table 5.1.). Interactions between Pronoun, Hemisphere and Electrode are found on temporal and on parasagittal sites. The main effect shows a higher negativity for the noun condition. The interaction effect shows that the effect is biggest on the left hemisphere, and especially on frontal electrodes. Figure 5.3 displays the effect on several electrodes and a topographical map shows the distribution of the effect (Figure 5.4).

Time window 300-500 ms

A main effect of the Factor pronoun was found on temporal, parasagittal and midline electrodes. Interaction effects between Pronoun, Hemisphere and Electrode were found on temporal electrodes (all significant results are reported in Table 5.1).

All electrodes show a higher positivity for the pronoun condition. The interaction effect shows a bigger effect on the left hemisphere, and the difference between the two conditions is largest on centro-parietal electrodes (see Figure 5.3 and Figure 5.4).

Table 5.1. Comparison of pronoun versus noun utterances on the frontal and the parietal component. Given are the F-values.
Abbreviations: Ant = Anterior-Posterior Factor, Hem = Hemisphere Factor

	Df	**200-300ms**	***Df***	**300-500ms**
Temporal (F7/8,Fc5/6,T7/8,Cp5/6,P7/8)				
Pronoun			1,14	5.03*
Pronoun x Hem	1,14	10.02***		
Pronoun x Hem x Ant	4,56	3.00*	4,56	4.80*
Fronto-central (F7,Fc5,F8,Fc6)				
Pronoun	1,14	9.78***		
Pronoun x Hem x Ant	1,14	5.97*		
Centro-parietal (T7,Cp5,T8,Cp6)				
Pronoun			1,14	5.56*
Pronoun x Hem	1,14	13.21**		
Parasagittal (F3/4,Fc1/2,C3/4,Cp1/2,P3/4,Po3/4,O1/2)				
Pronoun	1,14	5.28*	1,14	6.44*
Pronoun x Hem	1,14	13.55***		
Pronoun x Ant	6,84	11.48***		
Pronoun x Hem x Ant				
Fronto-central (F3,Fc1,F4,Fc2)	1,14	20.52***		
Pronoun				
Centro-parietal (C3,Cp1,C4,Cp2)	6,84	3.48*		
Pronoun				
Parieto-occipital (P3,Po3,O1,P4,Po4,O2)	1,14	4.66*	1,14	6.75*
Pronoun				
Midline (Fz,Cz,Pz)	1,14	10.13**		
Pronoun	2,28	19.39***	1,14	7.54*
Pronoun x Ant				
Fz	1,14	30.64***	1,14	6.08*
Pronoun				
Cz	1,14	9.85***		
Pronoun				

*** p < .001
** p < .01
* p < .05

Figure 5.3. Grand average ERPs at selected scalp sites time locked to the onset of the second picture pair. The noun condition gave rise to a more negative waveform starting at about 200 ms (in the blue area) and the parietal positivity for pronouns is displayed in the pink area (tw 300-500 ms).

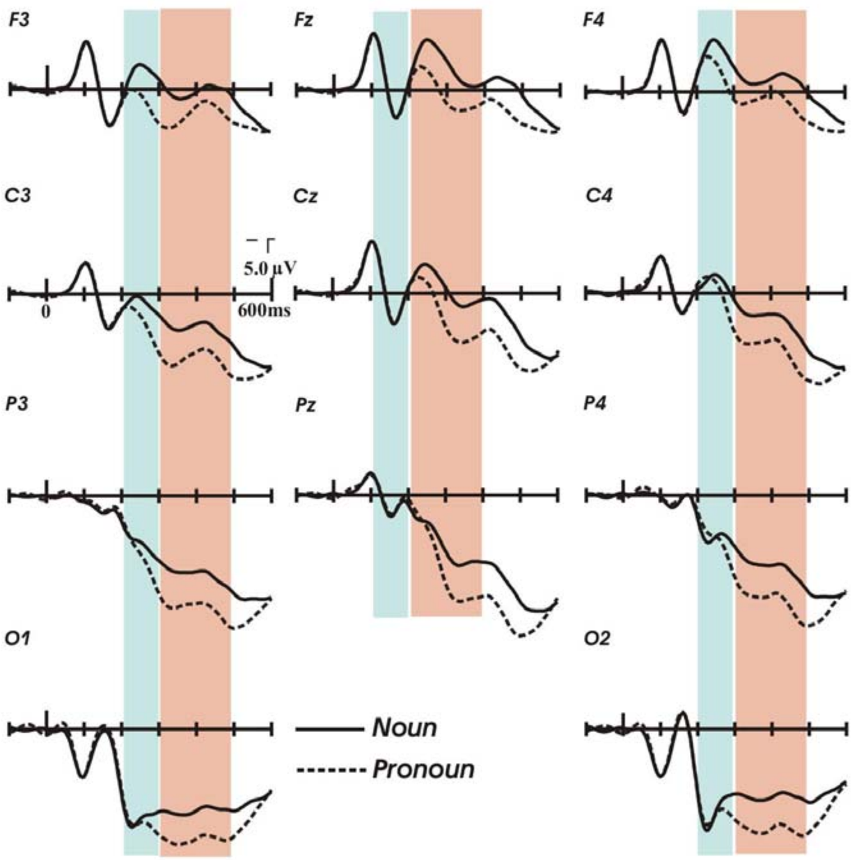
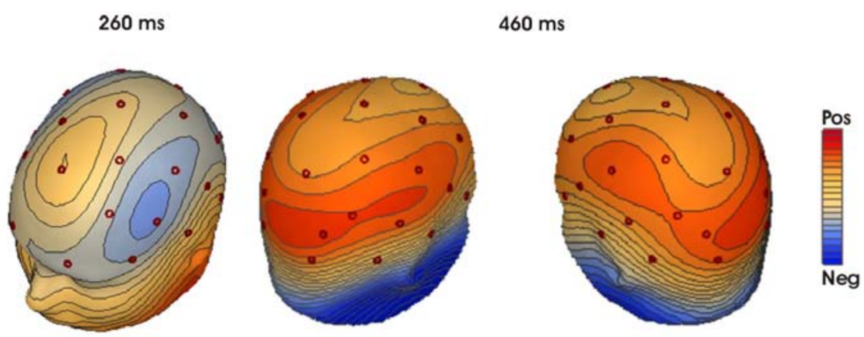


Figure 5.4. Spline interpolated isovoltage maps of the difference between the noun and pronoun condition. During the first phase a frontal distribution is evident, while around 400 ms a centro-parietal distribution emerges (min/max scaling: -0.52 to 0.52 µV at 260 ms; -0.42 and 0.42 at 460 ms).



5.4. Discussion Experiment 1

This study revealed a difference between the two conditions on a left fronto-central negativity in time window 200-300 ms (higher for the noun condition) and a centro-parietal positivity in the time window 300-500 ms (higher for pronouns).

The frontal negativity could be interpreted in terms of modulation of working memory, a result found in language studies before (King and Kutas 1995b; Mecklinger, et al. 1995; Müller, et al. 1997; Münte, et al. 1998b). Further, it also bears resemblance to the frontal effects found in the two macro-planning studies. Explaining the direction of the effect in terms of working memory load would mean that producing a (new) noun would require more working memory load in comparison to the production of a pronoun. At first glance, this seems unnatural because establishing co-reference is expected to demand more working memory load than the production of a single noun. The detailed explanation about the direction of this effect will follow in the general discussion section of this chapter.

The second component found during the present study is a centro-parietal positivity for the pronoun condition. Its distribution and polarity suggest that this may a P300, a component found in tasks investigating attention devoted to a stimulus, stimulus salience, task relevance, objective and subjective probability among a stimulus sequence, or the amount of resources needed to process a stimulus (Donchin, 1981; Johnson, 1986; Kutas et al., 1977; Münte et al., 2000; Verleger, 1988). The amount of attentional resources needed to process a stimulus is reflected by the amplitude of the component.

In this light, a higher positivity for the pronoun condition could lead to two explanations. First, the production of a pronoun requires more resources in comparison to the production of a noun utterance. This result is in the line with the expectations that establishing co-reference requires more conceptualization processes and since intracranial recordings pointed to wide-spread neural generators of this component (Clarke et al., 1999a; Clarke et al., 1999b), it is quite likely that these different generators support different cognitive operations and might be active in different combinations in a task-dependent fashion.

However, another explanation for this P300 effect could be related to the use of the faces. If repetition of the same face would give rise to a higher P300, then this effect could also be explained by visual processing. To rule out the possibility that the difference between the two conditions on the P300 component was caused by a visual repetition effect, a follow-up study was done that employed the same task but different stimulus material.

5.5. Experiment 2

Abstract

During this study, subjects only saw two coloured objects (red/yellow). The objects were presented sequentially and had the same colour (red/red and yellow/yellow) or two different colours (red/yellow and yellow/red).
The task was again to produce two short sentences, describing a male/female (depicted by the colour) using the objects. This was done by means of nominalization and pronominalization. During nominalization, two different colours were presented. During pronominalization, two red or yellow objects were presented.
The aim of this study was to see whether we could replicate the parietal effect found in the first experiment. If this was the case, we expected to find a higher positivity for the pronoun utterances as well.

5.6. Methods Experiment 2

5.6.2. Participants

Twenty-four right-handed, neurologically healthy subjects aged between 20 and 32 (mean age 24.3, 16 women) with normal or corrected to normal vision and German as their native language gave informed consent to participate in this study. Fourteen subjects were used for the final analysis, excluding ten because of excessive blinks and artefacts.

5.6.3. Stimuli

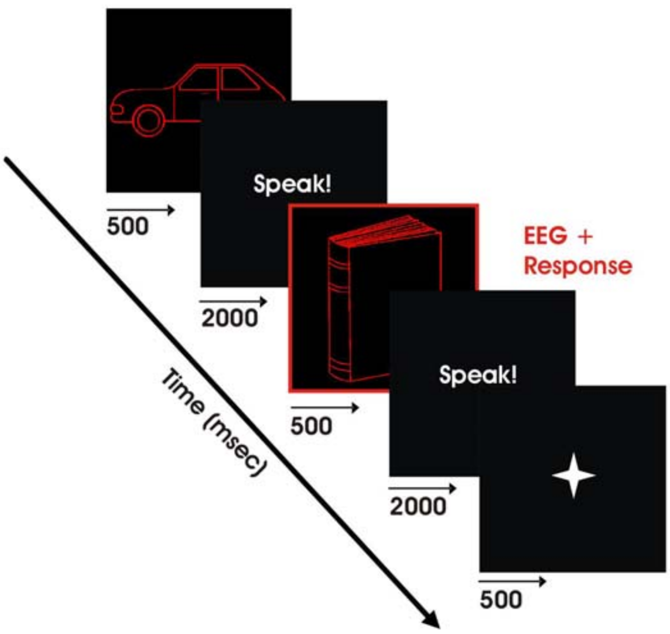
During this experiment, we did not use faces anymore. The same object pictures as in the first experiment were used, only this time they were red and yellow respectively, and presented on a black background. The color of the object (red or yellow, edited with CorelDraw 11.0) specified whether it was either a male or a female carrying out the depicted object.

Again, pictures were combined into pairs such that no semantic and phonological overlap between the words denoting the objects on the two pictures occurred.Each picture pair was presented twice in each condition with the position of the pictures rotated. This resulted in a total of 50 picture pairs per condition and 200 picture pairs for the entire experiment.

5.6.4. Procedure

Each trial comprised the following sequence: The first object picture was presented for 500 ms, followed by a speech prompt for 2000 ms (Figure 5.5. displays an example of a single trial). This was replaced by a second object picture, presented also for 500 ms, followed by another 2000 ms speaking command. At the end of each trial, a white fixation cross was shown for 500 ms to prepare the subjects for the next trial.

Figure 5.5. An example of a single Trial. EEG was triggered on the presentation of the second picture, indicated by the red square.



Instructions were the same as for the first experiment, action 1 required for object 1 was carried out by either a male or female, depicted by the color of the object. The task for action 2 associated with object 2 was similar. The use of a pronoun or noun in the second sentence part was contingent upon the color of the second object. When the second picture had the same color as the first object, this was an indication for the subjects that both actions were carried out by the same person. When they saw two different colors, two different people carried out the actions. For example, subjects saw a red 'book' followed by a yellow 'car'. The correct sentence would then be 'Ein Mann liest (ein Buch), eine Frau fährt (Auto)' (in English: 'A man reads (a book), a woman drives (a car). The same objects both presented in red, would require the utterance 'Ein Mann liest (ein Buch), er fährt (Auto)' (in English: 'A man reads (a book), he drives (a car). When both objects were presented in yellow, the correct utterance would have been 'Eine Frau liest (ein Buch), sie fährt (Auto)' (in English: 'A woman reads (a book), she drives (a car)'). Subjects were instructed to utter the required sentence at the speaking command. After the application of the EEG electrodes, the procedure, instructions and number and structure of practice runs were the same as during the first experiment.

5.6.5. Data acquisition and analysis

Data acquisition parameters were identical to the first experiment. To quantify the ERP effects, mean amplitudes were measured at midline (Fz, Cz, Pz), parasagittal (F3/4, Fc1/2, C3/4, Cp1/2, P3/4, Po3/4, O1/2), and temporal (F7/8, Fc5/6, T7/8, Cp5/6, P7/8) sites in two time-intervals chosen after visual inspection; 300-400 ms and 600-800 ms, relative to a baseline (-100 to 0 ms). These were subjected to repeated measures ANOVA. Factors were pronominalization (nouns versus pronouns), anterior/posterior (3 levels for midline, 5 levels for temporal, 7 levels for parasagittal) and hemisphere (left versus right, this factor was not used for midline analyses).

5.7. Results Experiment 2

The grand average ERPs, time-locked to the presentation of the second picture, show that the two conditions start to diverge around 280 ms, with the noun condition being more negative than the pronoun condition (see Figure 5.7). This first negativity lasts until 380 ms, and is followed by a second positivity emerging around 550 ms and lasting until 900 ms. The first effects seems to appear on left frontal electrodes first, but around 300 ms it already has a more central distribution, whereas the second effect seems to start at right parietal sites and has a right-central distribution throughout the whole time window.

The N1-P2 complex, normally occurring after visual stimulation, did not show any significant differences between the two conditions.

Time window 300-400 ms

Midline electrodes show a main effect of Pronoun (see Table 5.2 for all significant effects). These electrodes show a greater negativity for the noun condition. See Figure 5.6 for the effects on the electrodes and Figure 5.7 for the topographical map of the effect.

Time window 600-800 ms

For this time window, centro-parietal electrodes show two interaction effects, namely between Pronoun and Hemisphere, and between Hemisphere and the Factor Ant/Post. On parasagittal sites, fronto-central electrodes show an interaction between Pronoun and Hemisphere, and parietal electrodes reveal an interaction between Pronoun, Hemisphere and the Ant/Post Factor (Table 5.2 gives a full overview of all the significant effects).

Again, all electrodes show a higher positivity for the pronoun condition, and for this time window, the overall activation is greater on the right hemisphere (Figure 5.6 and Figure 5.7).

Table 5.2. Comparison of pronoun versus noun utterances on the frontal and the parietal component and their subsequent time-windows. Given are the F-values. Abbreviations: Ant = Anterior-Posterior Factor, Hem = Hemisphere Factor.

	Df	**300- 400ms**	***Df***	**600 - 800ms**
Temporal (F7/8,Fc5/6,T7/8,Cp5/6,P7/8)				
Pronoun x Hem			1,13	5.62*
Hem x Ant			4,52	3,83*
Centro-parietal (T7,Cp5,P7,T8,Cp6,P8)				
Pronoun x Hem			1,13	6.42*
Hem x Ant			2,26	4.50*
Parasagittal				
(F3/4,Fc1/2,C3/4,Cp1/2,P3/4,Po3/4,O1/2)			6,78	3.72*
Pronoun x Hem x Ant				
Fronto-central (F3,Fc1,F4,Fc2)			1,13	4.79*
Pronoun x Hem				
Centro-parietal (C3,Cp1,C4,Cp2)			1,13	5.16*
Pronoun x Hem				
Parieto-occipital (P3,Po3,O1,P4,Po4,O2)				
Pronoun x Hem x Ant			2,26	5.54**
Midline(Fz,Cz,Pz)				
Pronoun	1,13	4.84*		

*** p < .001
** p < .01
* p < .05

Figure 5.6. Grand average ERPs at selected scalp sites time locked to the onset of the second picture. The noun condition gave rise to a more negative waveform around 350 ms (depicted in the blue bar), followed by a centro-parietal positivity for the pronoun condition (time window 600-800 ms, depicted in the pink bar).

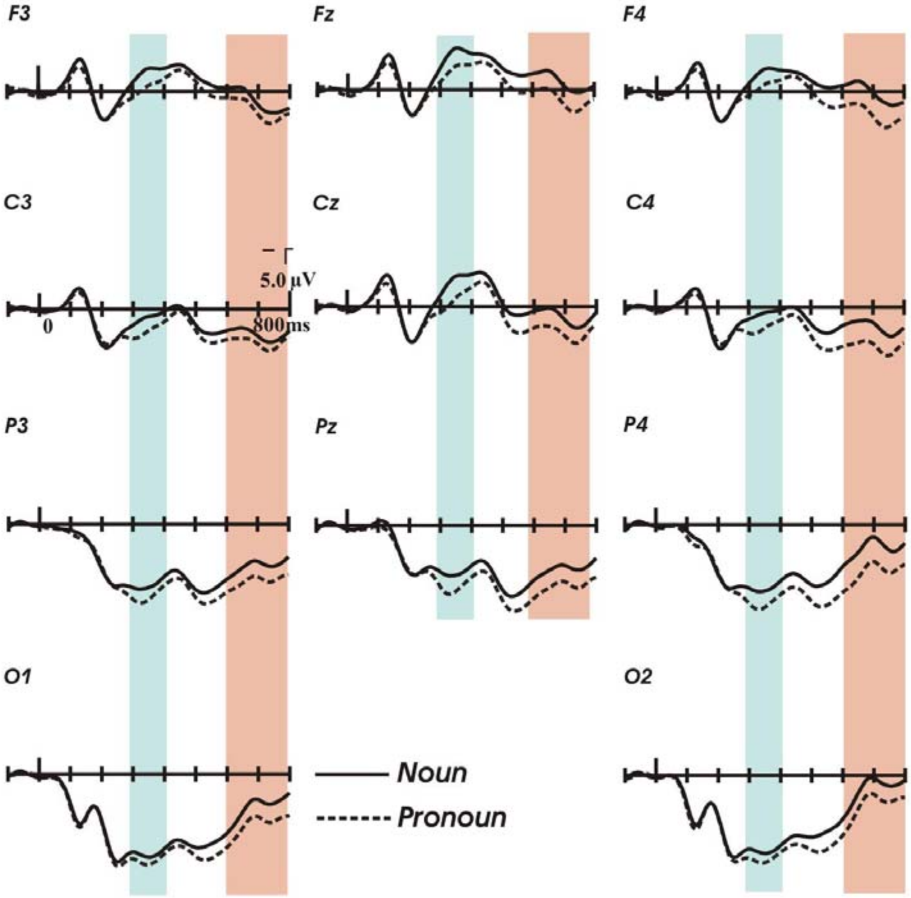
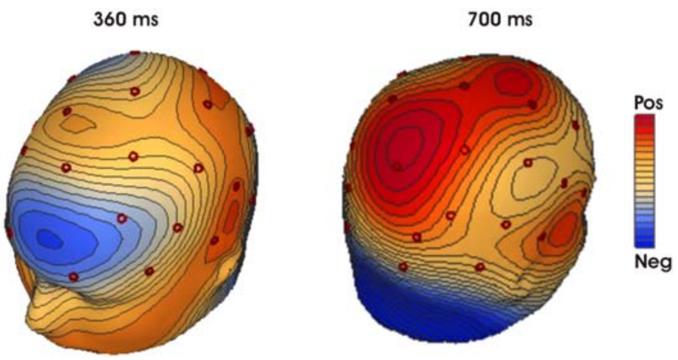


Figure 5.7. Spline interpolated isovoltage maps of the difference between the noun and pronoun condition. During the first phase a frontal distribution is evident, while around 700 ms a centro-parietal distribution emerges (min/max scaling: -1.0 to 1.0 µV at 360 ms and at 700 ms).



5.8. Discussion Experiment 2

This second study shows two components that reveal differences between the two conditions; a fronto-central negativity for the noun condition in time window 300-400 ms, followed by a centro-parietal positivity for the pronoun condition in time window 600-800 ms. The frontal negativity, explained in terms of working memory, implies more working memory demands for the noun condition, an effect similar to that found in the first study.

The parietal component resembles the activation found in the first study as well, showing a higher positivity for the pronoun condition.

5.9. General Discussion

Both studies show differences between the two conditions on a fronto-central negativity followed by a centro-parietal positivity.

The fronto-central negativity: When looking at the negativity, one could interpret this effect in terms of modulation of working memory, a result found in language comprehension studies before (King and Kutas 1995b; Kluender and Kutas 1993a; 1993b; Rösler, et al. 1998; Streb, et al. 2004). For example, Kluender and Kutas (1993a) looked at filler-gap dependencies with various complexities and found a left anterior negativity for the most complex constructions after the filler and after the gap. They concluded that the first LAN effect reflected storage of the filler in working memory, whilst the second was associated with retrieval of the filler. A similar result was reported by Streb et al. (2004), who looked at the comprehension of two types of anaphoric expressions; model-interpretative anaphors (ordinary pronouns, null complements and proper names) and ellipses (elliptic constructions are similar to filler-gap constructions in the sense that an ellipsis represents a gap as well; 'John drove the car and Sandra [ ] the motorbike') while varying the distance between antecedent and anaphor. They found a fronto-central negativity (LAN) for the resolution of ellipses. The process of gap filling, occurring in elliptic constructions, implies retrieval of the correct antecedent from working memory. Looking at the present studies, this retrieval process also occurs when producing a pronoun. However, both experiments show a higher frontal negativity for the noun condition. The direction of this effect can be explained by taking a closer look at the design of the studies. During the first study, subjects saw an object-face picture pair and a speech prompt, followed by a second picture pair and another speech prompt. On the second picture pair, they had to name the face either with a pronoun (when it was the same face) or with a noun (in case they saw a different face). In order to produce the correct pronoun on the second picture pair, the face that was presented in the first picture pair needed to be kept in mind. However, this was not only true for the pronoun condition. Also the noun condition required that the first face needed to be kept in mind, in order to make the right decision whether a new face or the same face was presented in the second picture pair. This means that, for both conditions, to make the right decision about the face in the second picture pair, the face presented in the first picture pair still needs to be kept 'online'.

In other words, during the pronoun condition one recognizes the same face and activates the corresponding pronoun, whereas during the noun condition one sees a different face and has to activate a new noun. The activation of two nouns creates more working memory load in comparison to the activation of one noun and its pronoun, and this is presumably what the frontal negativity reflects. Looking at the design of the second study, the direction of the effect can be explained similarly because the object pictures were presented sequentially. This time, the colour of picture indicated whether a male/female performed the action and, for both conditions, in order to produce the right noun/pronoun utterance on the second picture, the colour of the first picture had to be kept in mind.

In sum, both studies show more working memory activity when a new concept is presented in comparison to a concept that is already accessible.

Another possible explanation for this frontal effect comes from studies tapping into word class differences (Brown, et al. 1999; Neville, et al. 1992; Nobre and McCarthy 1994; Van Petten and Kutas 1991). Nouns belong to the open class words (or content words) category with the term ‘open’ referring to the fact that new nouns are added constantly to the language (e.g., computer, rocket, and so on: hence ‘open class’) and that nouns carry the meaning of an utterance (as opposed to articles, connectives, but similar to verbs and adjectives; hence ‘content words’). Pronouns on the other hand, belong to the closed class words (or function words) that serve the purpose of syntactically structuring a sentence. Besides these differences, these words from different classes also systematically differ in frequency and word length.

Closed class words in general have a much higher frequency, since they are used more often than open class words, and they are shorter in length.

Although several components have been linked to either word class differences, or to the consequent differences in word length and frequency, it is still not completely clear which component represents underlying differences in word class. For example, an anterior negativity (N280) for closed class words (pronouns) has been found in word class differences (Neville, 1992) although this effect has not consistently been replicated (King and Kutas 1995a; Münte, et al. 2001). Münte and colleagues (2001) investigated the difference between open and closed class words by using sentence reading and word lists tasks and by dividing both word groups into different frequency categories. They found a N280 for both word groups, but it showed a shorter latency as a function of higher word frequency. This confirmed results found by King and Kutas (1995) and is supportive for the idea that the N280 does not reflect different neural systems underlying the two word groups. A different negativity, the N400-700 showed an effect for high frequency closed class words and was therefore the only component that seemed to be sensitive to word class.

In sum, this would indicate that the N280 does not necessarily reflect differences between open and closed class words. Further, a higher negativity for function words (pronouns) is not what we find during the present study and therefore it seems reasonable to discard any word class explanations.

A third line of studies that report frontal activation during pronoun comprehension comes from Van Berkum et al. (1999a; 2003a; 2006).

They looked at pronoun resolution in a discourse context, thereby manipulating the number of referents for an antecedent. Subjects read little stories that either contained one clear referent for a noun or two referents, creating ambiguous co-reference. It turned out that ambiguous nouns elicited a negative deflection, arising approximately 300 ms after noun-onset at anterior sites. This effect has been interpreted as an index of a process concerned with 'establishing co-reference'. This process is associated with a higher negativity if the relationship between a noun and its pronoun is more ambiguous. Naturally, establishing co-reference also occurs during production of a pronoun. However, during the present study there was no manipulation of ambiguousness, since the nouns presented in both conditions (noun and pronoun) were exactly the same. Additionally, if the frontal component found in the present studies would reflect 'establishing of co-reference', independent from ambiguousness, this would reflect itself in a greater negativity for the pronoun condition. Since this is not what we find, it is plausible to expect that the frontal component does not reflect co-reference building.

In sum, both experiments show a higher negativity for the noun sentences. The most parsimonious explanation for this negativity seems to be in terms of working memory load.

The centro-parietal positivity: Both studies show an enhanced positivity for the pronoun condition on this component. The distribution and the time window of this component again resemble the P300, a component often found in attention and saliency tasks (Donchin, 1981; Johnson, 1986; Kutas et al., 1977; Münte et al., 2000; Verleger, 1988).

Intracranial recordings point to wide-spread neural generators of this component (Clarke et al., 1999a; Clarke et al., 1999b) and this makes it likely that these different generators might support different cognitive operations. The fact that we find a higher positivity for the pronoun condition on this component implies more need for conceptualization resources during this condition. As behavioural (Jescheniak and Levelt 1994; Meyer, et al. 1999) and ERP studies (Lamers, et al. 2006; Navarrete, et al. 2006; Schmitt, et al. 2002) have already shown, lemma retrieval is necessary in order to activate the correct pronoun. This lemma retrieval entails the meaning of a concept (semantics) and its syntactical information. The semantic information was the same for both conditions in the present studies, since both carried the meaning 'male' and 'female'. However, they differ in the syntactic structure. A lemma's syntactic information specifies the syntactic category, its assignment of grammatical functions and a set of diacritic feature variables (tense, mood, aspect, number, and person). Differences occur in the assignment of grammatical function because an active connection between the pronoun and its antecedent has to be established, whereas this connection is not needed during noun production.

This might lead to the conclusion that extra conceptual resources for the pronoun condition can be explained by the process of establishing co-reference.

A different interpretation for the P300 effect can be found when we look at a study by Heine et al. (2006) who focussed on accessibility differences by tapping into frequency of an antecedent and the influence of salience.

The authors state that a factor influencing the accessibility of an antecedent is saliency; i.e. the more salient an antecedent is, the lower its frequency and the more attention it attracts, thus leading to easier co-reference building. During this study, subjects saw sentences presented word-by-word of which the first part contained nouns that were divided into three different frequency classes (high, middle and low, matched for word length). The second sentence part contained the pronoun. ERPs time-locked to the presentation of the pronouns gave rise to a P300 that was largest for the pronouns referring back to the low-frequency nouns. This component has been found in word-frequency studies before (Rugg 1990) although there are also studies reporting a higher amplitude for high-frequency words (Polich and Donchin 1988). Heine et al. (2006) interpreted the effect as a lexical frequency effect at the presentation of the pronoun, leading to a general allocation of attentional resources. In other words, the process of establishing co-reference is influenced by the accessibility of the noun. And, when a pronoun refers back to a noun with a low frequency, or for that matter, a high saliency leading to more accessibility, the processing of the pronoun itself demands more attentional resources.

Although the design of the Heine et al. (2006) experiment was very different from the present study, both experiments address the process of establishing co-reference and demonstrate a relationship of this process to the P300 component. Apparently, the difficulty of this process is reflected by the amplitude of the P300.

A third explanation can be found by looking at the relationship between the P300 and the P600. As said before, this component has been interpreted in terms of syntactical reanalysis, revision processes (Friederici 1995; Hagoort, et al. 1993; Münte, et al. 1998a), syntactical ambiguity (Osterhout, et al. 1994; Van Berkum, et al. 1999a), complexity (Kaan, et al. 2000) and also as an index of unification processes (Hagoort 2003). There has been a debate whether this P600 is language specific or whether it is related to the P300 and indicating stimulus saliency or probability effects (Coulson, et al. 1998a; Gunter, et al. 1997). In the light of the unification model this would imply that this component could also reflect differences in integration due to differences in syntactical complexity. In this case, the present component would show more syntactical integration processes in producing a pronoun in comparison to the production of a noun. Since differences in noun and pronoun production can be traced to differences in syntactic lemma retrieval, this might be a plausible explanation.

Taken together, the positive component reflects conceptualization differences between the two conditions, either in terms of conceptual resources needed for both processes or in terms of syntactical integration differences.

VI. Micro-planning and fMRI

Abstract

The experimental setup of the experiment was similar to the second ERP experiment; a sequence of two coloured objects was shown, both followed by a speech prompt. The task was again to produce two short sentences, describing a male/female using the depicted object either with nominalization or pronominalization. During this experiment, subjects were instructed to produce the first sentence part covertly and only the second sentence part overtly.

The aim of this study was to gather information about the neuroanatomical areas underlying noun and pronoun production. We expected to find an enlarged BOLD signal for the pronoun condition in speech production related areas, most probable in the left temporal lobe, since this area has been associated with lemma retrieval processes.

6.1. Introduction

Indefrey and Levelt (2004) did a meta-analysis of speech production and comprehension studies and reported several areas that are involved in speech production. The studies that they used for the speech production meta-analysis included picture naming and word generation experiments. By means of this meta-analysis, they looked at similarities and differences between comprehension and production and expanded their speech production model with the relevant neuro-anatomical areas. This revealed that activation in the left middle temporal gyrus was associated with lemma retrieval. Although lemma retrieval is part of the more general conceptualization stage, Maess et al. (2002) showed that this region is rather activated during lemma retrieval than during conceptual processing per se. They found this result during a MEG study where subjects performed in a semantic interference task. Subjects had to name items that either belonged to the same semantical category or to a different one.

Naming semantically related items lead to longer RTs, an effect explained as the 'semantic context effect'. This context effect states that naming several items from one semantical category leads to competition because their corresponding lemmas compete for selection. This process affects selection latency and response times. The Maess et al. (2002) study showed the typical RT-effects of a semantic interference study. Moreover, the MEG results indicated that the area underlying this semantic interference effect was the left temporal region.

The left posterior middle and the superior temporal gyri are said to be involved in phonological word-form retrieval, since these areas become activated during word production versus non-word production (Indefrey and Levelt 2000), a result also found in the meta-analysis (Indefrey and Levelt, 2004). Sub-lexical phonological encoding (syllabification processes) has been found in the left inferior frontal gyrus (Broca's area) and the left mid-superior temporal gyrus (Indefrey and Levelt, 2000; 2004).

To sum up, parts of the conceptualization stage, lemma retrieval, seem to take place in the left middle temporal region, whereas phonological code retrieval appears to be located in the superior temporal region (Indefrey and Levelt, 2000; 2004).

An fMRI study that addresses aspects of pronoun processing during comprehension (by means of a violation paradigm), that may also be relevant for speech production was done by Hammer at al. (2006). Subjects read sentences that contained either a person antecedent (biological/semantic gender information) or a thing antecedent (pure syntactic gender information).

The antecedent was always presented in the first phrase, followed by a second phrase containing the pronoun. This pronoun either referred back to the antecedent (congruent condition) or was incongruent to the antecedent (violation condition). The results showed bilateral activation for incongruent compared to congruent person-pronouns in the inferior frontal gyrus (BA 44) and the supra-marginal gyrus (BA 39) and parts of the left medial frontal gyrus (BA6).

With regard to the word class differences between nouns and pronouns, an fMRI study focusing on class membership, concreteness and task (semantic versus syntactic) by Friederici et al. (2000) is relevant. Subjects saw words and had to do a semantical, syntactical and physical decision task. The stimuli used were counterbalanced for frequency and word length. The overall results showed activation in left frontal and temporal areas, varying as a function of word class, concreteness and task. An area that specifically responded to word class was the left post-central sulcus (BA 40/2).

During the present study, we tapped into pronoun versus noun production during an experiment where subjects saw sequentially presented, colored objects. The color of the object depicted the gender of the person using the object, and subjects had to utter these sentences after each object (covertly for the first picture, overtly for the second picture). We expected to find differences for pronoun versus noun production in speech production related areas, especially the left temporal lobe since it is said to be involved in lemma retrieval.

6.2. Methods

6.2.1. Participants

Sixteen right-handed, neurologically healthy participants aged between 20 and 29 (mean age 22.9, 8 women) with normal or corrected to normal vision and German as their native language gave informed consent and were paid for their participation.

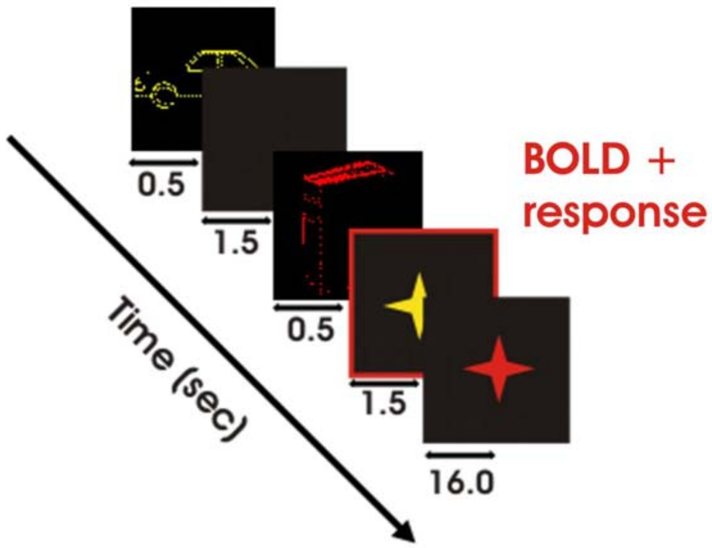
6.2.2. Stimuli

A total of 40 red and yellow line-drawings were taken from the objects used for the ERP studies. Pictures were exactly the same as the one used for the last EEG experiment. Each picture pair was presented twice in each condition (noun/pronoun), the position of the pictures rotated so that a total of 40 picture pairs per condition and 80 picture pairs were used for the entire experiment.

6.2.3. Procedure

Each trial in this slow event-related design comprised the following sequence: The first object picture was presented for 500 ms, followed by a blank screen for 1500 ms. This was replaced by a second object picture, presented also for 500 ms, followed by a white fixation cross for 1500 ms. This white fixation cross was replaced by a colored fixation cross to indicate that overt response time was over. This colored fixation cross lasted for 16 s, after which the next trial was presented (Figure 6.1 displays an example of a single trial).

Figure 6.1. An example of one single trial. BOLD signal was measured at the presentation of the fixation cross, as depicted by the red square.



Instructions were the same as for the last EEG experiment, action 1 required for object 1 was carried out by either a male or female, and this was indicated by the color of the object. The task for action 2 associated with object 2 was similar. For example, subjects saw a red ‘book’ and then a yellow ‘car’. The correct sentence would then be ‘Ein Mann liest (ein Buch), eine Frau fährt (Auto)’ (in English: ‘A man reads (a book), a woman drives (a car). The same objects both presented in red, would require the utterance ‘Ein Mann liest, er fährt (Auto)’ (in English: ‘A man reads (a book), he drives (a car). When both objects would have been yellow, the correct utterance would have been ‘Eine Frau liest (ein Buch), sie fährt (Auto)’ (in English: ‘A woman reads (a book), she drives (a car)’). Subjects were instructed to utter the first sentence covertly and the second sentence overtly.

To minimize variability among the answers and to keep overt production time as short as possible, subjects were instructed to use an identical structure for both sentences (except for the initial word).

Before subjects were placed into the scanner, they received the same three practice runs that were used during the EEG experiments and they were told to lay as still as possible.

6.2.4. Data Acquisition and Analysis

Images were obtained using a 3 Tesla Siemens Magnetom Trio Scanner (Siemens Medical Systems, Erlangen, Germany) and an eight channel head coil. High-resolution, anatomical images were acquired (MP-RAGE, TR = 2500 ms, TE = 1.68 ms, 192 sagittal slices, in-plane resolution 1 x 1 mm^2, slice thickness 1 mm, FOV = 256 mm, matrix size 256 x 256, flip angle 70 º). BOLD dependent functional magnetic resonance images covered the entire cortical volume (30 slices oriented parallel to the AC-PC line, specified with a midsagittal scout image; TR = 2000 ms, TE = 30 ms, FOV = 220 x 220, flip angle 80 º, matrix size = 64 x 64; in-plane resolution 3.5 x 3.5 mm^2, slice thickness 3.5 mm, inter-slice gap 0.35) using an echo planar imaging sequence. One functional run lasted approximately seven minutes, consisted of 210 volumes of which the first four were skipped to avoid T1 saturation effects. In total, there were four runs.Subjects were placed in the scanner and cushions were used to reduce head motion. The presentation of the visual stimuli was volume triggered. Stimuli were presented on a screen positioned at the head end of the magnet bore and subjects viewed the screen through mirror glasses. Overt responses were recorded with an eye-tracking camera aimed at the mouth.

Functional and anatomical images were analyzed with Brainvoyager QX software (Brain Innovation, Maastricht, The Netherlands).

Functional runs were corrected for slice scan time (sinc interpolation), 3D head motion (using trilinear/ sinc interpolation, within and between runs) and for linear trends and low-frequency drifts (high-pass filter of 3 cycles per time point). Functional data were then aligned to the anatomical images and normalized into the standard coordinate system Talairach space (Talairach and Tournoux 1988), followed by spatial smoothing with an 8 mm FWHM Gaussian kernel. A random effects GLM (General Linear Model) specified for the predictors (1) noun sentences, (2) pronoun sentences and (3) object pictures was computed. Significant differences between the two order conditions were assessed by means of contrast (t) maps. Multiple comparisons threshold was not controlled by the False Discovery Rate (FDR) t-value.

6.3. Results

The contrast noun versus pronoun shows activation in the left superior temporal gyrus (LSTG, BA 22) and the right inferior frontal gyrus (RIFG) ($t = 4.00$, $p < .001$) (Figure 6.2). Table 6.1 shows the exact talairach coordinates for each contrast.

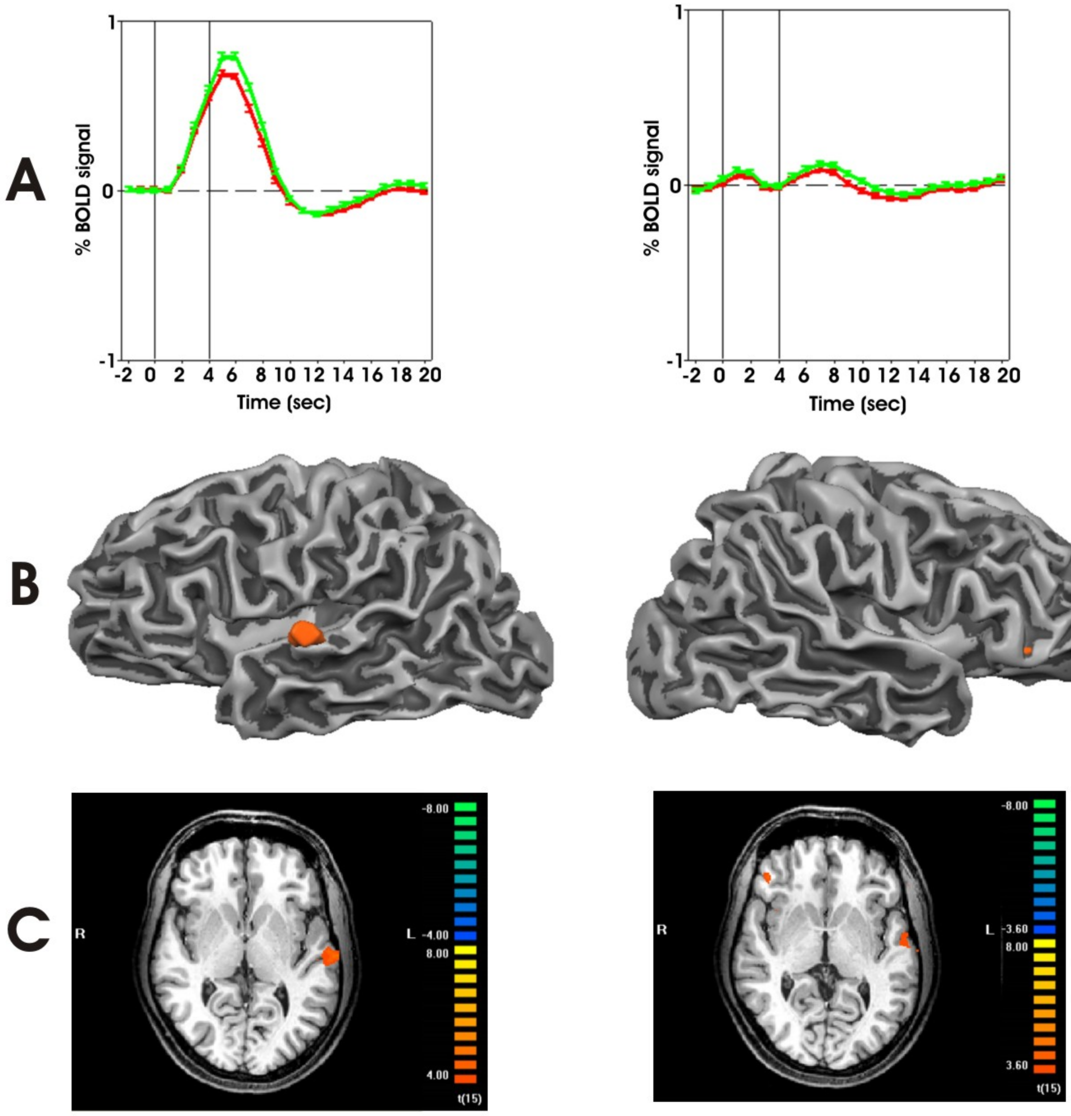


Figure 6.2. (**A**) Event-related average time course of the BOLD response for the area LSTG (green: noun condition; red: pronoun condition) in the left panel and area RIFG in the right panel.
(**B**) Activated voxels as revealed by GLM analysis for the noun condition in the left STG (left panel) and the right IFG (right panel).
(**C**) Activated areas superimposed on an axial slice of a standard brain transformed into Talairach space. The strongest activation was found in the LSTG (BA22), shown in the left panel. The IFG is displayed in the right panel. The left side of the image is the right side of the brain.

Table 6.1. Mean Talairach coordinates of areas of interest (mm ± SD) as defined by Talairach and Tournoux (1998; x: left-right; y: anterior-posterior origin in anterior commissure; z: inferior-superior) Abbreviations: STG: superior temporal gyrus; IFG: inferior frontal gyrus.

Area	*X*	*Y*	*Z*
Left STG	-62	-15	6
Right IFG	44	38	1

6.4. Discussion

The present study shows differences in noun versus pronoun processing in two areas, namely the left superior temporal gyrus (BA22) and the right inferior frontal gyrus, areas that have been found in speech production studies before (Alario, et al. 2006; Hagoort 2005; Indefrey and Levelt 2004; 2000). The middle part of the left temporal region is said to be involved in lexical retrieval processes (Indefrey, et al. 2001a; Indefrey and Levelt 2004; Kircher, et al. 2000; Maess, et al. 2002). The right inferior frontal gyrus (RIFG), that showed activation for the same contrast, has been found during production of SVO sentences, showing syntactical integration processes (Haller, et al. 2005). Further, the IFG has also been linked to verbal working memory in terms of integration processes (Hagoort, 2005; Martin 2003), again in a syntactic context (Haller, et al. 2005; Indefrey, et al. 2001a; Kolk 1995), but also in a task-independent context of maintenance and processing of stimuli (Indefrey, et al. 2001b).

In sum, in terms of speech production, the activation pattern in the LSTG could then be explained by more retrieval processes for the preparation of noun utterances whereas the RIFG would display syntactical integration processing. As explained before, a lemma contains semantical and syntactic information belonging to a concept.

In this light, a lower activation for pronoun production seems quite natural, since the noun corresponding to the pronoun has already been activated during the presentation of the first object picture. In order to produce the correct pronoun, the accompanying lemma information needs to be reactivated or kept active, whereas the presentation of a new concept (a new noun) will lead to complete retrieval of new semantic and syntactical information.

As for comprehension, anterior and posterior temporal activity has been found during semantical and syntactic sentence processing tasks (Dapretto and Bookheimer 1999; Just, et al. 1996; Ni, et al. 2000), often accompanied by inferior frontal gyrus activation (Dapretto and Bookheimer 1999; Kuperberg, et al. 2000; Ni, et al. 2000). Also, Hammer et al. (2006) showed that in congruency between nouns and pronouns leads to a higher activation in the bilateral inferior frontal gyrus.

Taken together, comprehension studies addressing understanding of sentences reveal a network that includes the left inferior frontal cortex and left temporal areas with the latter areas reflecting lexical processing and the activation of syntactic and semantical information (Friederici 2002; Kaan and Swaab 2002). The LIFG, that is said to be more involved in the underlying memory processes, has not been found activated during the present study. However, the RIFG does seem to play a role in integration processes as well.

In sum, both activation patterns show that retrieval and integration of a new concept requires more processing resources in comparison to an accessible concept.

VII. General Discussion

The set of experiments reported in this thesis aimed at investigating the neural correlates underlying conceptualization. To this end, linearization processes during macro-planning and accessibility processes during micro-planning were investigated. Across the different experiments, evidence suggested that both ERP and fMRI experiments reflected differences in conceptualization.

7.1. Summary of key findings

Macro-planning

- The first ERP experiment demonstrated that production of a natural order versus an unnatural order lead to differences in working memory load (in time window 200-250 ms) and conceptualization difficulty (time window 250-300 ms).
- The second ERP experiment revealed the same pattern of results; a frontal working memory component for the natural order condition (180-230 ms) was followed by parietal component, for the unnatural order condition, reflecting conceptualization difficulty (350-400).
- The fMRI study showed an enlarged BOLD response for the unnatural order condition in the left superior temporal region (BA21) and in the left (BA45) and right (BA47) inferior frontal gyrus.

Micro-planning

- The first ERP experiment demonstrated that production of a noun versus a pronoun lead to differences in amplitude on two components; a working memory component with a higher load for the noun condition (200-300 ms) followed by a parietal positivity for the pronoun condition, reflecting conceptualization difficulty (300-500 ms).

- The second ERP experiment showed the same pattern of results; a frontal negativity for the noun condition (300-400 ms) that reflected working memory processes, followed by more conceptualization processes for pronoun production on a parietal positivity (600-800 ms).
- The fMRI study showed an enlarged BOLD response for the production of nouns in the left superior temporal gyrus (BA22) and the right inferior frontal gyrus.

7.2. General discussion

Behavioral studies that tapped into differences between temporal terms for this found more difficulty in understanding *before* sentence constructions (Natsopoulos, et al. 1991; Stevenson and Pollitt 1987). An explanation for this difference in difficulty comes from research in the field of discourse semantics, who state that *before* initial sentences are more difficult since they express an inverted narration relation between events (Heinämäki 1974; Schilder 2001; Tenbrink and Schilder 2001). This difference expresses itself in more working memory processes, as has been shown by ERP studies investigating semantical and syntactic complexity in sentence processing (King and Kutas 1995; Mecklinger, et al. 1995; Müller, et al. 1997; Münte, et al. 1998). Additionally, fMRI studies addressing the same issue, reveal a bilateral fronto-temporal network in comprehension (Dapretto and Bookheimer 1999; Friederici 2002; Just, et al. 1996; Kuperberg, et al. 2000) and production (Haller, et al. 2005; Kircher, et al. 2000; Maess, et al. 2002).

This thesis' studies show that increased difficulty for the temporal connective 'before' is also found during production. Moreover, the conceptualization process has clearly shown to be in need of more resources during 'before' preparation, both in ERPs and fMRI.

Looking at micro-planning and accessibility, behavioural studies showed that lemma information is necessary in order to produce a correct pronoun (Jescheniak, et al. 2001; Meyer, et al. 1999), a result found during ERP studies as well (Lamers, et al. 2006; Navarrete, et al. 2006; Schmitt, et al. 2002). Further, ERP studies addressing anaphoric expressions in comprehension found more working memory demands in retrieval processes required during the process of establishing co-reference (Kluender and Kutas 1993a; Rösler, et al. 1998; Streb, et al. 2004), hereby implying that sentences containing these expressions require more processing resources. Additionally, an fMRI study (Hammer, et al. 2006) manipulating co-reference, by varying the amount of congruency between nouns and pronouns, revealed that increased difficulty lead to more activation in bilateral inferior frontal areas, areas that have been shown to be involved in semantical and syntactical sentence processing (Friederici 2002; Haller, et al. 2005; Just, et al. 1996).

The present studies reveal that the process of establishing co-reference leads to differences in conceptualization processes. The ERP studies reveal increased activity during co-reference processes whereas the fMRI study showed enhanced activity for production of noun sentences.

Taken together, this thesis gathered relevant information about timing and the underlying neuroanatomical areas involved in conceptualization processes. Moreover, both macro and micro- planning processes seem to take place within approximately 500 ms, with a fronto-temporal network being involved. Although studies from various sources have shown that the underlying processes of linearization entail semantical information and accessibility processes require semantical and syntactic information, future experiments have to be done to give a more exact picture of the underlying processes of conceptualization in language production.

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Picture pair combinations for stimulus material Chapter III (Macro-planning, exp 1 ERP):

Stapler – Drilling machine
Scales – Puzzle
Mixer – Book
Scissors – bike
Mop – Piggy bank
Couch- Spoon
Vacuum cleaner – Bell
Iron - Drums
Washing machine – microphone
Bath –Racket
Thread–Skate
Rake – Skittle
Broom – Skipping rope
Slide– Toaster
Land mower– Tent
Saw– Stove
Axe – Camera
Hammer – Swing
Palette – Phone
Flute – Calculator
Cup – Hairdryer
Brush – Pen
Gun – Printer
Suitcase – Cigarettes
Petrol – Football

Sentences produced during Macro-planning, ERP

Nachdem der Mann tackert, bohrt er
Bevor der Mann bohrt, tackert er
Nachdem die Frau tackert, bohrt sie
Bevor die Frau bohrt, tackert sie
Nachdem der Mann wiegt, puzzelt er
Bevor der Mann puzzelt, wiegt er
Nachdem die Frau wiegt, puzzelt sie
Bevor die Frau puzzelt, wiegt sie
Nachdem der Mann mixt, liest er
Bevor der Mann liest, mixt er
Nachdem die Frau mixt, liest sie
Bevor die Frau liest, mixt sie
Nachdem der Mann schneidet, fährt er
Bevor der Mann fährt, schneidet er
Nachdem die Frau fährt, schneidet sie
Bevor die Frau schneidet, fährt sie
Nachdem der Mann wischt, spart er
Bevor der Mann spart, wischt er
Nachdem die Frau wischt, spart sie
Bevor die Frau spart, wischt sie

Nachdem der Mann isst, sitzt er
Bevor der Mann sitzt, isst er
Nachdem die Frau sitzt, isst sie
Bevor die Frau isst, sitzt sie
Nachdem der Mann zeltet, läutet er
Bevor der Mann läutet, zeltet er
Nachdem die Frau zeltet, läutet sie
Bevor die Frau läutet, zeltet sie
Nachdem der Mann bügelt, tankt er
Bevor der Mann tankt, bügelt er
Nachdem die Frau bügelt, tankt sie
Bevor die Frau tankt, bügelt sie
Nachdem der Mann wäscht, singt er
Bevor der Mann singt, wäscht er
Nachdem die Frau singt, wäscht sie
Bevor die Frau wäscht, singt sie
Nachdem der Mann badet, rechnet er
Bevor der Mann rechnet, badet er
Nachdem die Frau badet, rechnet sie
Bevor die Frau rechnet, badet sie
Nachdem der Mann harkt, kegelt er
Bevor der Mann kegelt, harkt er
Nachdem die Frau harkt, kegelt sie
Bevor die Frau kegelt, harkt sie
Nachdem der Mann fegt, schläft er
Bevor der Mann schläft, fegt er
Nachdem die Frau schläft, fegt sie
Bevor die Frau fegt, schläft sie
Nachdem der Mann sägt, kocht er
Bevor der Mann kocht, sägt er
Nachdem die Frau sägt, kocht sie
Bevor die Frau kocht, sägt sie
Nachdem der Mann hackt, fotografiert er
Bevor der Mann fotografiert, hackt er
Nachdem die Frau hackt, fotografiert sie
Bevor die Frau fotografiert, hackt sie
Nachdem der Mann hämmert, schaukelt er
Bevor der Mann schaukelt, hämmert er
Nachdem die Frau hämmert, schaukelt sie
Bevor die Frau schaukelt, hämmert sie
Nachdem der Mann malt, telefoniert er
Bevor der Mann telefoniert, malt er
Nachdem die Frau malt, telefoniert sie
Bevor die Frau telefoniert, malt sie
Nachdem der Mann trinkt, föhnt er
Bevor der Mann föhnt, trinkt er
Nachdem die Frau föhnt, trinkt sie
Bevor die Frau trinkt, föhnt sie
Nachdem der Mann bürstet, schneidet er
Bevor der Mann schneidet, bürstet er
Nachdem die Frau bürstet, schneidet sie
Bevor die Frau bürstet, schneidet sie
Nachdem der Mann schießt, drückt er
Bevor der Mann drückt, schießt er
Nachdem die Frau schießt, drückt sie

Bevor die Frau drückt, schießt sie
Nachdem der Mann packt, raucht er
Bevor der Mann raucht, packt er
Nachdem die Frau packt, raucht sie
Bevor die Frau raucht, packt sie
Nachdem der Mann fegt, springt er
Bevor der Mann springt, fegt er
Nachdem die Frau fegt, springt sie
Bevor die Frau springt, fegt sie
Nachdem der Mann rutscht, toastet er
Bevor der Mann toastet, rutscht er
Nachdem die Frau rutscht, toastet sie
Bevor die Frau toastet, rutscht sie
Nachdem der Mann Schlagzeug spielt, sägt er
Bevor der Mann sägt, spielt er Schlagzeug
Nachdem die Frau Schlagzeug spielt, sägt sie
Bevor die Frau sägt, spielt sie Schlagzeug

Picture pair combinations for stimulus material Chapter III (Macro-planning, ERP 2):

Stapler – Drilling machine
Scales – Puzzle
Mixer – Book
Scissors – bike
Mop – Piggy bank
Couch- Spoon
Vacuum cleaner – Bell
Iron - Drums
Washing machine – microphone
Bath –Racket
Thread–Skate
Rake – Skittle
Broom – Skipping rope
Slide– Toaster
Land mower– Tent
Saw– Stove
Axe – Camera
Hammer – Swing
Palette – Phone
Flute – Calculator
Cup – Hairdryer
Brush – Pen
Gun – Printer
Suitcase – Cigarettes
Petrol – Football
Pen – Thread
Stapler - Land mower
Calculator – palette
Printer – drilling machine
Skate – rake
Microphone – spoon
Flute – skipping rope

Drums – saw
Hammer – cigarettes
Swing- phone
Slide – scissors
Camera – piggy bank
Gun – toaster
Skittle – couch
Book – hair dryer
Suitcase – vacuum cleaner
Puzzle – broom
Stove – Football
Iron – racket
Bath – mop
Axe – cup
Washing machine – mixer
Petrol – bell
Tent – Brush
Bike - scales
Drums – Saw
Land mower – Microphone
Skate – Stapler
Tent – Cigarettes
Flute – Palette
Bath – Pen
Spoon – Puzzle
Calculator – scissors
Skipping rope – mop
Bell – swing
Racket – vacuum cleaner
Iron – rake
Washing machine – phone
Hammer – camera
Hairdryer – suitcase
Cup – slide
Broom – gun
Petrol – thread
Bike – stove
Axe – toaster
Football – couch
Drilling machine – mixer
Scales – printer
Brush - Skittle
Piggy bank - book

Sentences produced during Macro-planning, ERP 2

Nachdem ich tackere, bohre ich
Nachdem ich bohre, tackere ich
Bevor ich tackere, bohre ich
Bevor ich bohre, tackere ich
Nachdem ich wiege, puzzele ich
Nachdem ich puzzele, wiege ich
Bevor ich wiege, puzzele ich
Bevor ich puzzele, wiege ich

Nachdem ich mixe, lese ich
Nachdem ich lese, mixe ich
Bevor ich mixe, lese ich
Bevor ich lese, mixe ich
Nachdem ich schneide, fahre ich
Nachdem ich fahre, schneide ich
Bevor ich schneide, fahre ich
Bevor ich fahre, schneide ich
Nachdem ich wische, spare ich
Nachdem ich spare, wische ich
Bevor ich wische, spare ich
Bevor ich spare, wische ich
Nachdem ich sitze, esse ich
Nachdem ich esse, sitze ich
Bevor ich sitze, esse ich
Bevor ich esse, sitze ich
Nachdem ich staubsauge, klingele ich
Nachdem ich klingele, staubsauge ich
Bevor ich staubsauge, klingele ich
Bevor ich klingele, staubsauge ich
Nachdem ich bügele, spiele ich Schlagzeug
Nachdem ich Schlagzeug spiele, bügele ich
Bevor ich bügele, spiel ich Schlagzeug ich
Bevor ich Schlagzeug spiele, bügele ich
Nachdem ich wasche, singe ich
Nachdem ich singe, wasche ich
Bevor ich wasche, singe ich
Bevor ich singe, wasche ich
Nachdem ich bade, spiele ich Tennis
Nachdem ich Tennis spiele, bade ich
Bevor ich bade, spiel ich Tennis
Bevor ich Tennis spiele, bade ich
Nachdem ich harke, kegele ich
Nachdem ich kegele, harke ich
Bevor ich harke, kegele ich
Bevor ich kegele, harke ich
Nachdem ich fege, springe ich
Nachdem ich springe, fege ich
Bevor ich fege, springe ich
Bevor ich springe, fege ich
Nachdem ich säge, koche ich
Nachdem ich koche, säge ich
Bevor ich säge, koche ich
Bevor ich koche, säge ich
Nachdem ich hacke, fotografiere ich
Nachdem ich fotografiere, hacke ich
Bevor ich hacke, fotografiere ich
Bevor ich fotografiere, hacke ich
Nachdem ich hämmere, schaukele ich
Nachdem ich schaukele, hämmere ich
Bevor ich hämmere, schaukele ich
Bevor ich schaukele, hämmere ich
Nachdem ich male, telefoniere ich
Nachdem ich telefoniere, male ich
Bevor ich telefoniere, male ich

Bevor ich male, telefoniere ich
Nachdem ich trinke, föhne ich
Nachdem ich föhne, trinke ich
Bevor ich trinke, föhne ich
Bevor ich föhne, trinke ich
Nachdem ich bürste, schreibe ich
Nachdem ich schreibe, bürste ich
Bevor ich bürste, schreibe ich
Bevor ich schreibe, bürste ich
Nachdem ich schieße, drücke ich
Nachdem ich drücke, schieße ich
Bevor ich schieße, drücke ich
Bevor ich drücke, schieße ich
Nachdem ich packe, rauche ich
Nachdem ich rauche, packe ich
Bevor ich packe, rauche ich
Bevor ich rauche, packe ich
Nachdem ich rutsche, toaste ich
Nachdem ich toaste, rutsche ich
Bevor ich rutsche, toaste ich
Bevor ich toaste, rutsche ich
Nachdem ich rasen mähe, zelte ich
Nachdem ich zelte, mähe ich rasen
Bevor ich rasen mähe, zelte ich
Bevor ich zelte, mähe ich rasen
Nachdem ich flöte, rechne ich
Nachdem ich rechne, flöte ich
Bevor ich flöte, rechne ich
Bevor ich rechne, flöte ich
Nachdem ich tanke, spiele ich Fußball
Nachdem ich Fußball spiele, tanke ich
Bevor ich tanke, spiele ich Fußball
Bevor ich Fußball spiele, tanke ich
Nachdem ich schreibe, nähe ich
Nachdem ich nähe, schreibe ich
Bevor ich schreibe, nähe ich
Bevor ich nähe, schreibe ich
Nachdem ich tackere, mähe ich Rasen
Nachdem ich Rasen mähe, tackere ich
Bevor ich tackere, mähe ich Rasen
Bevor ich Rasen mähe, tackere ich
Nachdem ich rechne, male ich
Nachdem ich male, rechne ich
Bevor ich rechne, male ich
Bevor ich male, rechne ich
Nachdem ich drücke, bohre ich
Nachdem ich bohre, drücke ich
Bevor ich drücke, bohre ich
Bevor ich bohre, drücke ich
Nachdem ich Schlittschuh laufe, harke ich
Nachdem ich harke, laufe ich Schlittschuh
Bevor ich Schlittschuh laufe, harke ich
Bevor ich harke, laufe ich Schlittschuh
Nachdem ich singe, esse ich
Nachdem ich esse, singe ich

Bevor ich singe, esse ich
Bevor ich esse, singe ich
Nachdem ich flöte, springe ich
Nachdem ich springe, flöte ich
Bevor ich flöte, springe ich
Bevor ich springe, flöte ich
Nachdem ich Schlagzeug spiele, säge ich
Nachdem ich säge, spiele ich Schlagzeug
Bevor ich Schlagzeug spiele, säge ich
Bevor ich säge, spiele ich Schlagzeug
Nachdem ich hämmere, rauche ich
Nachdem ich rauche, hämmere ich
Bevor ich hämmere, rauche ich
Bevor ich rauche, hämmere ich
Nachdem ich schaukele, telefoniere ich
Nachdem ich telefoniere, schaukele ich
Bevor ich schaukele, telefoniere ich
Bevor ich telefoniere, schaukele ich
Nachdem ich rutsche, schneide ich
Nachdem ich schneide, rutsche ich
Bevor ich rutsche, schneide ich
Bevor ich schneide, rutsche ich
Nachdem ich fotografiere, spare ich
Nachdem ich spare, fotografiere ich
Bevor ich fotografiere, spare ich
Bevor ich spare, fotografiere ich
Nachdem ich schieße, toaste ich
Nachdem ich toaste, schieße ich
Bevor ich schieße, toaste ich
Bevor ich toaste, schieße ich
Nachdem ich kegele, sitze ich
Nachdem ich sitze, kegele ich
Bevor ich kegele, sitze ich
Bevor ich sitze, kegele ich
Nachdem ich lese, föhne ich
Nachdem ich föhne, lese ich
Bevor ich lese, föhne ich
Bevor ich föhne, lese ich
Nachdem ich packe, sauge ich
Nachdem ich sauge, packe ich
Bevor ich packe, sauge ich
Bevor ich sauge, packe ich
Nachdem ich puzzele, fege ich
Nachdem ich fege, puzzele ich
Bevor ich puzzele, fege ich
Bevor ich fege, puzzele ich
Nachdem ich koche, spiele ich Fußball
Nachdem ich Fußball spiele, koche ich
Bevor ich koche, spiele ich Fußball
Bevor ich Fußball spiele, koche ich
Nachdem ich bügele, spiele ich Tennis
Nachdem ich Tennis spiele, bügele ich
Bevor ich bügele, spiele ich Tennis
Bevor ich Tennis spiele, bügele ich
Nachdem ich bade, fege ich

Nachdem ich fege, bade ich
Bevor ich bade, fege ich
Bevor ich fege, bade ich
Nachdem ich hacke, trinke ich
Nachdem ich trinke, hacke ich
Bevor ich hacke, trinke ich
Bevor ich trinke, hacke ich
Nachdem ich wasche, mixe ich
Nachdem ich mixe, wasche ich
Bevor ich wasche, mixe ich
Bevor ich mixe, wasche ich
Nachdem ich tanke, klingele ich
Nachdem ich klingele, tanke ich
Bevor ich tanke, klingele ich
Bevor ich klingele, tanke ich
Nachdem ich zelte, brüste ich
Nachdem ich brüste, zelte ich
Bevor ich zelte, brüste ich
Bevor ich brüste, zelte ich
Nachdem ich fahre, schneide ich
Nachdem ich schneide, fahre ich
Bevor ich fahre, schneide ich
Bevor ich schneide, fahre ich
Nachdem ich Schlagzeug spiele, säge ich
Nachdem ich säge, spiele ich Schlagzeug
Bevor ich Schlagzeug spiele, säge ich
Bevor ich säge, spiele ich Schlagzeug
Nachdem ich rasen mähe, singe ich
Nachdem ich singe, mähe ich rasen
Bevor ich rasen mähe, singe ich
Bevor ich singe, mähe ich rasen
Nachdem ich Schlittschuh laufe, tackere ich
Nachdem ich tackere, laufe ich Schlittschuh
Bevor ich Schlittschuh laufe, tackere ich
Bevor ich tackere, laufe ich Schlittschuh
Nachdem ich zelte, rauche ich
Nachdem ich rauche, zelte ich
Bevor ich zelte, rauche ich
Bevor ich rauche, zelte ich
Nachdem ich flöte, male ich
Nachdem ich male, flöte ich
Bevor ich flöte, male ich
Bevor ich male, flöte ich
Nachdem ich bade, schreibe ich
Nachdem ich schreibe, bade ich
Bevor ich bade, schreibe ich
Bevor ich schreibe, bade ich
Nachdem ich esse, puzzele ich
Nachdem ich puzzele, esse ich
Bevor ich esse, puzzele ich
Bevor ich puzzele, esse ich
Nachdem ich rechne, schneide ich
Nachdem ich schneide, rechne ich
Bevor ich rechne, schneide ich
Bevor ich schneide, rechne ich

Nachdem ich springe, fege ich
Nachdem ich fege, springe ich
Bevor ich springe, fege ich
Bevor ich fege, springe ich
Nachdem ich klingele, schaukele ich
Nachdem ich schaukele, klingele ich
Bevor ich klingele, schaukele ich
Bevor ich schaukele, klingele ich
Nachdem ich Tennis spiele, sauge ich
Nachdem ich sauge, spiele ich Tennis
Bevor ich Tennis spiele, sauge ich
Bevor ich sauge, spiele ich Tennis
Nachdem ich bügele, harke ich
Nachdem ich harke, bügele ich
Bevor ich bügele, harke ich
Bevor ich harke, bügele ich
Nachdem ich wasche, telefoniere ich
Nachdem ich telefoniere, wasche ich
Bevor ich wasche, telefoniere ich
Bevor ich telefoniere, wasche ich
Nachdem ich hämmere, fotografiere ich
Nachdem ich fotografiere, hämmere ich
Bevor ich hämmere, fotografiere ich
Bevor ich fotografiere, hämmere ich
Nachdem ich föhne, packe ich
Nachdem ich packe, föhne ich
Bevor ich föhne, packe ich
Bevor ich packe, föhne ich
Nachdem ich trinke, rutsche ich
Nachdem ich rutsche, trinke ich
Bevor ich trinke, rutsche ich
Bevor ich rutsche, trinke ich
Nachdem ich fege, schieße ich
Nachdem ich schieße, fege ich
Bevor ich fege, schieße ich
Bevor ich schieße, fege ich
Nachdem ich tanke, nähe ich
Nachdem ich nähe, tanke ich
Bevor ich tanke, nähe ich
Bevor ich nähe, tanke ich
Nachdem ich fahre, koche ich
Nachdem ich koche, fahre ich
Bevor ich fahre, koche ich
Bevor ich koche, fahre ich
Nachdem ich hacke, toaste ich
Nachdem ich toaste, hacke ich
Bevor ich hacke, toaste ich
Bevor ich toaste, hacke ich
Nachdem ich Fußball spiele, sitze ich
Nachdem ich sitze, spiele ich Fußball
Bevor ich Fußball spiele, sitze ich
Bevor ich sitze, spiele ich Fußball
Nachdem ich bohre, mixe ich
Nachdem ich mixe, bohre ich
Bevor ich bohre, mixe ich

Bevor ich mixe, bohre ich
Nachdem ich tackere, drücke ich
Nachdem ich drücke, tackere ich
Bevor ich tackere, drücke ich
Bevor ich drücke, tackere ich
Nachdem ich brüste, kegele ich
Nachdem ich kegele, brüste ich
Bevor ich brüste, kegele ich
Bevor ich kegele, brüste ich
Nachdem ich spare, lese ich
Nachdem ich lese, spare ich
Bevor ich spare, lese ich
Bevor ich lese, spare ich

Picture pair combinations for stimulus material Chapter IV (Macro-planning fMRI):

Stapler – Drilling machine
Scales – Puzzle
Mixer – Book
Scissors – Car
Hammer – Swing
Glass – Hair dryer
Tent – Bell
Rake – Skittle
Gun – Printer
Axe – Camera
Mop – Piggy bank
Couch – Spoon
Iron – Petrol
Washing machine – Microphone
Bath – Calculator
Broom - Bed
Saw – Stove
Palette – Phone
Brush – Pencil
Bag - Cigar

Sentences produced during Macro-planning fMRI:

Nachdem ich tackere, bohre ich
Nachdem ich bohre, tackere ich
Bevor ich tackere, bohre ich
Bevor ich bohre, tackere ich
Nachdem ich wiege, puzzele ich
Nachdem ich puzzele, wiege ich
Bevor ich wiege, puzzele ich
Bevor ich puzzele, wiege ich
Nachdem ich mixe, lese ich
Nachdem ich lese, mixe ich
Bevor ich mixe, lese ich
Bevor ich lese, mixe ich
Nachdem ich schneide, fahre ich

Nachdem ich fahre, schneide ich
Bevor ich schneide, fahre ich
Bevor ich fahre, schneide ich
Nachdem ich wische, spare ich
Nachdem ich spare, wische ich
Bevor ich wische, spare ich
Bevor ich spare, wische ich
Nachdem ich sitze, esse ich
Nachdem ich esse, sitze ich
Bevor ich sitze, esse ich
Bevor ich esse, sitze ich
Nachdem ich zelte, läute ich
Nachdem ich läute, zelte ich
Bevor ich zelte, läute ich
Bevor ich läute, zelte ich
Nachdem ich bügele, tanke ich
Nachdem ich tanke, bügele ich
Bevor ich bügele, tanke ich
Bevor ich tanke, bügele ich
Nachdem ich wasche, singe ich
Nachdem ich singe, wasche ich
Bevor ich wasche, singe ich
Bevor ich singe, wasche ich
Nachdem ich bade, rechne ich
Nachdem ich rechne, bade ich
Bevor ich bade, rechne ich
Bevor ich rechne, bade ich
Nachdem ich harke, kegele ich
Nachdem ich kegele, harke ich
Bevor ich harke, kegele ich
Bevor ich kegele, harke ich
Nachdem ich fege, schlafe ich
Nachdem ich schlafe, fege ich
Bevor ich fege, schlafe ich
Bevor ich schlafe, fege ich
Nachdem ich säge, koche ich
Nachdem ich koche, säge ich
Bevor ich säge, koche ich
Bevor ich koche, säge ich
Nachdem ich hacke, fotografiere ich
Nachdem ich fotografiere, hacke ich
Bevor ich hacke, fotografiere ich
Bevor ich fotografiere, hacke ich
Nachdem ich hämmere, schaukele ich
Nachdem ich schaukele, hämmere ich
Bevor ich hämmere, schaukele ich
Bevor ich schaukele, hämmere ich
Nachdem ich male, telefoniere ich
Nachdem ich telefoniere, male ich
Bevor ich telefoniere, male ich
Bevor ich male, telefoniere ich
Nachdem ich trinke, föhne ich
Nachdem ich föhne, trinke ich
Bevor ich trinke, föhne ich
Bevor ich föhne, trinke ich

Nachdem ich bürste, schreibe ich
Nachdem ich schreibe, bürste ich
Bevor ich bürste, schreibe ich
Bevor ich schreibe, bürste ich
Nachdem ich schieße, drücke ich
Nachdem ich drücke, schieße ich
Bevor ich schieße, drücke ich
Bevor ich drücke, schieße ich
Nachdem ich packe, rauche ich
Nachdem ich rauche, packe ich
Bevor ich packe, rauche ich
Bevor ich rauche, packe ich

Picture pair combinations for stimulus material Chapter V (Micro-planning, ERP 1):

Stapler – Drilling machine
Scales – Puzzle
Mixer – Book
Scissors – bike
Mop – Piggy bank
Couch- Spoon
Vacuum cleaner – Bell
Iron - Drums
Washing machine – microphone
Bath –Racket
Thread–Skate
Rake – Skittle
Broom – Skipping rope
Slide– Toaster
Land mower– Tent
Saw– Stove
Axe – Camera
Hammer – Swing
Palette – Phone
Flute – Calculator
Cup – Hairdryer
Brush – Pen
Gun – Printer
Suitcase – Cigarettes
Petrol – Football

Sentences produced during Micro-planning, ERP 1:

Der Mann tackert, Die Frau bohrt
Der Mann bohrt, Die Frau tackert
Die Frau tackert, Der Mann bohrt
Die Frau bohrt, Der Mann tackert
Der Mann tackert, er bohrt
Der Mann bohrt, er tackert
Die Frau tackert, sie bohrt
Die Frau bohrt, sie tackert

Der Mann wiegt, Die Frau puzzelt
Der Mann puzzelt, Die Frau wiegt
Die Frau wiegt, Der Mann puzzelt
Die Frau puzzelt, Der Mann wiegt
Der Mann wiegt, er puzzelt
Der Mann puzzelt, er wiegt
Die Frau wiegt, sie puzzelt
Die Frau puzzelt, sie wiegt
Der Mann mixt, Die Frau liest
Der Mann liest, Die Frau mixt
Die Frau mixt, Der Mann liest
Die Frau liest, Der Mann mixt
Der Mann mixt, er liest
Der Mann liest, er mixt
Die Frau mixt, sie liest
Die Frau liest, sie mixt
Der Mann schneidet, Die Frau fährt
Der Mann fährt, Die Frau schneidet
Die Frau schneidet, Der Mann fährt
Die Frau fährt, Der Mann schneidet
Der Mann fährt, er schneidet
Der Mann schneidet, er fährt
Die Frau fährt, sie schneidet
Die Frau schneidet, sie fährt
Der Mann fegt, Die Frau spart
Der Mann spart, Die Frau fegt
Die Frau fegt, Der Mann spart
Die Frau spart, Der Mann fegt
Der Mann spart, er fegt
Der Mann fegt, er spart
Die Frau spart, sie fegt
Die Frau fegt, sie spart
Der Mann sitzt, Die Frau isst
Der Mann isst, Die Frau sitzt
Die Frau sitzt, Der Mann isst
Die Frau isst, Der Mann sitzt
Der Mann isst, er sitzt
Der Mann sitzt, er isst
Die Frau isst, sie sitzt
Die Frau sitzt, sie isst
Der Mann saugt, Die Frau klingelt
Der Mann klingelt, Die Frau saugt
Die Frau saugt, Der Mann klingelt
Die Frau klingelt, Der Mann saugt
Der Mann klingelt, er saugt
Der Mann saugt, er klingelt
Die Frau klingelt, sie saugt
Die Frau saugt, sie klingelt
Der Mann bügelt, Die Frau spielt Schlagzeug
Der Mann spielt Schlagzeug, Die Frau bügelt
Die Frau bügelt, Der Mann spielt Schlagzeug
Die Frau spielt Schlagzeug, Der Mann bügelt
Der Mann spielt Schlagzeug, er bügelt
Der Mann bügelt, er spielt Schlagzeug
Die Frau spielt Schlagzeug, sie bügelt

Die Frau bügelt, sie spielt Schlagzeug
Der Mann wäscht, Die Frau singt
Der Mann singt, Die Frau wäscht
Die Frau wäscht, Der Mann singt
Die Frau singt, Der Mann wäscht
Der Mann singt, er wäscht
Der Mann wäscht, er singt
Die Frau singt, sie wäscht
Die Frau wäscht, sie singt
Der Mann badet, Die Frau spielt Tennis
Der Mann spielt Tennis, Die Frau badet
Die Frau badet, Der Mann spielt Tennis
Die Frau spielt Tennis, Der Mann badet
Der Mann spielt Tennis, er badet
Der Mann badet, er spielt Tennis
Die Frau spielt Tennis, sie badet
Die Frau badet, sie spielt Tennis
Der Mann näht, Die Frau läuft Schlittschuh
Der Mann läuft Schlittschuh, Die Frau näht
Die Frau näht, Der Mann läuft Schlittschuh
Die Frau läuft Schlittschuh, Der Mann näht
Der Mann läuft Schlittschuh, er näht
Der Mann näht, er läuft Schlittschuh
Die Frau läuft Schlittschuh, sie näht
Die Frau näht, sie läuft Schlittschuh
Der Mann harkt, Die Frau kegelt
Der Mann kegelt, Die Frau harkt
Die Frau harkt, Der Mann kegelt
Die Frau kegelt, Der Mann harkt
Der Mann kegelt, er harkt
Der Mann harkt, er kegelt
Die Frau kegelt, sie harkt
Die Frau harkt, sie kegelt
Der Mann fegt, Die Frau springt
Der Mann springt, Die Frau fegt
Die Frau fegt, Der Mann springt
Die Frau springt, Der Mann fegt
Der Mann springt, er fegt
Der Mann fegt, er springt
Die Frau springt, sie fegt
Die Frau fegt, sie springt
Der Mann rutscht, Die Frau toastet
Der Mann toastet, Die Frau rutscht
Die Frau rutscht, Der Mann toastet
Die Frau toastet, Der Mann rutscht
Der Mann toastet, er rutscht
Der Mann rutscht, er toastet
Die Frau toastet, sie rutscht
Die Frau rutscht, sie toastet
Der Mann mäht rasen, Die Frau zeltet
Der Mann zeltet, Die Frau mäht rasen
Die Frau mäht rasen, Der Mann zeltet
Die Frau zeltet, Der Mann mäht rasen
Der Mann zeltet, er mäht rasen
Der Mann mäht rasen, er zeltet

Die Frau zeltet, sie mäht rasen
Die Frau mäht rasen, sie zeltet
Der Mann sägt, Die Frau kocht
Der Mann kocht, Die Frau sägt
Die Frau sägt, Der Mann kocht
Die Frau kocht, Der Mann sägt
Der Mann kocht, er sägt
Der Mann sägt, er kocht
Die Frau kocht, sie sägt
Die Frau sägt, sie kocht
Der Mann hackt, Die Frau fotografiert
Der Mann fotografiert, Die Frau hackt
Die Frau hackt, Der Mann fotografiert
Die Frau fotografiert, Der Mann hackt
Der Mann fotografiert, er hackt
Der Mann hackt, er fotografiert
Die Frau fotografiert, sie hackt
Die Frau hackt, sie fotografiert
Der Mann hämmert, Die Frau schaukelt
Der Mann schaukelt, Die Frau hämmert
Die Frau hämmert, Der Mann schaukelt
Die Frau schaukelt, Der Mann hämmert
Der Mann schaukelt, er hämmert
Der Mann hämmert, er schaukelt
Die Frau schaukelt, sie hämmert
Die Frau hämmert, sie schaukelt
Der Mann malt, Die Frau telefoniert
Der Mann telefoniert, Die Frau malt
Die Frau malt, Der Mann telefoniert
Die Frau telefoniert, Der Mann malt
Der Mann telefoniert, er malt
Der Mann malt, er telefoniert
Die Frau telefoniert, sie malt
Die Frau malt, sie telefoniert
Der Mann flötet, Die Frau rechnet
Der Mann rechnet, Die Frau flötet
Die Frau flötet, Der Mann rechnet
Die Frau rechnet, Der Mann flötet
Der Mann rechnet, er flötet
Der Mann flötet, er rechnet
Die Frau rechnet, sie flötet
Die Frau flötet, sie rechnet
Der Mann bürstet, Die Frau schreibt
Der Mann schreibt, Die Frau bürstet
Die Frau bürstet, Der Mann schreibt
Die Frau schreibt, Der Mann bürstet
Der Mann schreibt, er bürstet
Der Mann bürstet, er schreibt
Die Frau schreibt, sie bürstet
Die Frau bürstet, sie schreibt
Der Mann packt, Die Frau raucht
Der Mann raucht, Die Frau packt
Die Frau packt, Der Mann raucht
Die Frau raucht, Der Mann packt
Der Mann raucht, er packt

Der Mann packt, er raucht
Die Frau raucht, sie packt
Die Frau packt, sie raucht
Der Mann tankt, Die Frau spielt Fußball
Der Mann spielt Fußball, Die Frau tankt
Die Frau tankt, Der Mann spielt Fußball
Die Frau spielt Fußball, Der Mann tankt
Der Mann spielt Fußball, er tankt
Der Mann tankt, er spielt Fußball
Die Frau spielt Fußball, sie tankt
Die Frau tankt, sie spielt Fußball
Der Mann trinkt, Die Frau föhnt
Der Mann föhnt, Die Frau trinkt
Die Frau trinkt, Der Mann föhnt
Die Frau föhnt, Der Mann trinkt
Der Mann föhnt, er trinkt
Der Mann trinkt, er föhnt
Die Frau föhnt, sie trinkt
Die Frau trinkt, sie föhnt
Der Mann schießt, Die Frau drückt
Der Mann drückt, Die Frau schießt
Die Frau schießt, Der Mann drückt
Die Frau drückt, Der Mann schießt
Der Mann drückt, er schießt
Der Mann schießt, er drückt
Die Frau drückt, sie schießt
Die Frau schießt, sie drückt

Picture pair combinations for stimulus material Chapter V (Micro-planning, ERP 2):

Stapler – Drilling machine
Scales – Puzzle
Mixer – Book
Scissors – bike
Mop – Piggy bank
Couch- Spoon
Vacuum cleaner – Bell
Iron - Drums
Washing machine – microphone
Bath –Racket
Thread–Skate
Rake – Skittle
Broom – Skipping rope
Slide– Toaster
Land mower– Tent
Saw– Stove
Axe – Camera
Hammer – Swing
Palette – Phone
Flute – Calculator
Cup – Hairdryer
Brush – Pen
Gun – Printer

Suitcase – Cigarettes
Petrol – Football

Sentences produced during Micro-planning, ERP 2:

Der Mann tackert, Die Frau bohrt
Der Mann bohrt, Die Frau tackert
Die Frau tackert, Der Mann bohrt
Die Frau bohrt, Der Mann tackert
Der Mann tackert, er bohrt
Der Mann bohrt, er tackert
Die Frau tackert, sie bohrt
Die Frau bohrt, sie tackert
Der Mann wiegt, Die Frau puzzelt
Der Mann puzzelt, Die Frau wiegt
Die Frau wiegt, Der Mann puzzelt
Die Frau puzzelt, Der Mann wiegt
Der Mann wiegt, er puzzelt
Der Mann puzzelt, er wiegt
Die Frau wiegt, sie puzzelt
Die Frau puzzelt, sie wiegt
Der Mann mixt, Die Frau liest
Der Mann liest, Die Frau mixt
Die Frau mixt, Der Mann liest
Die Frau liest, Der Mann mixt
Der Mann mixt, er liest
Der Mann liest, er mixt
Die Frau mixt, sie liest
Die Frau liest, sie mixt
Der Mann schneidet, Die Frau fährt
Der Mann fährt, Die Frau schneidet
Die Frau schneidet, Der Mann fährt
Die Frau fährt, Der Mann schneidet
Der Mann fährt, er schneidet
Der Mann schneidet, er fährt
Die Frau fährt, sie schneidet
Die Frau schneidet, sie fährt
Der Mann fegt, Die Frau spart
Der Mann spart, Die Frau fegt
Die Frau fegt, Der Mann spart
Die Frau spart, Der Mann fegt
Der Mann spart, er fegt
Der Mann fegt, er spart
Die Frau spart, sie fegt
Die Frau fegt, sie spart
Der Mann sitzt, Die Frau isst
Der Mann isst, Die Frau sitzt
Die Frau sitzt, Der Mann isst
Die Frau isst, Der Mann sitzt
Der Mann isst, er sitzt
Der Mann sitzt, er isst
Die Frau isst, sie sitzt
Die Frau sitzt, sie isst

Der Mann saugt, Die Frau klingelt
Der Mann klingelt, Die Frau saugt
Die Frau saugt, Der Mann klingelt
Die Frau klingelt, Der Mann saugt
Der Mann klingelt, er saugt
Der Mann saugt, er klingelt
Die Frau klingelt, sie saugt
Die Frau saugt, sie klingelt
Der Mann bügelt, Die Frau spielt Schlagzeug
Der Mann spielt Schlagzeug, Die Frau bügelt
Die Frau bügelt, Der Mann spielt Schlagzeug
Die Frau spielt Schlagzeug, Der Mann bügelt
Der Mann spielt Schlagzeug, er bügelt
Der Mann bügelt, er spielt Schlagzeug
Die Frau spielt Schlagzeug, sie bügelt
Die Frau bügelt, sie spielt Schlagzeug
Der Mann wäscht, Die Frau singt
Der Mann singt, Die Frau wäscht
Die Frau wäscht, Der Mann singt
Die Frau singt, Der Mann wäscht
Der Mann singt, er wäscht
Der Mann wäscht, er singt
Die Frau singt, sie wäscht
Die Frau wäscht, sie singt
Der Mann badet, Die Frau spielt Tennis
Der Mann spielt Tennis, Die Frau badet
Die Frau badet, Der Mann spielt Tennis
Die Frau spielt Tennis, Der Mann badet
Der Mann spielt Tennis, er badet
Der Mann badet, er spielt Tennis
Die Frau spielt Tennis, sie badet
Die Frau badet, sie spielt Tennis
Der Mann näht, Die Frau läuft Schlittschuh
Der Mann läuft Schlittschuh, Die Frau näht
Die Frau näht, Der Mann läuft Schlittschuh
Die Frau läuft Schlittschuh, Der Mann näht
Der Mann läuft Schlittschuh, er näht
Der Mann näht, er läuft Schlittschuh
Die Frau läuft Schlittschuh, sie näht
Die Frau näht, sie läuft Schlittschuh
Der Mann harkt, Die Frau kegelt
Der Mann kegelt, Die Frau harkt
Die Frau harkt, Der Mann kegelt
Die Frau kegelt, Der Mann harkt
Der Mann kegelt, er harkt
Der Mann harkt, er kegelt
Die Frau kegelt, sie harkt
Die Frau harkt, sie kegelt
Der Mann fegt, Die Frau springt
Der Mann springt, Die Frau fegt
Die Frau fegt, Der Mann springt
Die Frau springt, Der Mann fegt
Der Mann springt, er fegt
Der Mann fegt, er springt
Die Frau springt, sie fegt

Die Frau fegt, sie springt
Der Mann rutscht, Die Frau toastet
Der Mann toastet, Die Frau rutscht
Die Frau rutscht, Der Mann toastet
Die Frau toastet, Der Mann rutscht
Der Mann toastet, er rutscht
Der Mann rutscht, er toastet
Die Frau toastet, sie rutscht
Die Frau rutscht, sie toastet
Der Mann mäht rasen, Die Frau zeltet
Der Mann zeltet, Die Frau mäht rasen
Die Frau mäht rasen, Der Mann zeltet
Die Frau zeltet, Der Mann mäht rasen
Der Mann zeltet, er mäht rasen
Der Mann mäht rasen, er zeltet
Die Frau zeltet, sie mäht rasen
Die Frau mäht rasen, sie zeltet
Der Mann sägt, Die Frau kocht
Der Mann kocht, Die Frau sägt
Die Frau sägt, Der Mann kocht
Die Frau kocht, Der Mann sägt
Der Mann kocht, er sägt
Der Mann sägt, er kocht
Die Frau kocht, sie sägt
Die Frau sägt, sie kocht
Der Mann hackt, Die Frau fotografiert
Der Mann fotografiert, Die Frau hackt
Die Frau hackt, Der Mann fotografiert
Die Frau fotografiert, Der Mann hackt
Der Mann fotografiert, er hackt
Der Mann hackt, er fotografiert
Die Frau fotografiert, sie hackt
Die Frau hackt, sie fotografiert
Der Mann hämmert, Die Frau schaukelt
Der Mann schaukelt, Die Frau hämmert
Die Frau hämmert, Der Mann schaukelt
Die Frau schaukelt, Der Mann hämmert
Der Mann schaukelt, er hämmert
Der Mann hämmert, er schaukelt
Die Frau schaukelt, sie hämmert
Die Frau hämmert, sie schaukelt
Der Mann malt, Die Frau telefoniert
Der Mann telefoniert, Die Frau malt
Die Frau malt, Der Mann telefoniert
Die Frau telefoniert, Der Mann malt
Der Mann telefoniert, er malt
Der Mann malt, er telefoniert
Die Frau telefoniert, sie malt
Die Frau malt, sie telefoniert
Der Mann flötet, Die Frau rechnet
Der Mann rechnet, Die Frau flötet
Die Frau flötet, Der Mann rechnet
Die Frau rechnet, Der Mann flötet
Der Mann rechnet, er flötet
Der Mann flötet, er rechnet

Die Frau rechnet, sie flötet
Die Frau flötet, sie rechnet
Der Mann bürstet, Die Frau schreibt
Der Mann schreibt, Die Frau bürstet
Die Frau bürstet, Der Mann schreibt
Die Frau schreibt, Der Mann bürstet
Der Mann schreibt, er bürstet
Der Mann bürstet, er schreibt
Die Frau schreibt, sie bürstet
Die Frau bürstet, sie schreibt
Der Mann packt, Die Frau raucht
Der Mann raucht, Die Frau packt
Die Frau packt, Der Mann raucht
Die Frau raucht, Der Mann packt
Der Mann raucht, er packt
Der Mann packt, er raucht
Die Frau raucht, sie packt
Die Frau packt, sie raucht
Der Mann tankt, Die Frau spielt Fußball
Der Mann spielt Fußball, Die Frau tankt
Die Frau tankt, Der Mann spielt Fußball
Die Frau spielt Fußball, Der Mann tankt
Der Mann spielt Fußball, er tankt
Der Mann tankt, er spielt Fußball
Die Frau spielt Fußball, sie tankt
Die Frau tankt, sie spielt Fußball
Der Mann trinkt, Die Frau föhnt
Der Mann föhnt, Die Frau trinkt
Die Frau trinkt, Der Mann föhnt
Die Frau föhnt, Der Mann trinkt
Der Mann föhnt, er trinkt
Der Mann trinkt, er föhnt
Die Frau föhnt, sie trinkt
Die Frau trinkt, sie föhnt
Der Mann schießt, Die Frau drückt
Der Mann drückt, Die Frau schießt
Die Frau schießt, Der Mann drückt
Die Frau drückt, Der Mann schießt
Der Mann drückt, er schießt
Der Mann schießt, er drückt
Die Frau drückt, sie schießt
Die Frau schießt, sie drückt

Picture pair combinations for stimulus material Chapter VI (Micro-planning fMRI):

Stapler – Drilling machine
Scales – Puzzle
Mixer – Book
Scissors – Car
Hammer – Swing
Glass – Hair dryer
Tent – Bell
Rake – Skittle

Gun – Printer
Axe – Camera
Mop – Piggy bank
Couch – Spoon
Iron – Petrol
Washing machine – Microphone
Bath – Calculator
Broom - Bed
Saw – Stove
Palette – Phone
Brush – Pencil
Bag - Cigar

Sentences produced during Micro-planning fMRI:

Covert: Der Mann tackert.	Overt: Die Frau bohrt
Covert: Der Mann bohrt,	Overt: Die Frau tackert
Covert: Die Frau tackert,	Overt: Der Mann bohrt
Covert: Die Frau bohrt,	Overt: Der Mann tackert
Covert: Der Mann tackert,	Overt: er bohrt
Covert: Der Mann bohrt,	Overt: er tackert
Covert: Die Frau tackert,	Overt: sie bohrt
Covert: Die Frau bohrt,	Overt: sie tackert
Covert: Der Mann wiegt,	Overt: Die Frau puzzelt
Covert: Der Mann puzzelt,	Overt: Die Frau wiegt
Covert: Die Frau wiegt,	Overt: Der Mann puzzelt
Covert: Die Frau puzzelt,	Overt: Der Mann wiegt
Covert: Der Mann wiegt,	Overt: er puzzelt
Covert: Der Mann puzzelt,	Overt: er wiegt
Covert: Die Frau wiegt,	Overt: sie puzzelt
Covert: Die Frau puzzelt,	Overt: sie wiegt
Covert: Der Mann mixt,	Overt: Die Frau liest
Covert: Der Mann liest,	Overt: Die Frau mixt
Covert: Die Frau mixt,	Overt: Der Mann liest
Covert: Die Frau liest,	Overt: Der Mann mixt
Covert: Der Mann mixt,	Overt: er liest
Covert: Der Mann liest,	Overt: er mixt
Covert: Die Frau mixt,	Overt: sie liest
Covert: Die Frau liest,	Overt: sie mixt
Covert: Der Mann schneidet,	Overt: Die Frau fährt
Covert: Der Mann fährt,	Overt: Die Frau schneidet
Covert: Die Frau schneidet,	Overt: Der Mann fährt
Covert: Die Frau fährt,	Overt: Der Mann schneidet
Covert: Der Mann fährt,	Overt: er schneidet
Covert: Der Mann schneidet,	Overt: er fährt
Covert: Die Frau fährt,	Overt: sie schneidet
Covert: Die Frau schneidet,	Overt: sie fährt
Covert: Der Mann hämmert,	Overt: Die Frau schaukelt
Covert: Der Mann schaukelt,	Overt: Die Frau hämmert
Covert: Die Frau hämmert,	Overt: Der Mann schaukelt
Covert: Die Frau schaukelt,	Overt: Der Mann hämmert
Covert: Der Mann schaukelt,	Overt: er hämmert
Covert: Der Mann hämmert,	Overt: er schaukelt
Covert: Die Frau schaukelt,	Overt: sie hämmert

Covert: Die Frau hämmert, Overt: sie schaukelt
Covert: Der Mann trinkt, Overt: Die Frau föhnt
Covert: Der Mann föhnt, Overt: Die Frau trinkt
Covert: Die Frau trinkt, Overt: Der Mann föhnt
Covert: Die Frau föhnt, Overt: Der Mann trinkt
Covert: Der Mann föhnt, Overt: er trinkt
Covert: Der Mann trinkt, Overt: er föhnt
Covert: Die Frau föhnt, Overt: sie trinkt
Covert: Die Frau trinkt, Overt: sie föhnt
Covert: Der Mann zeltet, Overt: Die Frau klingelt
Covert: Der Mann klingelt, Overt: Die Frau zeltet
Covert: Die Frau zeltet, Overt: Der Mann klingelt
Covert: Die Frau klingelt, Overt: Der Mann zeltet
Covert: Der Mann klingelt, Overt: er zeltet
Covert: Der Mann zeltet, Overt: er klingelt
Covert: Die Frau klingelt, Overt: sie zeltet
Covert: Die Frau zeltet, Overt: sie klingelt
Covert: Der Mann harkt, Overt: Die Frau kegelt
Covert: Der Mann kegelt, Overt: Die Frau harkt
Covert: Die Frau harkt, Overt: Der Mann kegelt
Covert: Die Frau kegelt, Overt: Der Mann harkt
Covert: Der Mann kegelt, Overt: er harkt
Covert: Der Mann harkt, Overt: er kegelt
Covert: Die Frau kegelt, Overt: sie harkt
Covert: Die Frau harkt, Overt: sie kegelt
Covert: Der Mann schießt, Overt: Die Frau drückt
Covert: Der Mann drückt, Overt: Die Frau schießt
Covert: Die Frau schießt, Overt: Der Mann drückt
Covert: Die Frau drückt, Overt: Der Mann schießt
Covert: Der Mann drückt, Overt: er schießt
Covert: Der Mann schießt, Overt: er drückt
Covert: Die Frau drückt, Overt: sie schießt
Covert: Die Frau schießt, Overt: sie drückt
Covert: Der Mann hackt, Overt: Die Frau fotografiert
Covert: Der Mann fotografiert, Overt: Die Frau hackt
Covert: Die Frau hackt, Overt: Der Mann fotografiert
Covert: Die Frau fotografiert, Overt: Der Mann hackt
Covert: Der Mann fotografiert, Overt: er hackt
Covert: Der Mann hackt, Overt: er fotografiert
Covert: Die Frau fotografiert, Overt: sie hackt
Covert: Die Frau hackt, Overt: sie fotografiert

Curriculum vitae

Personalia

Name	Boukje Habets
Birthday	19.07.1978
Birthplace	Geleen, The Netherlands
Adress	Schellheimerplatz 2 39108 Magdeburg
Family status	Unwed
Nationality	Dutch

Education

1990-1996	VWO (highest high school level) at College Sittard, Sittard (The Netherlands)
1996-1997	Physics and Chemistry (high school level), Leeuwenborgh Opleidingen, Sittard (The Netherlands)
1997-2003	Psychology at the University of Maastricht, Maastricht (The Netherlands)
Since October 2003	PhD position at the Otto-von-Guericke University Magdeburg Department of Neuropsychology

Magdeburg, February 2007