STAGES OF LANGUAGE PROCESSING AND THEIR IMPAIRMENTS IN APHASIA: EVIDENCE FROM TOPOGRAPHIC ANALYSIS OF EVENT RELATED POTENTIALS

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You taught me language; and my profit on ‘t
Is, I know how to curse. The red plague rid you
For learning me your language!
Act I, Scene II

Be not afeard; the isle is full of noises,
Sounds and sweet airs, that give delight, and hurt not.
Sometimes a thousand twangling instruments
Will hum about mine ears; and sometime voices,
That, if I then had wak’d after long sleep,
Will make me sleep again: and then, in dreaming,
The clouds methought would open, and show riches
Ready to drop upon me; that, when I wak’d,
I cried to dream again.
Act III, Scene II

Caliban in *The Tempest* by William Shakespeare

Preface

This dissertation would not have been possible without the help of a number of people whom I want to express my sincere gratitude. Through all of the studies I was guided by the supervisors of the project: Prof. Dr. Brigitte Rockstroh, Prof. Dr. Rudolf Cohen and Prof. Dr. Dr. Paul-Walter Schönle. At all stages from task development to data analysis, they were most helpful and influential by their discussions, their critical comments and their willingness to solve problems. I want especially thank Brigitte for her engagement and her long-lasting encouragement. She has been my “doctoral mother”, but I think she would prefer “doctoral bigger sister” (which describes her better).

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Zusammenfassung

In dieser Arbeit wurde der Versuch unternommen drei Forschungsbereiche, die sich mit dem Studium der Sprache beschäftigen, zu integrieren. Die Erkenntnisse stammen aus der Neuropsychologie, der kognitiven Wissenschaft und psychophysiologischen Studien. Diese Ansätze werden im einleitenden Teil zusammengefaßt.

Es gibt eine Reihe von Hinweisen für die Dominanz der linken Hemisphäre für sprachliche Fähigkeiten. Läsionen dieser Hemisphäre führen im Allgemeinen zu einem aphasischen Syndrom, wobei auf allen linguistischen Ebenenen der Sprache aphasische Symptome möglich sind. Eine Reihe von Ergebnissen legt nahe, daß aphasische Patienten im Lauf der Rehabilitation eine rechtsphemisphärische Dominanz für Sprache entwickeln. Prozesse, die zu einer Veränderung der Hirnaktivierung führen, werden als Folge von Restitution, Substitution oder Kompensation erklärt. In der Einleitung wird ein kognitives Modell der Sprachproduktion von Willem Levelt vorgestellt, innerhalb dessen die Erklärung einiger aphasischer Symptome möglich ist. Im Anschluß daran wird im Überblick dargestellt, auf welche Weise Sprache mit Hilfe ereigniskorrelierter Potentiale (EKP) untersucht wurde.

Der experimentelle Teil besteht aus vier Teilen. Nach einer Darstellung der durchgeführten Aufgabenserie werden alle Aufgaben statistisch analysiert im Hinblick auf die Frage, ob die Serie als Ganzes – und welche Aufgabe zu welchem Grad – geeignet ist zwischen aphasischen und nicht-aphasischen Gruppen zu unterscheiden. Die Aufgaben werden dann anhand des Sprachproduktionsmodells in drei Abschnitte gegliedert. Jedem Abschnitt geht eine kurze Einleitung voran, so daß die Abschnitte unabhängig voneinander gelesen werden können.

Im ersten Abschnitt werden die Aufgaben zur “Feature Comparison” analysiert. Diese wurden inspiriert durch den Token Test, einem neuropsychologischen Test zur Aphasiediagnostik. Die vorliegenden Ergebnisse zeigten, daß Aphasiker bei diesen Aufgaben schlechter als Kontrollprobanden abschnitten, auch wenn nur bildhaftes Stimulusmaterial verwendet wurde. Der deutlichste Unterschied in der Hirnaktivierung zwischen Aphasikern und Kontrollen zeigte sich in einer ausgeprägten Negativierung über links anterioren Arealen bei Aphasikern nach Darbietung eines Warnreizes. Dies wurde interpretiert als Folge von Prozessen des Arbeitsgedächtnisses, die auf Grund kompensatorischer Anstrengungen aktiviert sein können.

Im zweiten Abschnitt werden Ergebnisse von Aufgaben zur “Artikel Bestimmung” und einer Kontrollbedingung, die semantische Klassifizierung erfordert, referiert. Aphasiker reagierten langsamer und machten mehr Fehler bei der Aufgabe zur “Artikel Bestimmung” im Vergleich zur Kontrollbedingung. Es zeigte sich bei beiden Aufgaben im EKP eine deutliche links anteriore Negativierung. Es wird vermutet, daß Aphasiker eine Strategie benutzten, die Vorteile bei der semantischen Aufgabe bringt, aber nicht bei der “Artikel Bestimmung”.

Der letzte Abschnitt behandelt zwei Aufgaben zum “Wortverständnis” und zum “Reimen”. In der ersten Aufgabe zeigten Aphasiker relativ gute Leistungen im Vergleich zur zweiten. Keine Unterschiede in den EKPs zwischen den aphasischen Patienten und Kontrollprobanden wurden in der Wortverstädnisaufgabe gefunden. Dies scheint auf eine Rückbildung von Funktionen im Sinne von Restitution hinzudeuten. Im Gegensatz dazu wurde bei der Reimaufgabe bei den Aphasikern stärkere rechts-, als linkshemisphärische Aktivierung im Vergleich zu den Kontrollen gefunden. Dies war besonders deutlich bei flüssigen Aphasikern, wo die rechtshemisphärische Aktivierung mit Zeit seit der Läsion korrelierte. Dieser Befund wurde als das Resultat von substitutiven Prozessen interpretiert.
In der allgemeinen Diskussion werden die Ergebnisse aller Abschnitte zusammengefaßt und Vorschläge für zukünftige Untersuchungen gemacht.

Summary

This thesis presents a series of experiments that were designed as an integration of different approaches to study language, from neuropsychology, cognitive science and psychophysiological studies. These approaches are summarised in the introductory part.

Evidence suggests that the left hemisphere is dominant for language. Lesions to this hemisphere lead to one of several aphasic syndromes. These syndromes are characterised on dysfunctions on all linguistic levels. It has been suggested that some of these patients develop in the course of recovery a right hemispheric dominance for language. Processes that lead to a changed activity pattern are restitution, substitution and compensation of function.

In the following part of the introduction a cognitive model of speech production is introduced that was proposed by Willem Levelt and it will be shown how some aphasic symptoms are conceived within this model. Following this, an overview is given how language was studied with means of Event Related Potentials (ERPs).

The experimental part consists of four parts. After a short presentation of the task series all tasks will be analysed statistically to find out whether the task series – and which task to what extent – is suitable to discriminate groups. The tasks are then grouped into three sections according to the levels of speech production. Before each section a short introduction is given, so that these sections can be read independently from each other.

In the first section the results of the Feature Comparison tasks (FCT) are reviewed. They were based on the Token test, a neuropsychological test for the diagnosis of aphasia. Even when the stimuli comprise no verbal material, aphasics performed worse in these tasks than control subjects. The most prominent difference in brain activity between aphasics and controls consisted of prominent left anterior negativity over frontal regions in aphasics, following the presentation of a warning stimulus. This was interpreted as a reflection of working memory processes due to compensatory efforts to adapt to the language dysfunction.

In the second section the gender decision and semantic classification tasks are analysed. Aphasics commit more errors and respond slower in the gender decision task compared to the semantic control condition. However, in both tasks their ERPs are marked by a prevailing left anterior negativity. It is proposed that aphasics adhere to a strategy that is beneficial in the semantic task, but not in the gender decision task.

In the last section two tasks are presented, Word Comprehension and Rhyming. In the first task aphasics performed well compared to second. In the ERPs of the Word Comprehension task no differences between aphasics and controls were found pointing

towards recovery of function. In the Rhyming task, however, aphasics display stronger right hemispheric activity than controls. This was particularly prominent in fluent aphasics, where the right hemispheric activity correlated with elapsed time since lesion. This finding was interpreted as a result of substitutional processes.

In the general discussion the results of all sections are summarised and suggestions for future studies are given.

1. Introduction

The main topic of this thesis is the integration of several approaches to study language. Three fields of evidence will be combined that show how we can learn about the representation of language: by examining language dysfunctions after brain lesions, by modelling speech production and by measuring cortical brain correlates of language with Event Related Potentials (ERPs). Then, a series of experiments will be reported in which these approaches were taken together.

In these experiments ERPs were recorded in healthy and neurological control subjects and aphasic patients. Aphasics suffer from language disorders following a brain lesion of the left hemisphere. Therefore, hemisphere specific ERP patterns are assumed in language related tasks. More recent evidence suggests that aphasics display brain activity that is different from control subjects, as the right hemisphere seems to be activated more strongly. This pattern of brain activity has been measured with different methods during different tasks. The present studies were developed to extend and elaborate these findings with respect to clinical variables and different language processes. The tasks that are described and discussed in the present thesis should fulfil several requirements: 1) They should evoke clear left hemispheric activation in controls to provide a basis for the expected change in asymmetry in aphasics. 2) By systematic variation of experimental parameters across tasks, they should allow an investigation in order to substantiate the relationship between a particular activation and a specific language process. 3) They should allow ERP recording.

The development of the present tasks was guided by evidence from neuropsychological tests. It was assumed that tests that distinguish aphasics are tests that require left hemispheric processing. The development was also influenced by the cognitive model of speech production for healthy speakers by Levelt. This model allows to understand aphasic symptoms and to develop specific language tasks compatible with the ERP methodology.

In the subsequent introductory part a case will be made that shows, why the study of language is fascinating: language is universal, not because it has been invented all over the world, but because it is part of the biological makeup of human brains. I will review three fields that contributed to the understanding of language representations in the brain. 1) From the study of aphasia it was concluded, that language is usually located within the left hemisphere. Other methods contributing to this finding will be reviewed and basic knowledge about aphasia will be outlined. However, based on recent studies it was suggested that there is a different language site in aphasics. The reasons and studies that led researchers to assume this will be reviewed and the mechanisms for such a change will be outlined. 2) The cognitive model of speech production by Levelt will be introduced to show that it is not the correct way to approach language as a unitary process. Different stages of language processing will be outlined. Finally it will be shown, how specific aphasic symptoms can be conceived within this framework. 3) In the final part of the introduction a short overview will be given about the role of ERPs within the study of language.

"When it comes to linguistic form, Plato walks with the Macedonian swineherd, Confucius with the head-hunting savage of Assam."
Edwald Sapir

1.1 The Biological Basis of Language

1.1.1 Language: Cultural Artefact or Instinct?

The Australian prospector Michael Leahy described in his diary on the 26th of May 1930 a scenery that might have happened very often in the history of mankind in similar forms. Leahy was journeying through an unexplored, isolated plateau of New Guinea and met an, until then, unknown tribe of highlanders. He describes the scene as follows:

"When a few of them finally got up courage to approach, we could see that they were utterly thunderstruck by our appearance. When I took off my hat, those nearest to me backed away in terror. One old chap came forward gingerly with open mouth, and touched me to see if I was real. Then he knelt down, and rubbed his hands over my bare legs, possibly to find if they were painted, and grabbed me around the knees and hugged them, rubbing his bushy head against me... The women and children gradually got up courage to approach also, and presently the camp was swarming with the lot of them, all running about and jabbering at once, pointing to... everything that was new to them." (Connolly and Anderson, 1987).

This „jabbering" was a fully developed language; one of the 800 languages that have been distinguished until the 1960s on this plateau. There is no known tribe or population in the world without a complex highly developed language[1] (Sapir, 1921). This universality is especially amazing if one regards the high variance in other domains of human abilities. One

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[1] Languages are of course different in many aspects but there is no primitive language that is in general less complex than any other language (for more details see Sapir, 1921).

population heats food over an open fire ignited by rubbing sticks together and another population uses microwave ovens for such a task.

One might argue conversely that universality is not a good proof for a “product” having a biological basis, as Coca Cola or McDonalds are nowadays equally universal and the preference for some TV programs hardly differs all over the world. A very strong statement in favour of language having a biological basis is made by Pinker (1994, p.32): „The crux of the argument is that complex language is universal because children actually reinvent it; generation after generation – not because they are taught, not because they are generally smart, not because it is useful to them, but because they just can’t help it“. This is why he conceives of language as an “instinct” that has not to be learned like writing but develops by itself in complex forms if not inhibited. To prove this, one has to investigate how new, complex languages are created from scratch. The linguist Derek Bickerton (1984) did this by studying pidgins and creoles.

When speakers of different languages have to communicate with each other without the opportunity or need to learn each others language, they develop a so called pidgin. This has been often observed in the course of colonization when workers of different countries have been brought together to carry out practical work. “Pidgins are choppy strings of words borrowed from the language of the colonizers or plantation owners, highly variable in order and with little in the way of grammar”(Pinker, 1994). As pidgins do not have the grammatical resources to convey exact meaning to the listener, the intentions of the speaker have to be filled in by the listener. Bickerton has studied pidgin speaking workers brought in from China, Japan, Portugal and the Philippines that were working on Hawaiian sugar plantations. The interesting point about Bickerton’s findings is that the Hawaiian born children of these speakers spoke quite differently. These children had developed a creole. A creole is the result “when children make a pidgin their native tongue” (Pinker, 1994; p. 33). Contrary to a pidgin, creoles consist of a systematic grammar with specific characteristics such as auxiliaries, prepositions, case markers. Obviously the children did not learn this Hawaiian creole from their parents.

Even though Bickertons claims are controversial, the basic idea has been corroborated by recent discoveries on sign languages in Nicaragua (Kegl & Lopez, 1989). Children brought together in a school for the deaf, which only focused on lip reading and speech and did not teach any sign language, developed for themselves a sign language based on the signs they used at home (a pidgin). The younger children, however, who learned this sign language from

the older ones developed a new more complex and elaborated sign language, a creole, just as predicted by Bickerton.
If we approach language as part of our biological makeup, then it seems plausible to assume that it has an identifiable location in the brain.

1.2.1 Localizing Language: Left or Right?

One way to explore which hemisphere is more involved in language is to anaesthetise one hemisphere. This is done with the intracoritid sodium amytal (amobarbital) test, first described by John Wada (1949). Wada observed that injection of amobarbital in the left hemisphere resulted in speech arrest. He concluded that the left hemisphere is dominant for language as had been proposed earlier. It is by now generally assumed that this holds for 96% of right handed and 70% of left-handed individuals. For 15% of the left handers the right-hemisphere seems to be the dominant and in the remaining 15% bilateral speech representation is assumed (Rasmussen & Milner, 1977).

While the Wada test blocks the functioning of a whole hemisphere another method was developed to inhibit more circumscribed areas. It is called intra-operative cortical stimulation and is applied preceding resective surgery for epilepsy or cerebral tumors. A particular area is electrically stimulated while the patient names a picture. Whenever the naming response is blocked or contains an error, the area is mapped as a language site. This is done to avoid injuring speech relevant areas through the operation. The method of intra-operative cortical stimulation (Ojemann, 1983; Ojemann et al., 1989; Haglund et al., 1994) determined language-related functions to be primarily related to activity in the superior temporal gyrus, the motor strip and Broca's area of the left hemisphere and also in the medial temporal gyrus and the parietal and prefrontal cortices. This wide range of locations clearly shows that language does not have a narrow, circumscribed representation within the left hemisphere. Another important finding was that no single cortical area was involved in all patients. This suggests that speech has not a uniform cortical organization among speakers.
The first systematic attempt to localise the location of language in the brain was stimulated by the study of the aphasias, since left hemispheric lesions result in language impairments.
The next chapter briefly introduces the field of aphasia, followed by evidence that suggests a different language site in aphasics.

1.2 Acquired Language Disorders: the Aphasias

Aphasia is characterised by symptoms on all linguistic levels. It is distinguished from disorders of executive aspects of language (i.e. articulatory processes) that are called dysarthrophonia (formerly called dysarthria). The different types of aphasic symptoms are usually grouped into four aphasic syndromes: Broca's aphasia, Wernicke's aphasia, Amnestic aphasia and Global Aphasia. Even though there are doubts that these syndromes exist in a pure form (Zurif, 1987; Kelter, 1990; Caplan, 1994), they are still often used for diagnosis and description of clinical samples.

1.2.1 Aphasic Syndromes

Global Aphasia

In global aphasics speech output is non-fluent, very effortful and strongly reduced with very poor articulation. If the patient speaks at all, speech is full of recurring utterances (e.g. "oh, my God") and patients show strong tendencies to perseverate. Speech comprehension is impaired to a very large degree so that all in all communication is hardly possible.

Broca's Aphasia

Other terms: motor aphasia; efferent motor aphasia (Lurija)

In Broca's aphasics verbal output is non-fluent, effortful and reduced. It is often agrammatic, characterised by the omission of grammatical words (e.g. propositions, denominators etc.) and the incorrect usage of inflections. The resulting speech is frequently reduced to strings of words (groupings of one to three words) which are described as "telegraphic". The quality of articulation varies as a function of the familiarity of the words in the message. Language comprehension is relatively preserved. Here is a typical example from Goodglass (1976) of an agrammatic patient who is trying to explain that he has returned to the hospital to have work done on his gums:

" Ah ... Monday... ah, Dad and Paul Haney [referring to himself by his full name] and Dad... hospital. Two... ah, doctors..., and ah... thirty minutes... and yes... ah... hospital. And, er, Wednesday... nine o'clock. And er Thursday, ten o'clock... doctors. Two doctors... and ah... teeth. Yeah, ... fine.

Wernicke's Aphasia

Other terms: sensory aphasia; temporo-acoustic and acoustic-mnestic aphasia (Lurija)

In Wernicke’s aphasia verbal output is fluent and facile in articulation and sentence structure, but so called paraphasias are common. Verbal (also called literal or semantic) paraphasia denotes the replacement of one word by another that exists in the speakers language (e.g. replacing ‘cat’ by ‘dog’). A phonemic paraphasia is a word that has some resemblance to the target word (e.g.‘peherst’ instead of ‘perhaps’). Wernicke’s aphasics often produce neologisms (non-existent words in the speakers language e.g. ‘postocus’ for the target word ‘octopus’ (examples were taken from Goodglass, 1993). If language becomes distorted by such symptoms to an incomprehensible degree it is termed Jargon. In spite of the presence of inappropriately chosen or neologistic words, there is no lack of morphology - that is articles, prepositions, auxiliary verbs, and noun and verb inflections fall into place just as effortlessly as in the speech of a normal person. However, the choice, the combination and the positioning of words is often different from grammatically acceptable sentences. Patients produce long sentences with embedded constructions and sentences that begin with subordinate clauses. These phenomenona are grouped together as paragrammatism. Language comprehension is in Wernicke’s aphasics impaired. Kreindler et al. (1971) cite an example of a Jargon aphasic who was asked how he was: ’I felt worse because I can no longer keep in my mind from the mind of the minds to keep me from my mind and up to the ear which can be to find among ourselves.’ Here is a speech example full of neologisms (Brown, 1975): ‘Then he graf, so I’ll graf, I’m giving ink, no, fefergen, in pane, I can’t grasp. I haven’t grab the grabben, I’m going to the glimmeril let me go’.

Amnestic Aphasia

Other terms: anomic aphasia; nominal aphasia; semantic aphasia

In amnestic aphasia language is fluent with respect to rate, syntactic form, and articulation, but within this fluency there are notable word finding difficulties (anomia). Patients often display semantic paraphasias with only small semantic deviations from the target word. Comprehension is preserved and the ability to communicate is good. Here is a typical example taken from Kay and Ellis (1987). The patient attempted to describe a kitchen scene (the “Cookie Theft Test”, a test on spontaneous speech by Goodglass and Kaplan):
“Er... two children, one girl one male... the... the girl, they’re in a ... and their, their mother was behind them in in , they’re in the kitchen... the boy is trying to get ... a ...er, a part of a cooking... jar... He’s standing on... the lad, the boy is standing on a ... standing on a... standing on a... I’m calling it a seat, I can’t I forget what it’s, what the name of it is... It is er a higher, it’s a seat, standing on that, ‘e’s standing on that... this boy is standing on this, seat... getting

some of this er stuff to... biscuit to eat. As he is doing that, the post, it's not a post, it's the, seat, is falling down, is falling over...

There are several other forms of aphasia that appear less often (Goodglass, 1993; Huber et al.; 1983) and that are characterised by very well preserved or strongly impaired abilities to repeat.

Conduction Aphasia

Other terms: afferent motor aphasia (Lurija)

These patients speak fluently with many phonemic paraphasias. The main symptom compared to other well preserved language abilities is an impairment in the repetition of words or sentences.

Transcortical Motor Aphasia

Other terms: frontal dynamic aphasia (Lurija)

Patients with this syndrome produce hardly spontaneous speech, but are able to repeat with relatively well preserved syntax and articulation.

Transcortical Sensory Aphasia

Verbal output is fluent and comparable to Wernicke's aphasia with mainly semantic paraphasias. Patients often repeat questions and other utterances (echolalia), but do not understand them. Perseverative intrusions of previously used words and perseveration of content is common. In testing situations repetition is well preserved, but patients do not understand the meaning of their utterances.

1.2.2 Etiology and Locus of Lesion in Aphasia

The most common causes of aphasia (10 000 cases in Germany each year; 200 000 cases in the US) are head trauma and stroke. Studies of patients with discrete vascular lesions have increased the understanding of aphasia, because these lesions do not progress and the anatomy of the damaged region often directly relates to the distribution of critical blood vessels (Kandel et al., 1991). In these patients the syndromes are most clearly evident.

As already outlined the left hemisphere is assumed to comprise responsible areas for language functions. Language dysfunctions in aphasics have led researchers assume that there is a “language zone” (Goodglass, 1993; Poeck, 1994) within the language dominant hemisphere which comprises brain areas that lead consistently to various language dysfunctions. This zone covers the frontal operculum, the superior convexity of the temporal lobe and the gyrus angularis.

The several syndromes are related to different lesions to the language zone:

Broca’s aphasia follows lesions encompassing the pars opercularis and pars triangularis of the left frontal lobe (Broca’s area), often extending posteriorly to include the lower portion of the motor strip.

Wernicke’s aphasia is the result of lesions including the posterior portion of the first temporal gyrus (Wernicke’s area). Lesions extending posteriorly including the angular gyrus lead to severe impairments of reading and writing.

Amnestic aphasia is caused by temporo-parietal lesions, e.g. after cerebral tumors and abscesses of the temporal lobes or degenerative processes.

Global aphasia is assumed to be the consequence of functional impairments within the supply area of the A. cerebri media.

A summary of the main aphasic symptoms and syndromes together with the corresponding locus of lesion can be found in Table 1.

Table 1: Main aphasic syndromes and locus of lesion (Poeck, 1994)

NAME OF SYNDROME	**Symptoms**	**Locus of Lesion**
non-fluent		
Broca’s	effort in speech, agrammatism, well preserved speech comprehension	prerolandic lesions (supply area of the A. precentralis)
Global	all expressive and receptive language functions are dysfunctional to a comparable extent	insufficient functioning in the whole supply area of the A. cerebri media
fluent		
Wernicke’s	paraphasic speech production with paragrammatism and large problems in language comprehension	retrorolandic lesions (supply area of the A. temporalis posterior)
Amnestic	word finding difficulties that are overcome by strategies	temporo-parietal lesions. Frequently seen in tumors and temporal lobe abscesses and cerebral degenerative processes

1.2.3 A Different Language Site in Aphasics: Formerly Left, Now Right ?

Different lines of research provide evidence that language has a different lateralization in aphasics: the right hemisphere shows activity which is not apparent in brain healthy control subjects. These sources of evidence have been very recently critically reviewed by Kinsbourne (1998):

- Patients who had recovered from aphasia became aphasic again after a right hemispheric stroke (Lee et al., 1984; Cambier et al., 1983; Basso et al., 1989; Cappa et al., 1994).
- Intracarotid amytal injections which normally lead to speech arrest in healthy subjects after a left sided injection occurs in aphasics after a right sided injection. Kinsbourne (1971) reported two cases of aphasics, in which left sided injections did not lead to speech arrest, but speech arrest followed right sided injections. Similar findings were reported by Czopf (1972).
- In dichotic listening and visual hemifield tests healthy subjects usually show an advantage of the right ear or right visual field for verbal material. In aphasics a reversed pattern has been found (Johnson et al., 1977; Moore & Weidner, 1974, 1975). In longitudinal studies the left ear bias has increased over time suggesting a gradual “take-over” of the right hemisphere (Petit & Noll, 1979).
- Electrophysiological and studies using positron emission tomography (PET) provided evidence for more right than left hemispheric activity in aphasics. These findings are reviewed below.

Evidence for a stronger participation of the right hemisphere in language processing has been seen in larger right- than left-hemispheric EEG-alpha-blocking in aphasic patients upon presentation of language-related stimuli (Moore, 1984, 1986) or larger right- than left-hemispheric amplitudes of the auditory evoked N100-P200 in aphasics (Papanicolaou et al, 1987). Thomas, Altenmüller et al. (1997) recorded the negative DC potential in 4 Broca’s, 4 Amnestic and 3 Wernicke’s patients as well as 12 normal controls while subjects searched for synonyms to orally presented nouns (common objects or abstract expressions). In Broca’s aphasics a right hemispheric preponderance found during the first four weeks post stroke changed to a left frontal lateralization later in their clinical course of recovery, while in Wernicke’s aphasia a right hemispheric preponderance remained across time.

Selinger and co-workers (1989) presented auditory probes to aphasics and controls while they performed a verbal and a music task. The auditory ERPs (P2, N2) of the aphasic patients were larger over the right than over the left hemisphere in the verbal task, and this asymmetry was significantly correlated with the severity of aphasia. No such asymmetry was found during baseline or during the music condition. The authors interpreted this pattern as indicating a ”possible functional reorganization for language related tasks in aphasic patients” (p. 387).

Further evidence was obtained from rCBF (regional cerebral blood flow) studies. Weiller et al. (1995) examined the rCBF during a verb generation task and during repetition of pseudowords in six Wernicke’s aphasics, who had improved during rehabilitation. Among the aphasics, an increase of cerebral activity was seen in the same left-frontal and left-temporal areas as in the controls, except for the circumscribed area of the lesion. In addition, however, patients also exhibited pronounced activation in homotopic areas of the right hemisphere that were lesioned in the left hemisphere. Knopman et al. (1984) reported diffuse right hemisphere increases of rCBF in aphasics during a semantic detection task compared to a baseline condition. Three months later those patients who showed an almost complete recovery of language functions also showed an increase of rCBF in left posterior temporal-inferior regions with a decrease of right hemispheric activity; in patients with incomplete recovery the increased right hemisphere activation prevailed also in the second testing. Similarly, Heiss et al. (1997) reported good recovery of function (4 weeks and 12-18 months following stroke) in three aphasics to be related to an increase of activation in the left superior temporal gyrus “surrounding the infarct” during word repetition, while right hemispheric rCBF predominance remained in three other patients with persistent aphasia.

Thus, lesions producing aphasia seem to be accompanied by increased right hemispheric activation during language tasks early after the lesion. This activation may reflect a compensatory reliance on the linguistic functions of the right hemisphere or general increase of activation following the trauma or diaschisis (see below). During later recovery there seems to be a decrease of this right hemispheric activation, sometimes together with a new increase of left-hemispheric activity. As was pointed out by Cappa et al. (1997), hypometabolism in both hemispheres characterises the first months after the lesion, with language recovery being associated with an overall increase in activation in structurally unaffected regions particularly in the right hemisphere.

In a recent PET study by Karbe et al. (1998) the authors investigated a group of mostly global aphasics with a word-repetition task. In the subacute state the aphasics displayed stroke-caused impairments of metabolic activation within the left cerebral cortex. But compared to the control subjects, the aphasics showed additional activation in both cerebral hemispheres mostly in the supplementary motor areas (SMA), which appeared more consistently on the left than on the right side. Besides this, some patients with severe aphasia clearly activated the right inferior frontal cortex. At a reinvestigation of the patients one year later the additional right hemispheric activation did not continue or increase. Good outcome, as measured with the Token Test, was predicted best by "the repair of left superior temporal cortex function, whereas the recruitment of right hemisphere regions was significantly less effective".

1.2.4 What are the Supposed Mechanisms that Might Lead to a Different Language Site?

In the last chapter some studies have been presented that showed stronger right than left hemispheric activity in aphasics which is usually interpreted as an indication of recovery of function. However, other studies have suggested that the left hemisphere is responsible for the amelioration of the symptoms. Another possibility might be that the participation of the hemispheres in the course of recovery varies with time.

What is the neurological basis of recovery? It is well known, that the human central nervous system has only a limited potential for regeneration because damaged axons do not show spontaneous regrowth. At the macroscopic level two hypotheses have been proposed to explain recovery of function after brain damage (reviewed by Cappa, 1998):

1. "Take-over" of function: Already 1895 Gowers proposed that the undamaged right hemisphere might take over linguistic functions after damage to the dominant left hemisphere. Other authors did not exclude that the left hemisphere might be responsible for such 'substitutional processes', e.g. Caplan (1994, p.1038): "other areas of the left hemisphere or the right hemisphere can take over the functions spared in this condition". In the studies cited above that showed right hemispheric activity in aphasics, the authors generally assume that substitutional processes had taken place.

   Evidence for substitution is seen in the development of normal speech in children who had undergone left-sided hemispherectomy early in life (Stiles & Thal, 1993; Huttenlocher, 1994). In the recent years a large body of evidence demonstrated that the capacity of the human brain for cortical reorganisation is retained into adulthood (for a review see Sterr et al., 1999). It has been shown that deafferented neurons change their original receptive field properties and are able to take over functions of neighbouring neurons. This form of injury-related reorganization has been termed *Invasion* because adjacent representations "invade" the deafferented field. It has been demonstrated, e.g. in amputees (Elbert et al., 1994). A further form of cortical reorganization is *Expansion* due to use-related changes, which has been demonstrated in amputees (Elbert et al., 1997). Following an increased use of the remaining hand, the intact hemisphere is the target of enhanced sensory stimulation, which was reflected in distinctive alterations of the deafferented compared to the intact hemisphere. The authors found an increased representation of the hand which was not amputated, i.e. ipsilateral to the amputation. This was interpreted as result of an increased use of this hand.

For aphasics it might be assumed that the increased activity of the right hemisphere reflects the enhanced use of right hemispheric functions that are otherwise inhibited by an intact language-dominant left hemisphere. This approach to rehabilitation was first proposed by J.H. Jackson and was recently reviewed by York & Steinberg (1995). Such an explanation would be supported by findings from Pulvermüller (1999). According to him language is represented within widely distributed Hebbian cell assemblies with a denser distribution within the left hemisphere. Lesions to one part of the hemisphere can be compensated by the remaining networks.

2. Regression of diaschisis: In the early phase after a brain lesion distant unaffected areas show functional impairments. These areas are connected to the damaged area and are located in the ipsi-, or contralateral hemisphere. This phenomenon was called diaschisis (von Monakow, 1914). It is assumed that areas are "reactivated" during regression of diaschisis. In his study from 1997 Cappa concluded that the "regression of intrahemispheric and transhemispheric diaschisis may be associated with the recovery of a function, such as language, which is subserved by an extensive network of interconnected regions in both hemispheres..." (p.65). This mechanism has also been called 'restitution'. It is suggested that this process is responsible for spontaneous recovery within the first six months after stroke.

3. Compensation due to strategies: During the course of rehabilitation and recovery patients might develop strategies to adapt to impaired functions. This would result in a cortical activation pattern that is different from control subjects. The possibility of adaptive strategies has been emphasized by Kolk (for a review see Kolk, 1998) who proposed an economy hypothesis. It was suggested that aphasics adapt the syntactic complexity of their

utterances to their reduced computational capacity and thereby use only a subset of the normal inventory of syntactic forms. A further possibility might be that working memory functions are stressed to a larger degree to compensate for impaired functions.

Up to this point language was approached as a unitary process. From the reviewed evidence on aphasia, however, it became clear that different lesions (anterior or posterior) lead to different symptoms and consequently language cannot be considered a homogenous process. The heterogeneity of different language processes is at the core of the cognitive model of speech production by Willem Levelt (1989, 1999).

1.3 Stages of Language Processing: Levelt's Model of Speech Production

Speaking is a very impressive performance, where a large store of information with roughly 20000 items, the so called output lexicon, has to be searched through and still three words per second can be produced (Levelt, 1989). At this rate, the average speaker chooses one wrong word per million and commits one error per million. This performance is usually explained by a massive parallel architecture of the system and an almost simultaneous activation of multiple components.

Levelt, Roelofs & Meyer (1999) introduced very recently a model for the production of single words that is testable by methods with high abilities in the temporal domain. The earlier version of this model (Levelt, 1989) was less focused on the production of single words but on the production of sentences. These language production models are similar to others that have also influenced them (Garrett (1975), Kempen und Hoenkamp (1987), Bock (1987), Cooper & Paccia-Cooper (1980), Dell (1986)).

Speaking is conceived as a staged process leading from conceptual preparation via lexical selection, morpho-phonological encoding and phonetic encoding to the initiation of articulation (see Figure1 for a larger overview of the model and Figure 2 for a specific example). Each stage accepts specific input representations and produces characteristic output representations. It is assumed that these stages are strongly connected and are active almost simultaneously. In the following overview of the model it will be explained what the different stages are supposed to achieve and what their specific input and output representations are.

Figure 1:

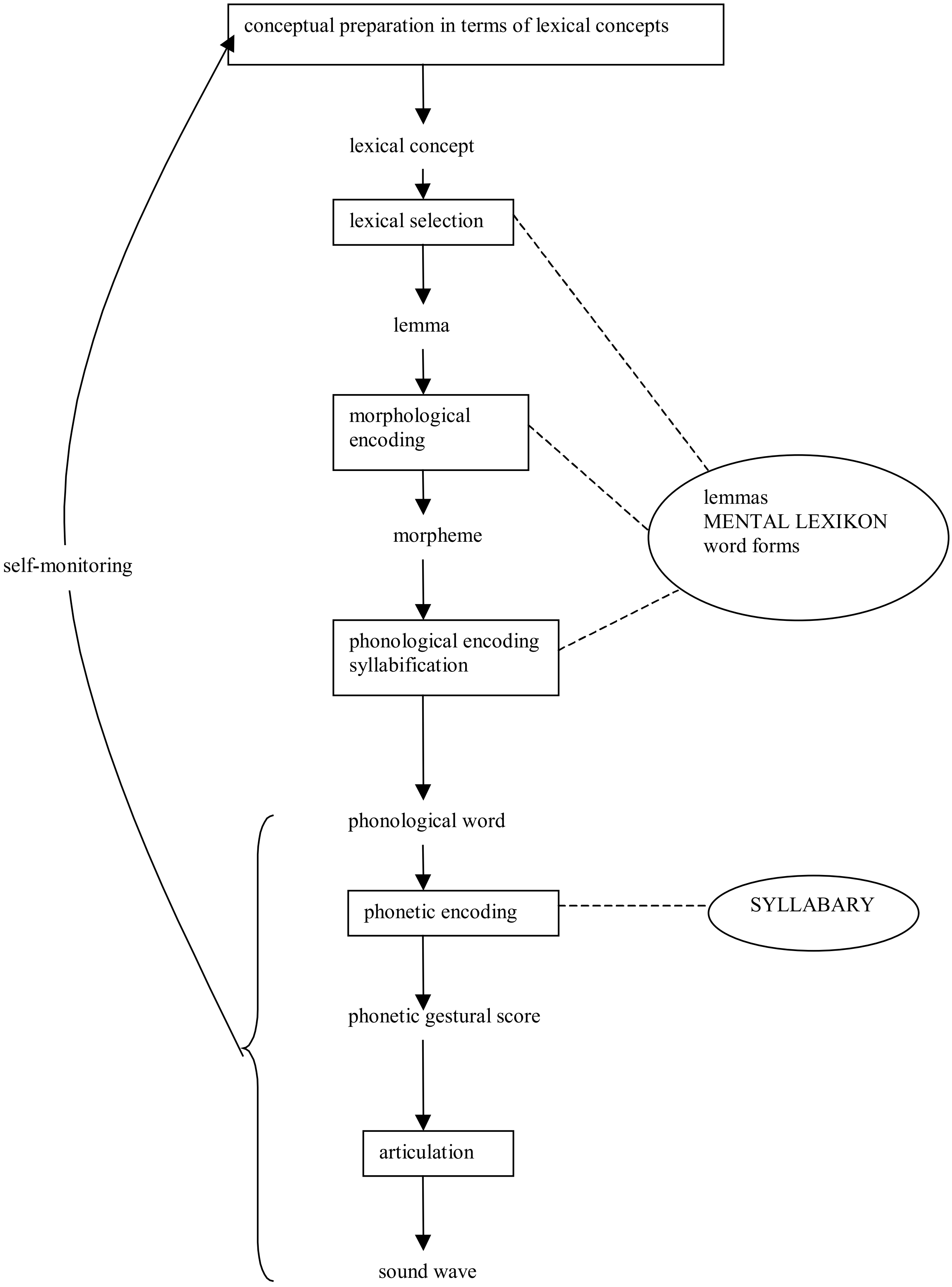
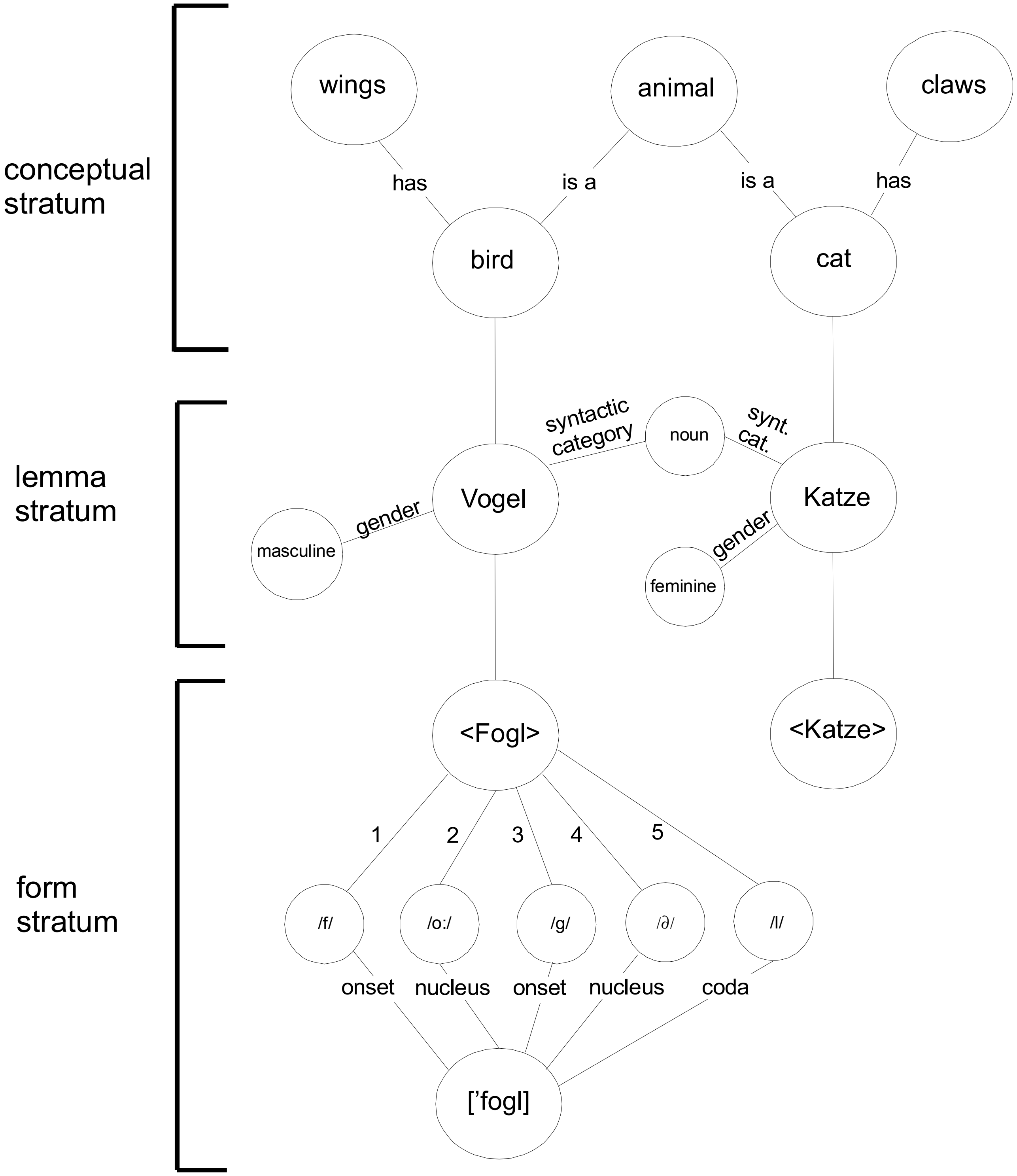

conceptual preparation in terms of lexical concepts
lexical concept
lexical selection
lemma
morphological encoding
morpheme
phonological encoding syllabification
phonological word
phonetic encoding
phonetic gestural score
articulation
sound wave
lemmas
MENTAL LEXIKON
word forms
SYLLABARY
self-monitoring

Figure 2 :


conceptual stratum
lemma stratum
form stratum
wings
animal
claws
has
is a
is a
has
bird
cat
syntactic category
noun
synt. cat.
Vogel
Katze
gender
masculine
gender
feminine
<Fogl>
<Katze>
1
2
3
4
5
/f/
/o:/
/g/
/∂/
/l/
onset
nucleus
onset
nucleus
coda
['fogl]

1.3.1 Conceptual Preparation

The intentional (i.e. relevant for the speech act) production of a meaningful word involves the activation of its lexical concept representing a word’s meaning. The process leading up to that stage is called „conceptual preparation“. In normal use of language (e.g. a conversation) a lexical concept is often part of a larger message that the speaker tries to communicate. The concept that is going to be activated (e.g. cop vs. policeman) is influenced by pragmatic, context-dependent considerations. In object naming and similar tasks like ones presented in this thesis, the activation of a concept depends on the visual analysis of a presented stimulus, perspective taking (i.e. choosing among alternative lexical concepts according to the task given by the experimenter) and situational knowledge (i.e. agreement to cooperate in the situation at hand and understanding what the experimental task is). A main part of the theory is that the concept nodes are linked to other semantically related concept nodes. In the example (Figure 2) the concept node for ‚bird‘ (German: Vogel) is activated. It can be seen that links to other concept nodes are activated, such as cat (German: Katze) or the superordinate ‘animal’. This latter link is from a IS-A character, because a cat is an animal. Other links form a ‚HAS-A‘ connection as they are linked to properties of the object, e.g. wings. It is assumed that these concepts are not represented by semantic features, but as undivided wholes. One reason for this assumption is the so called hyperonym problem (Levelt, 1989). Given semantic representations by features, when a word’s semantic features are active the features of the hyperonyms or superordinates should be active as well. From this one can hypothesize that speakers tend to produce hyperonyms instead of target words. In the same representational form a semantic complexity effect would exist, i.e. words with a more complex feature set are harder to access than simpler ones (Levelt et al., 1978). For both predictions (activation of superordinates and complexity effect) no evidence could be found with reaction time studies and speech error studies (for a more detailed discussion see Levelt 1989).

The product of conceptualizing is a preverbal message. Such a message can be deposited in the so called working memory (Baddeley, 1986). „Working memory contains all the information currently accessible to the speaker, i.e., all the information that can be processed by message-generating procedures or by monitoring procedures. It is the information attended to by the speaker.“ (Levelt, 1989, p.10). Thus it should be noted that the conceptualizer is strongly connected to all kinds of memory stores, like working memory, situational knowledge etc.

1.3.2 Lexical Selection

After a concept has been activated a lemma is retrieved from the mental lexicon. A lemma contains the syntactic properties of a word (word class; transitive or intransitive etc.). Upon the activation of a lemma its syntax becomes available for further grammatical encoding, i.e. the appropriate syntactic environment for the word is created. In the example the German lemma 'bird' will make available that it is a noun with masculine gender. The process of grammatical encoding is especially important in the production of whole sentences. Most words that are produced have so called diacritic features (features for number, person, tense, mood) that have to be set. The values of these features will in part derive from the conceptual preparation. Other features, like a verb's number, are set during grammatical encoding as determined by the sentence subject's number feature. For further details the reader is referred to Levelt (1989).

1.3.3 Morpho-phonological Encoding

After lemma selection, the speaker shifts from the conceptual/ syntactic domain to the phonological/ articulatory domain. This is a process with relatively frequent breakdowns as can be seen in the tip of the tongue phenomenon, where speakers have problems selecting a specific word form. It can be hypothesized, that during such a state the syntactic features of this word are active. This has been demonstrated in healthy Italian speakers by Vigliocco et al. (1997) and in an anomic aphasic by Badecker et al. (1995). This patient will be described in more detail in chapter 1.3.2.

According to the theory, accessing the word form means activation of three kinds of information of a word, the morphological make-up, the metrical shape and its segmental make-up. The morphological make-up involves information about the root and the suffixes of a word. Then the metrical and segmental properties will be spelled out, i.e. of how many syllables one of the word's morphemes consist and where the stress pattern lies. It has to be noted that at this level no syllables exist. The syllabification is a later process, because it depends on the already existing phonological environment. It is assumed that a morpheme's segments or its phonemes will become simultaneously available with labelled links indicating their correct ordering. In the example of figure 1 the German word "Vogel" has four phonemes: /f/ /o:/ /g/ /∂/ /l/ (∂ denotes a Schwa which occurs for example in the final vowel in the word *sofa*) with links from 1-5 indicating their ordering. The output of this stage is called a phonological word.

1.3.4 Phonetic Encoding

The aim of this part of the theory is to explain how a phonological word's gestural score is computed. This is still an abstract representation of the articulatory gestures to be performed at different articulatory tiers, a glottal, a nasal and an oral tier. These defined tiers reflect the fact that phonetic features correspond to independent articulatory gestures and the subsequent acoustic events, e.g. tongue placement and movement. One task of the oral tier is for example to close the lips. This is conceived as abstract representations, because closing the lips is not the same for different phonemes. The representation of articulatory gestures involves the notion of a syllabary which is assumed to be a repository of gestural scores for frequently used syllables of a particular language. Speakers do most of their talking with only a few hundred syllables. So it is highly advantageous for the brain to have direct access to these frequently used syllables and not to have them computed over and over again. These syllabic scores are activated by the segments of the phonological syllables. As phonological syllables are successively composed the corresponding gestural scores are successively retrieved and as soon as all syllabic scores of a word have been retrieved the word's articulation can be initiated.

Besides this, speakers can also produce entirely new syllables, for example in reading new words or non-words. The output of the syllabification process are called phonological or prosodic words.

1.3.5 Articulation

The articulatory system is a highly complex motor system that transforms abstract gestural scores into spoken words and overt language involving lungs, larynx and vocal tract. The functioning of this system is not covered by Levelt's model and will also not be a topic of this thesis, as yet there are no reasonable methods to investigate it with brain imaging methods.

1.3.6 Self-monitoring

The speaker himself monitors his own speech output and is able to discover errors in the delivery of his own speech. This means that a speaker listens to his „internal speech“ much as he listens to an interlocutor's speech. Levelt (1989) suggests, that „internal speech“ is monitored at the phonetic stage after the output of phonetic encoding or even on a more abstract level on the phonological word representation (Wheeldon and Levelt, 1995).

In this chapter a model of speech production has been introduced emphasizing different levels of language processing. In the next chapter it will be shown how aphasic symptoms can be understood on the levels of Levelt's model. More emphasis will be put on symptoms related to the production of single words than sentences or language comprehension referring to the tasks developed in this thesis. By interpreting aphasic symptoms with reference to Levelt's model the assumption of different language areas is substantiated.

1.4 Aphasic Symptoms within Stages of Speech Production

1.4.1 Conceptual Impairments

As laid out in the chapter on Levelt's model the first step of speech production, e.g. for naming an object, is the activation of a lexical concept. These are represented on the so called conceptual level. There is a longstanding and firm tradition to describe aphasia as conceptual impairment. Already at 1870 Finkelnburg described the aphasias as 'disorders of the symbolic function' or 'asymbolia'. He observed an inability in these patients to recognize pantomimed actions and various conventional symbols (such as coins and military signs). This idea was further elaborated by Jackson (1878) stating that aphasics suffer from a 'loss or defect in symbolizing relations of things in any way'. Jackson's work was revived by Head (1926), again explaining aphasia as a defect of 'symbolic formulation and expression'. The notion that the aphasic's disorder of thinking is not a general deficit, i.e. that aphasics are 'lame in thinking' (Jackson, 1878), but that it is a specific conceptual impairment was first recognized by Goldstein. According to Goldstein the aphasic's impairment is the "loss of the abstract attitude, which entails (a) language disruption, particularly in amnestic aphasia (Goldstein, 1924), and (b) inability to perform non-verbal tasks requiring the patient to pick out (in Gestalt terms) the essential in a field, to hold the figure clearly against the ground and, if necessary, to shift intentionally from a concept-directed classification to another (Goldstein and Scheerer, 1941)" (reviewed in Vignolo, 1989).

In line with this were investigations of Cohen and collaborators on cognitive impairments in aphasia. These studies were led by the quest to find out, why the Token Test separates aphasics so well from subjects with no language impairment.

Since its introduction in 1962 (de Renzi and Vignolo, 1962) the Token Test has gained wide acceptance as a diagnostic instrument for aphasia. Today it is part of many test batteries like the Aachener Aphasie Test (Huber et al., 1983). In the most basic part of this test plastic tokens varying in form, size and colour are placed in front of the patient and the experimenter asks the patient in an elementary syntactical form to point to a specific token (e.g. "Point at the large red circle"). In the more difficult part of the test the commands increase in lexical and syntactical complexity (e.g. "Touch all the circles except the green one!"). While it is obvious that successful performance in this test is dependent on auditory comprehension, a number of findings suggest that other cognitive processes are involved (see Cohen et al., 1983): the test discriminates patients with a predominance of symptoms in language comprehension as reliably from other brain-damaged patients as patients with a predominance of symptoms in language production are separated from other brain-damaged patients (Cohen et al., 1976; Orgass, 1976). The final part of the test (which is the grammatically most complex) is not more powerful in discriminating aphasics form controls than the less complex parts (Orgass, 1976; Woll et al., 1976). Even if the test is administered in a non-verbal form (the token that the patient has to select is not described verbally, but presented visually; i.e. in this form the experimenter does not speak a single word) it discriminates aphasics from other brain-damaged subjects. In addition to correlations with measures of language impairments, the test is also correlated with the performance in matching colours or sounds to pictures (Cohen et al., 1980; Basso et al., 1976).

From findings like these, it was suggested that a crucial factor in aphasia is a "deficiency in the analytical isolation and cognitive handling of individual features of concepts" (Cohen et al., 1980). In contrast to that, the performance of aphasics was not impaired in categorizing concepts having a whole complex of associations in common and few individual features, i.e. common situational contexts are relatively spared.

So far the conclusion can be drawn that aphasics in general show impairments on the conceptual level, particularly if the application of certain cognitive strategies to concepts is necessary.

However, this still has to be taken with caution, because an alternative interpretation has to be ruled out, i.e. that the impairments in performance are a result of poorly structured and "fuzzy" concepts. As a result of their diffuse structure an analytic decomposition would be hard to achieve. Indeed there is some evidence for such a possibility, for example if one regards verbal paraphasias. These become manifest through the utterance of semantically closely related concepts during spontaneous speech (Buckingham and Rekart, 1979), e.g. saying 'cat' instead of 'dog'. In comprehension tasks an often reported finding is the inability to point to the correct picture or object in an array of semantically similar items (Daujat et al., 1974).

Hagoort (1998) reviewed recently priming experiments performed with patients displaying impairments of lexical-semantic processing including aphasics. These patients displayed dysfunctions, when they had to perform semantic judgements or other types of semantic evaluations. Other studies using the sematic priming technique have found contrary evidence. It is a robust finding in psycholinguistic studies that the processing of a word benefits from a preceding word related in meaning, resulting in a priming effect (i.e. subjects name the word 'cat' faster when it is preceded by 'dog' compared to 'door'). In aphasics priming effects have been found for priming of purely semantically as well as associatively related words (Hagoort, et al., 1996; Hagoort, 1997; Ostrin & Tyler, 1993). Hagoort concluded that "these priming effects have been taken as evidence that in many aphasic patients with semantic impairments, lexical-semantic representations are largely unaffected, but that they have a problem in accessing these representations." (1998; p. 245).

Taken together, it is concluded that aphasics have intact lexical concepts, but that they show impairments in accessing these representations and to perform cognitive strategies, such as analytical isolation, on these concepts.

1.4.2 Evidence for the Lemma Level

Models of speech production proposed several stages for retrieving a word form (Levelt, 1989, 1999). A non-linguistic concept is activated first, a modality-neutral lemma is retrieved then and subsequently the word form. It was suggested that at the lemma level information about syntax is stored, but no information about the phonologic or orthographic code is included.

Semenza and co-workers (1997) presented in a single case study evidence for the separate storage of grammatical rules, that are said to be stored at the lemma level. Their formerly aphasic patient had almost completely recovered, but displayed an isolated deficit concerning use of grammatical rules of mass nouns (like water, calcium). Mass nouns for example cannot take the plural or indefinite articles. Their patient accepted sentences like “I am putting some whipped creams on my strawberries” as correct. When she had to construct sentences, she made errors like “I spread a butter on a roll”. The authors conclude: “a case where the all and only rules concerning the use of mass nouns are selectively lost demonstrates that such rules are indeed stored as an independent set ready to use in a variety of tasks(p. 674)”.

Evidence for the independence of a lemma level from the word form level has been presented in an amnestic aphasic named Dante investigated by Badecker (1995).
At the time of the investigation, Dante was a 24-year-old male native Italian speaker. Due to a meningoencephalitis a non-homogenous superficial hypodensity located in fronto-temporo-parietal regions was found in the computer tomography. Word-finding difficulties and anterograde amnesia were the main cognitive deficits (Token Test: 32 out of 36 correct). In a number of experiments the authors were able to demonstrate convincingly, that Dante was able to retrieve word-specific syntactic information (gender decision correctly performed in several experiments >95%) even when he was unable to give any information about the phonological or orthographic form of a lexical item (word form correctly named < 64%) or about a related function word that might indirectly encode the gender information (as it is possible in Italian). Since alternative explanations such as naming difficulties due to articulatory impairments were ruled out (Dante was fully able to repeat and read the words he could not name), this single-case study provided strong evidence for a dissociation between the lemma and the form stratum.

It should be noted that the assumption of a process of lexical retrieval containing a lemma level is relatively new in language research and so there are not yet many data to prove or reject this hypothesis. Reviewing the case of Dante it has been hypothesized (Ellis & Young, 1997) that the performance of other amnestic patients like EST (Kay & Ellis, 1987) might be interpreted as the ability to get access to the lemma level but as an impairment to proceed to the word form. EST is a well investigated patient who had no problems performing semantic decision tasks but showed strong naming impairments. Kay and Ellis showed that his naming performance depended on the frequency of a particular word. Pictures he could name without delay had a high frequency. Word frequency counts provide a rough measure of the relative frequencies of usage of words in the language (e.g. Francis & Kucera, 1982). Jescheniak & Levelt (1994) showed that the frequency effect arises on the word form level and not during an earlier stage (this will be reviewed in the experimental part).

Thus, it can be hypothesized that amnestic aphasics are able to access the lemma level even though they show naming impairments depending on word frequency. Future research may show if dissociations between the conceptual and the lemma level exist as well.

1.4.3 Phonological Impairments

It is generally assumed (Blumstein, 1995) that all aphasics, independent of lesion site or syndrome, display some phonological errors, the occurrence of which cannot be predicted. A patient may on one occasion produce a phonological error when articulating a specific word and at other times produce it correctly.

Four categories of errors are assumed as a consequence of a deficit in selection or phonological planning (Blumstein, 1995; p. 918): phoneme substitution (one phoneme is substituted for another), simplification (phonemes are deleted), addition (extra phonemes are added) and environment errors (the occurrence of a particular phoneme is influenced by the surrounding context).

Though these errors are not specific to an aphasic syndrome there is a number of symptoms mostly present in Wernicke's aphasia (see e.g. Poeck, 1994), such as verbal paraphasias, phonemic paraphasias or neologisms. Several authors (Buckingham & Kertesz, 1976; Butterworth, 1979, 1985; Ellis & Young, 1997; Kohn & Smith, 1994; Shattuck-Hufnagel, 1987) suggest that these symptoms arise on the level of the output lexicon. In a recent study about paraphasias and neologisms in fluent aphasics Gagnon and co-workers (1997) conclude: "the aphasic system is vulnerable to lexical substitutions at a level of the retrieval system that is responsible to word frequency and grammatical class".

Evidence for this comes from a number of sources. It has been shown that incorrectly produced words are subject to the frequency effect (Ellis et al.,1983), i.e. less frequent words are more error prone. As mentioned above, Jescheniak and Levelt (1994) have shown that the source of this effect is at the word form level and not before. Studies with interest in the elapsed time between spoken words showed that incorrectly produced words followed longer pauses, which was taken as an indicator of an unsuccessful search in the output lexicon (Butterworth, 1979; Ellis et al., 1983). It is assumed that if only partial information about a word form can be retrieved aphasic speakers produce phonological approximation errors, if little or no information at all can be accessed aphasics may produce neologisms. Ellis and Young (1997) claim that the difference between patients producing paraphasias and neologisms, and amnestic patients like EST is probably rooted in their ability to comprehend language and to monitor their own speech output, which is fulfilled by the same processors (see above; Levelt, 1989, 1999).

Wernicke's and Jargon aphasics show typically more impairments in speech comprehension than amnestic patients and therefore cannot recognize or learn which words are hard to access and cause problems. Consistent with this view is the observation that Wernicke's patients are difficult to distinguish from amnestic aphasics in the course of their disorder (Handbook of the AAT, Huber et al. 1983; p.14). This is related to an improvement in speech comprehension, i.e. when they are able again to monitor their own speech output. Words that were originally mispronounced become replaced by anomic gaps (Ellis & Young, 1997; p.126 ff), i.e. they are not spoken.

1.4.4 Phonetic Impairments

Following the articulatory planning of the utterance, the phonetic string is converted into a set of motor commands to the articulatory system. Reviewing deficits of aphasics on this level of speech production Blumstein concluded that "anterior aphasics (Note from C.D.: i.e. Broca's) show clear-cut phonetic impairments while posterior patients (Note from C.D.: i.e. Wernicke's) show subclinical phonetic impairments" (1995; p. 923). Broca's aphasics display difficulties producing phonetic gestures, which require exact timing of two independent articulators. This has been found for voicing and nasality across different languages (e.g. Blumstein et al., 1980; Shewan, Leeper, and Booth, 1984; Itoh, Sasanuma, and Ushijima, 1979). In voicing studies the studied parameter is voice-onset time, i.e. the time relationship between the release of a stop consonant and the onset of vocal cord vibration. Nasality as well involves exact timing of two articulators, the release of the closure in the oral cavity and the opening of the velum.

Broca's aphasics also show impairments with laryngeal control which influences intonation (i.e. the melody of language). Analyzing two-word utterances Cooper et al. (1984) showed that Broca's aphasics have control over prosodic features like terminal falling e.g. at the end of a sentence, but that the fundamental frequency range is restricted (Cooper et al., 1984; Ryalls, 1982). This appears as monotone speech. From these findings Blumstein concluded that in Broca's aphasics "phonological planning is relatively intact and it is the ultimate timing or coordination of the articulatory movements that is impaired."(p. 922)

It can be concluded that all aphasics display impairments on the conceptual level if this involves the handling of concepts or the isolation of features of concepts. Wernicke and Amnestic aphasics show major impairments on the phonological stage and Broca aphasics display problems on the phonetic level. It can be assumed, that the lemma level is intact in at least one type of aphasia, i.e. Amnestic aphasia.

1.4.5 Additional Remarks on Aphasia

The preceding chapter summarised some findings on aphasia. However, it should be kept in mind that the overt and measured behaviour of every single patient is influenced by many different symptoms and their interaction. This may indicate that the cortical organization of language is different in every speaker (see studies on electrical stimulation; e.g. Haglund et al., 1994) and that lesions never affect exactly the same neuronal tissue. In the reported single case studies, patients were chosen, because they displayed a specific symptom in a ‘pure’ form, i.e. not in combination with other symptoms that might make a reasonable investigation impossible. Recognizing that syndromal classification usually comprises heterogeneous groups of aphasics many authors disprove of group studies (e.g. Caramazza, 1986). It has to be mentioned though that studying single cases might be the appropriate approach if one is interested in the structure of cognitive processes (as Caramazza acknowledges himself, 1984), but in other cases, e.g. in studies on therapy, the group study approach seems more sensible (for a methodological review see Shallice, 1988).

Furthermore, when interpreting the patients behaviour and an underlying dysfunctional process is inferred, caution seems justified, because also strategic factors might mediate between the underlying dysfunctional representation and the measured performance (Caramazza, 1984). A typical example is agrammatism (see above) where patients use only very rarely or not at all functions words, such as propositions and denominators. They communicate only via content words (nouns, adjectives...). It has been assumed that such problems can be described as a loss of syntactic knowledge that manifests itself in language production and comprehension (Berndt & Caramazza, 1980). On the other hand this might be an effective strategy to adapt to a different impairment, such as a reduction of computational capacity. By choosing only content words, the speaker transmits only the most important information and adapts thereby to this reduction (Kolk & van Grunsven, 1985). In line with this argument, it has been shown that healthy subjects develop syntactic comprehension breakdowns quantitatively and qualitatively similar to aphasic subjects if their computational capacity is reduced by speeding up the presentation of syntactically complex sentences. (Miyake, Carpenter and Just, 1994).

In the final part of the introduction a short overview how ERPs have been applied in the study of language will be given.

1.5 Investigating Language Processes by Means of Event Related Potentials

1.5.1 General overview

Event-related brain potentials (ERPs) have been increasingly used to investigate brain functions involved in language comprehension and production (for reviews: Molfese, 1983; Neville, 1980; Caplan, 1994; Kutas & van Petten, 1994; Friederici, 1995; Friederici, Hahne & Mecklinger, 1996). Most of the research focused on the differentiation of syntactic and semantic processes by means of ERP components such as the N200 (Brown et al., 1980; Neville et al., 1991; Friederici et al., 1993; Osterhout et al., 1997; Pulvermüller, 1996, 1999), the N400 in response to the violation of semantic expectations or semantic rules (Kutas & Hillyard, 1980; review: Kutas & van Petten, 1994), the P600 in response to syntactic anomalies (Hagoort, Brown, & Groothusen, 1993; review: Friederici et al., 1996), or the lateralized readiness potential for studying the time course of conceptual, grammatical, and phonological processing (van Turennout, 1997; van Turennout et al., 1998).

Based on patients with lesion-induced language dysfunctions and on intra-operative cortical stimulation (Ojemann, 1983; Ojemann et al., 1989), language-related functions have primarily been related to activity in frontal and temporal areas of the left hemisphere (see also above); correspondingly, left-hemispheric lateralization of ERPs was observed in several tasks requiring verbal (as compared to spatial) processing (Vitouch et al., 1997), including the recognition of function - compared to content words (Pulvermüller, 1996, 1999), and phonological encoding as required in a rhyming task (Angrilli et al., 1999; Barrett & Rugg, 1990). In aphasic patients, quite consistently prolonged latencies and reduced amplitudes have been found for the - largely symmetrically distributed - N400 in response to semantic abnormalities (e.g., Hagoort, Brown, and Swaab, 1996; see also Swaab, Brown, & Hagoort, 1997; Hagoort & Kutas, 1995; Reuter, Schönle, and Kurthen, 1994).

1.5.2 Studies with relevance to stages of speech production

Lexical-semantic processes

Semantic-conceptual processes have often been investigated with the N400 as electrocortical correlate. In these studies usually sentences are presented where the expected meaningful ending of a phrase is violated (i.e. ‘ I have my coffee with milk and cement’). Upon the last word, a broadly distributed negativity occurring about 400 msec after presentation of the unexpected word has reliably been found. The N400 shows almost no lateralization with slightly more negativity over the right hemisphere (Kutas & van Petten, 1994; Friederici, 1995). Due to its broad distribution the N400 seems not useful to investigate changes of lateralization, because changes are harder to detect. Additionally, the studies by Pulvermüller (for overviews see Pulvermüller, 1996, 1999) show that semantic representations are very widely represented over the whole cortex.

While there are many N400 studies dealing with semantic representations, there seems to be only one study requiring isolated representation of semantic features. Vitouch and co-workers (1997) presented an ERP study where verbal and spatial processing was contrasted. In the verbal condition subjects had to indicate, if a verbal statement such as ‘bird’ is related to ‘nest’ like ‘man’ is related to ‘house’ is correct. Vitouch found, that the presentation of such a stimulus correlated with a slow negative potential shift over left anterior areas. To succeed in this task, it is necessary to represent the function or a feature of a concept in isolation. As shown above, it was put forward, that this is one of the defective functions that lead to impaired performance of aphasics in the Token Test.

Phonological Encoding

Michael Rugg (Rugg et al., 1984a, b) has performed a series of studies where he demonstrated, that phonological encoding correlates with left hemispheric negativity. In these tasks subjects had to indicate, whether two successively presented items rhymed. Rugg has investigated the contingent negative variation (CNV), that develops in the interval after the presentation of a warning stimulus in preparation to an imperative stimulus. In these studies, the CNV had been strongest over left temporal areas for orthographically presented stimuli and showed a more frontal distribution upon presentation of pictorial stimuli (Barrett & Rugg, 1990). There is no effect of handedness on this distribution (Barret & Rugg, 1989).
While in these studies emphasis was put mainly on a specific stage of speech production, there are also studies that investigate all stages within one task by employing naming.

Naming

The first ERP studies with an interest in naming were performed by Stuss and Picton (1984, 1986). Subjects had to name pictures that were presented as warning stimuli after the presentation of an imperative stimulus. Upon the presentation of the warning stimulus the

ERP contained an overlapping parietal P3 and a frontal N400. The P3 was interpreted as an updating of target-expectations and the N400 as activation of memory search.

In a recent study Levelt et al. (1998) investigated the proposed processing stages of his model in a magnetoencephalography (MEG) study employing naming. Reviewing several empirical findings concerning speech production, four stages of naming were defined with fixed time windows. These time windows were the basis for dipole source analysis that resulted in sources of activity during these time intervals.

During the first time window (0- 150 msec post picture onset) comprising visual processing and accessing the lexical concept the occipital cortex especially of the right hemisphere was activated.

During the second window (150-275 msec), denoted lemma access, the right parietal cortex was found to be active. This finding was unexpected and interpreted as indication of attention to the global features of the picture and a “strategy of rapidly disengaging visual attention from the picture just named in order to be ready for the next one” (p. 562). The involvement of the right parietal region when attention to global features is required, was demonstrated in a PET study by Fink et al. (1996). Husain and co-workers (1997) showed in a single case study, that lesions in this area impaired the patient’s ability to disengage visual attention from one stimulus to the next.

In the third epoch (275-400 msec), denoted phonological encoding, sources within the left temporal cortex of the left hemisphere were mostly active. From this it was suggested, that it is Wernicke’s area where phonological encoding takes place in naming.

During the fourth stage (400-600 msec), the sources of activity were quite scattered with largest activity in the sensory-motor cortex and in the parietal and temporal lobes. This activity was suggested to be related to self-monitoring rather than phonetic encoding. In general the findings of this study corroborated an earlier MEG study by Salmelin et al. (1994) as a “steady progression of activation from the occipital to the parietal-temporal and frontal areas of the brain” (Levelt, 1989; p. 562).

1.6 Summary and Conclusions

In the introductory part of the thesis it was argued that language has a biological basis and that areas involved in language processing are mainly located within the left hemisphere. However, there is evidence that aphasic patients show increased right hemispheric activity when their language functions recovered (Weiller et al., 1995). In these patients homotopic areas of the right hemisphere were active that were lesioned in the left hemisphere. In contrast to that, other studies stressed the role of the left hemisphere during the course of recovery, especially of the left superior temporal cortex (Karbe et al., 1998). Other authors suggested (Thomas et al. 1995) that the activation pattern differs for Broca's and Wernicke's aphasics during their course of recovery. A right hemispheric preponderance found during the first four weeks post stroke changed to a left frontal lateralization later in their clinical course of recovery in Broca's aphasics, while in Wernicke's aphasia a right hemispheric preponderance remained across time.

On this background, this thesis aimed at integrating several approaches by examining ERPs in various tasks in aphasics and language unimpaired subjects. The tasks were developed from Levelt's model and the Token test.
In the next chapter the tasks will be described. The experiments were grouped according to Levelt's proposed stages of speech production A) *Feature Comparison Tasks* investigating conceptual processes, B) *Gender Decision* and *Semantic Classification* investigating lemma access vs. decisions on the semantic stratum as control condition and C) *Word Comprehension* and *Rhyming* investigating lexical-semantic vs. processes of phonological encoding.

2. The Present Experiments

2.1 The Tasks

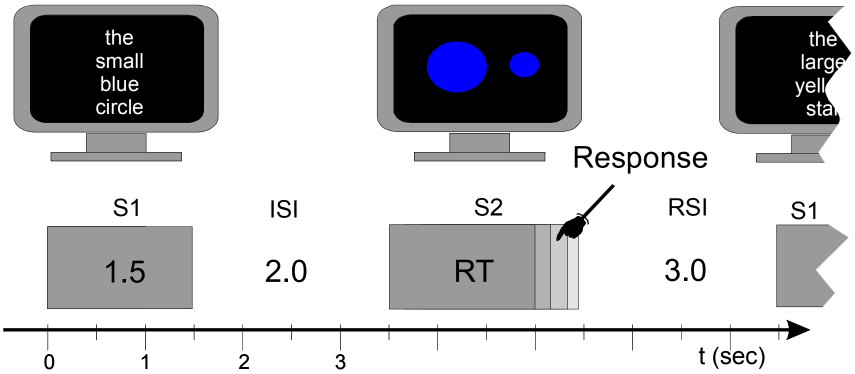
The following section illustrates the basic designs of the experimental tasks and their respective control conditions. For the exact methodological parameters, the reader is referred to the corresponding chapters of each task.

2.1.1 Feature Comparison Tasks

The Feature Comparison Tasks were stimulated by the Token Test (particularly the Word-Picture Task resembles the Token Test). By variation of the modality of S1 and S2 four tasks were created. As it has been shown that the performance in such tasks is dependent on speech comprehension, but also on the analytical isolation and cognitive handling of individual features of concepts (see above), these tasks can be regarded as tasks critically emphasizing processing on the conceptual stratum.

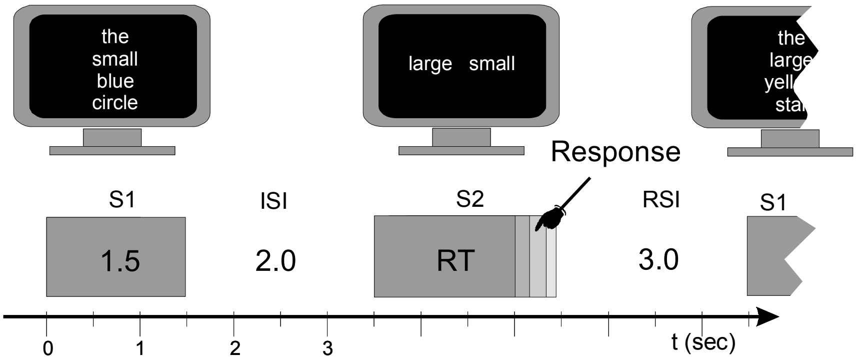
Word-Picture Task: Subjects had to indicate via button press which of the two presented objects of the S2 is described better by the noun phrase given as S1.

Figure 3:



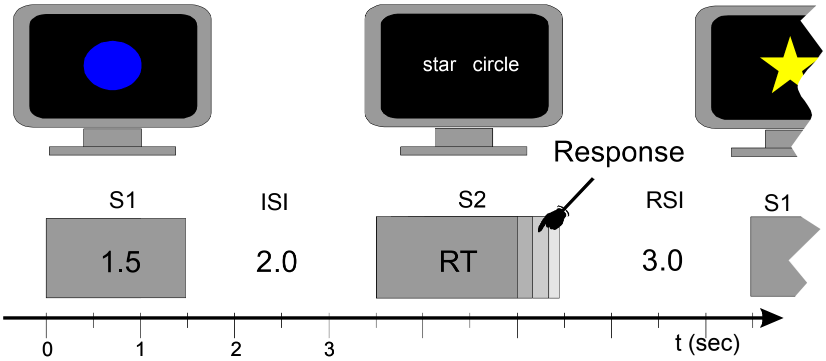
Word-Word Task: Subjects had to indicate via button press which of the two presented words of the S2 was part of the noun phrase given as S1.

Figure 4:



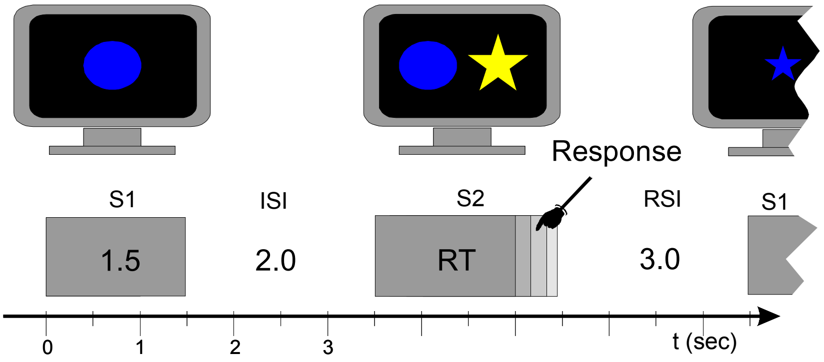
Picture-Word Task: Subjects had to indicate via button press which of the two presented words of the S2 describes better a feature of the presented object of the S1.

Figure 5:



Picture-Picture Task: Subjects had to indicate via button press which of the two presented objects of the S2 is identical with the presented object of the S1.

Figure 6:



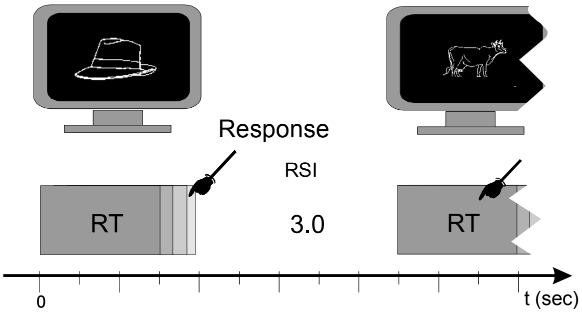
2.1.2 Gender Decision and Semantic Classification

The task *Gender Decision* was adapted from Jescheniak and Levelt (1994) as a task requiring lemma access. In this task the picture of an object is presented and subjects have to decide to which of two grammatical classes the corresponding lexical concept belongs to. The task *Semantic Classification* was designed as a semantic control task. The same objects were presented in both tasks.

Gender Decision: Subjects had to indicate via button press whether the German denominator “der” or “die” belongs to the verbal label of the presented object.

Semantic Classification: Subjects had to indicate via button press if the presented object is man-made or nature-made.

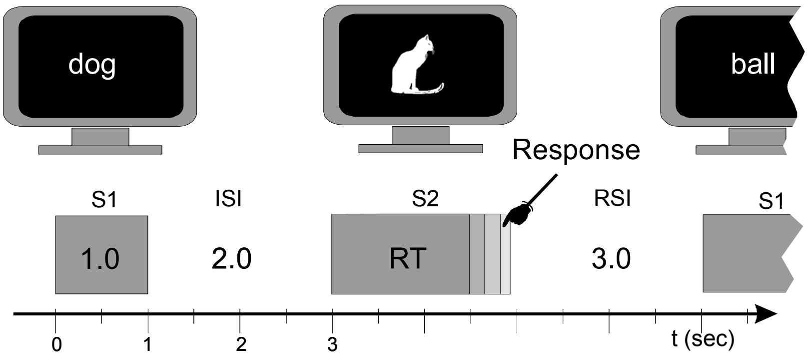
Figure 7:



2.1.3 Word Comprehension and Phonological Encoding

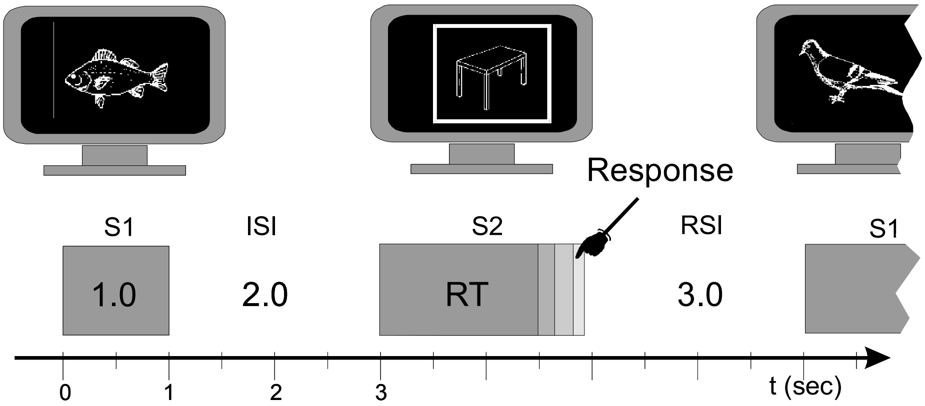
Word Comprehension Task: Subjects had to indicate via button press whether word and picture correspond. By presenting a word, a lexical concept is activated that has to be compared to a concrete picture. According to Levelt (1998) and Jescheniak and Levelt (1994) this can be considered as a task involving lexical-semantic processes.

Figure 8:



Rhyming Task: Subjects had to indicate via button press whether the verbal labels of the presented objects rhyme. To perform successfully, one has to perform all stages of picture naming from object recognition to retrieval of the word form.

Figure 9:



2.2 Methods

2.2.1 Patient Selection

The aphasic patients and neurological controls were recruited at the German rehabilitation center Kliniken Schmieder, Allensbach. All aphasic patients were inpatients and received treatment for aphasia from the group of speech therapists. Patients were diagnosed as aphasic by the supervising neurologist and in more detail by the leading neurolinguist, Peter Koebbel, with the Aachener Aphasie Test. Patients suitable for the study were recommended to the experimenter on the basis of the impression that a patient might be willing and able to cooperate and able to perform the experiments. In the course of the whole study it became clear that severely impaired patients (according to the AAT) could not participate. It became also clear, however, that some tasks were especially difficult for all patients and could only be performed by relatively small numbers of aphasic subjects. All patients were highly motivated and very willing to give their best. As neurological control group patients of the rehabilitation center were chosen which had no indication of a language disorder (e.g. slipped discs).

On a first appointment, lasting about 15 minutes, the aim and methodology of the study was explained and patients were asked, if they would like to participate in the study. During the second appointment, lasting between 2 and 3 hours, the examination was performed. During a third appointment, again lasting about 15 minutes, patients were debriefed and they were informed about their performance. Before the second appointment the supervising neurologist was asked, if anything would stand against a participation in the study. All patients were investigated at the EEG laboratory of the Lurija Institute. This institute, located at the Schmieder Kliniken Allensbach, is a cooperation between the Kliniken Schmieder and the University of Konstanz.

2.2.2 Procedure

After having given their written consent about participation in the study and information about handedness and demographical data, all subjects were explained, how the EEG recording is going to be performed. While the electrodes were mounted, the patients sat already in front of the monitor and all pictures of objects that they would encounter later were presented to them on the screen. The patients were encouraged to inspect the pictures as long as they wanted and to notify the experimenters, if they did not recognize any of the them. After this procedure a test for reading capability was then administered via monitor, to make sure that basic reading functions were present. This test consisted of the presentation of the 10 longest words used in a later test (Word Comprehension). Each word was presented one at a time for 1 sec. Patients then were asked what they read. All patients were able to perform this test. Prior to running the EEG experiments, a calibration run, necessary for later correction of eye movement artefacts (see Appendix), was done. Practice trials before each experiment assured, that instructions were adequately understood. Following the recording, electrode positions, as well as the four reference points nasion, inion, left and right preauricular, were digitized in three dimensions using a 3D digitizer (Polhemus Inc.).

Visual stimuli were generated by the STIM system (NEUROSCAN) and presented on a 14-inch monitor, placed at a distance of about 1.50 m in front of the subject. Response buttons were easily manageable microswitches mounted on the arm-rest of the subject's chair.

2.2.3 Data acquisition and ERP analysis

For each subject and each task the percentage of correct decisions and the median reaction time were determined as performance indices. The EEG was recorded with a DC-amplifier (MES, Munich) from 19 positions (Fz, Cz, Pz, Fp1, C3, F3, F7, T3, T5, P3, O1, Fp2, C4, F4, F8, T4, T6, P4, O2, M1, M2) using an electrode cap (Electrocap Inc.). The vertical and horizontal EOG were recorded for the correction of movement artefacts on ERPs (see next paragraph) with two electrodes placed about 1 cm horizontally to the eyes on the left and right outer canthi, two eclectrodes about 1 cm below the eyes and one on the forehead between the eyes. Bandwidth ranged from DC to 30 Hz (6 dB/octave). Electrode impedances were kept below 5 kOhm. Data were digitized at 1 bin/µV, 16-bit A/D, and sampled at 100 Hz with filter settings DC-30 Hz. Data were recorded continuously and stored for off-line analysis.

The continuously recorded data were first corrected for slow DC shifts by polynomial correction over the whole recording. Epochs starting 1 s before S1 and ending 5 s after were determined, data of each epoch being referred to a pre-S1 baseline of 500 ms. Data were transformed to average reference and filtered between 0.05 and 5 Hz. Epochs were corrected for eye movement and blink artefacts following a method of Berg and Scherg (1994; see Appendix) that allows to use also the electrodes around the eyes as EEG electrodes. This method distinguishes between ocular and brain activity and corrects for ocular artefacts only. After correction each trial was visually inspected and excluded, if there were remaining artefacts of any kind (muscle potentials, large drifts etc.).

For artefact-free trials and trials with correct responses, the distribution of the average amplitude was determined for ERP components, that were chosen specifically for each task after visual inspection and comparison of the grand means of each group. Since motor responses were required with the left hand, a readiness potential has to be expected to contribute more to the amplitude of the tCNV over the right (contralateral) hemisphere.

In addition the sources of activity were estimated using the "pseudoinverse" or "minimum norm" (MN) method (see Appendix). The result of this method delivered the amount current density values under each electrode. These current density values do not differentiate between positivity and negativity relative to some reference but allow a measure of cortical activity at the respective electrode site. Having only positive values, lateralization of activity was evaluated by determining a *laterality index* for the MN values. The sum of all the Minimum Norm values from the right hemisphere sites was subtracted from the sum of all activation indices from the left hemisphere divided by their sum.

2.3.4 Statistical Analysis

All statistical analysis were performed with the Statistical Analysis System (SAS).
Task- and group-specific differences for performance measures were evaluated by means of analyses of variance (ANOVA) with the between-factor GROUP (comparing aphasics and control subjects) and SYNDROME (comparing fluent (Wernicke's/Amnestic) and non-fluent (Broca's) aphasics). For evaluation of the ERP topography the normalized[2] (the value of each electrode was divided by the Sd of all electrodes for each subject) potential data and the MN values were analyzed with an ANOVA with repeated measurement for between-subject factors GROUP, SYNDROME and within-factors GRADIENT (anterior vs. posterior areas) and HEMISPHERE (left vs. right hemisphere with electrodes grouped into four areas: left anterior: F9, Fp1, F7, F3, C3; right anterior: F10, Fp2, F8, F4, C4; left posterior: P3, T7, P7, M1, O1 and right posterior : P4, T8, P8, M2, O2). For the within-subject comparison p-values were determined after adjusting the degrees of freedom with the Greenhouse-Geisser-Epsilon. Post-hoc comparisons were accomplished by ANOVAs on subsets of data or planned mean comparisons. Laterality indices were submitted to an ANOVA with the same factors as ERP amplitudes and MN values. In aphasics the relationship between the laterality index and clinical variables was evaluated by correlational analyses.

In the following, performance data of all tasks will be statistically analysed to evaluate if the task series – and which task to what extent- separates aphasics from controls. The employed statistical methods will be explained.

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[2] Normalization was performed, because there is a "fundamental incompatibility" between the additive model upon which ANOVAs are based and the multiplicative effect on ERP voltages produced by differences in source strength" (Picton et al., 1995). This problem was avoided by normalizing the data to eliminate overall amplitude differences between conditions.

2.3 Performance across All Tasks

Performance of subjects (response latencies of correct responses and number of errors) are of interest for the following reasons: From the neuropsychological perspective, it is of interest, whether the tasks – and which task to what extent – is suitable to discriminate groups. Thus, are the tasks developed for ERP recording purposes as suited to distinguishing aphasics as are neuropsychological tests such as the AAT?

Groups to be distinguished were: aphasics vs. controls, fluent aphasics vs. non-fluent aphasics and healthy controls vs. neurological controls.

Nearest neighbour analysis were performed. The aim of this nonparametric version of a discriminance analysis is to find a classification rule which is based on empirical variables such as latencies and errors (Nagl, 1992). In the present study more than half of the variables were not normally distributed and therefore the parametric version was not performed. In the nearest neighbour analysis a subject is classified into a group depending on the group of his closest neighbour or neighbours. The closest neighbour is the one, who has the smallest euclidian distance with respect to all empirical variables. In the present data set this distance is measured in msec or percent errors. This concept of nearest neighbour can be extended to the k-nearest neighbour (in the present study k=3 was chosen, i.e. the subject in question is classified according to his three next neighbours; this results in a more robust and reliable classification, because the influence of outliers is reduced by basing the classification on more than one subject).

A crossvalidation procedure was performed to avoid underestimation of the estimated classification error. Prior probabilities were chosen proportional to the respective number of subjects in each group. Otherwise the group sizes would have been taken as equal. Latencies and percent errors were standardised (M=0; S=1) to rule out an improportional influence of one variable.

Subjects

Twenty four aphasic patients were able to complete all tasks (see Table 3 for individual characteristics; 14 male, 10 female, mean age 51± 11 years, mean level of education 11±2 years). Twenty three of the patients suffered from a left hemispheric cerebrovascular insult, most of them from an infarct of the arteria cerebri media. In addition, one patient suffered from aphasia following a cerebral trauma including subdural bleeding in the temporal-parietal area and compression of the left lateral ventricle. Diagnoses of aphasia were determined by the Aachener Aphasie Test (AAT; Huber et al., 1983). The AAT diagnoses were compared with the diagnosis given by the speech therapist and the neurologist in charge. According to the AAT classification guidelines, the diagnosis of aphasia syndromes was given with a probability >75% in patients in accordance with the diagnoses of the speech therapist and the neurologist. Eleven patients were classified as Broca's-, 4 as Wernicke's-, 8 as Amnestic aphasics, and one as a conduction aphasic. In the one patient without cerebrovascular insult (see above) the probability was below 75%. For him syndrome classification was 40% Wernicke's and 60% amnestic aphasia. The speech therapist classified this patient as amnestic. In one patient the syndrome classification was 48% for Broca's aphasia and 52% for Amnestic aphasia. According to the speech therapist the patient was classified as conduction aphasic.

The time interval since the insult varied between 1 and 163 months around a mean of 30±39 months.

Thirty-two subjects were examined as control subjects (18 male, 14 female); 19 of them were healthy controls, 13 neurological patients without any indication of a language disorder (e.g. slipped discs). The mean age was 43±14 years, the mean level of education 11±2 years.

In all Ss handedness was evaluated by a modified version of the Edinburgh Handedness Questionnaire (Oldfield, 1971), asking for hand preferences prior to the insult. Twenty-two control Ss were right-handed, while the laterality index indicated left-handedness (-100) in one and ambidexterity (-64) in another control. One of the twenty-four aphasics reported to have been ambidexter before the insult. For him, the laterality index was –40.

Table 2: Clinical and demographical data of patients

								Spontaneous Speech						AAT Subtests				
Patient	**Sex**	**Age**	**Handedness**	**Years of Education**	**Months Since Lesion**	**Verbal Output**	**Type of Aphasia**	**Communicative Behaviour**	**Articulation and Prosody**	**Automatic Speech**	**Semantic Structure**	**Phonetic Structure**	**Syntactic Structure**	**Token Test**	**Repetition**	**Written Language**	**Naming**	**Comprehension**
1	M	46	R	13	11	non-fluent	Broca	3	2	5	4	3	4	5	119	75	115	111
2	M	52	R	13	62	non-fluent	Broca	1	4	4	3	4	1	30	134	60	64	100
3	W	56	R	9	21	non-fluent	Broca	2	3	5	3	4	2	35	111	75	82	92
4	W	39	R	9	99	non-fluent	Broca	3	4	5	3	4	2	12	133	61	98	99
5	M	68	R	9	15	non-fluent	Broca	1	3	5	3	1	2	20	86	65	101	94
6	W	42	R	9	34	non-fluent	Broca	2	3	2	3	3	1	10	107	56	90	86
7	M	57	R	13	47	non-fluent	Broca	3	4	5	3	4	2	13	140	52	95	115
8	W	58	R	9	54	non-fluent	Broca	2	3	5	3	4	2	17	118	67	105	84
9	W	52	R	9	18	non-fluent	Broca	4	5	4	4	4	2	20	142	62	109	115
10	W	51	R	9	7	non-fluent	Broca	3	5	3	4	2	2	17	116	71	104	90
11	W	22	R	13	3	non-fluent	Broca	2	2	5	3	4	1	30	145	70	45	71
12	W	34	R	9	35	fluent	Amnestic	4	4	5	5	4	4	9	115	79	110	118
13	M	51	R	13	20	fluent	Amnestic	3	5	5	4	4	4	17	124	86	97	102
14	M	48	R	13	20	fluent	Amnestic	3	5	5	3	4	3	8	130	90	103	113
15	M	62	R	10	74	fluent	Amnestic	3	4	5	4	3	4	20	133	48	98	106
16	W	58	R	9	163	fluent	Amnestic	4	4	5	4	4	4	14	120	88	96	96
17	M	46	L	9	9	fluent	Amnestic	4	4	5	4	4	4	8	140	83	114	94
18	W	47	R	9	3	fluent	Amnestic	4	5	5	4	5	4	12	146	89	92	84
19	M	69	R	13	2	fluent	Amnestic	4	4	5	3	4	4	14	134	74	104	108
20	M	58	R	9	2	fluent	Cond.	3	2	4	4	2	4	14	125	75	103	98
21	M	51	R	9	1	fluent	Wernicke	3	5	5	3	3	4	29	96	71	70	72
22	M	67	R	13	11	fluent	Wernicke	3	4	5	3	3	3	5	120	77	89	79
23	M	50	R	10	7	fluent	Wernicke	3	5	5	3	3	3	37	108	66	82	91
24	M	40	R	9	2	fluent	Wernicke	2	5	5	2	3	4	36	138	54	41	71

Maximal values of „spontaneous speech“ is 5, denoting „no dysfunction“. Maximal values of AAT subtests denoting „no dysfunction“: Repetition 150, Written language 90, Naming 120, Comprehension 120. Values of Token test denote number of errors made (max: 50).
Handedness: l left, r right

Results and Discussion

Table 3 summarises the percent of correctly classified subjects and error count estimates based on all tasks separately for the performance indices. Error count estimates indicate the estimated classification error with respect to number of subjects in each group that had to be classified.

Table 3: percent of correctly classified subjects and error count estimates

Classification	**Type of Performance**	**Error count estimates**	**correctly classified**	**correctly classified**
aphasics vs. controls	Latencies	8%	88% aphasics	94% controls
	% errors	16%	63% aphasics	100% controls
fluent vs. non-fluent	Latencies	58%	42% fluent	42% non-fluent
Aphasics	% errors	33%	75% fluent	59% non-fluent
healthy vs. neurological	Latencies	63%	47% healthy controls	23% neurological controls
Controls	% errors	63%	53% healthy controls	15% neurological controls

These results suggest several conclusions. The whole task series allows to distinguish aphasics and controls sufficiently well. Latencies allow a better distinction than percent errors. Control subjects are almost always classified correctly. The task series is less well able to distinguish between fluent and non-fluent aphasics. Percent errors allow better distinction than latencies and with these measures fluent aphasics are more reliably classified.
None of the performance indices enables the distinction of healthy and neurological controls. It can be concluded that the task series is suitable to distinguish aphasics from otherwise brain damaged or brain-healthy subjects.

It remains to be seen which tests of the battery are well able to separate these groups and which tests show lesser abilities. To answer this question F-values and determination coefficients (R^2) were calculated.

The following tables show F-values, R^2 and p- values for each task separately for latencies and percent errors sorted in descending order of F-values. They were obtained by the first step of a stepwise discriminant analysis which gives these values within one step. Separate ANOVAS for each task with the factor GROUP would have resulted in the same values.

Table 4 and 5: Aphasics vs. Controls: Latencies and Percent Errors

Table 4: Latencies (dF= 1,50)

Task	R^2	F	Prob >
Rhyming	0,60	80,00	0.0001
Gender Decision	0,46	46,05	0.0001
FCT: P-W	0,44	43,02	0.0001
FCT: W-P	0,39	34,06	0.0001
Semantic	0,30	23,45	0.0001
FCT: W-W	0,30	23,04	0.0001
FCT: P-P	0,30	22,90	0.0001
Word	0,30	22,80	0.0001

Table 5: % errors (dF= 1,50)

Task	R^2	F	Prob >
FCT: W-W	0,61	83,14	0.0001
FCT: W-P	0,52	59,04	0.0001
FCT: P-W	0,34	27,98	0.0001
Rhyming	0,30	22,68	0.0001
Gender Decision	0,24	17,52	0.0001
Word	0,23	16,15	0.0002
FCT: P-P	0,16	9,96	0.0026
Semantic	0,03	1,72	0.1959

Table 6 and 7: Non-fluent vs. Fluent Aphasics: Latencies and Percent Errors

Table 6: Latencies (dF= 1,31)

Task	R^2	F	Prob >
FCT: W-W	0,09	2,14	0.1575
FCT: W-P	0,08	2,03	0.1680
Gender Decision	0,08	2,03	0.1684
Word	0,04	0,82	0.3753
Semantic	0,03	0,73	0.4017
FCT: P-W	0,01	0,23	0.6356
FCT: P-P	0,01	0,19	0.6687
Rhyming	0,00	0,01	0.9136

Table 7: % errors (dF= 1,31)

Task	R^2	F	Prob >
FCT: W-W	0,33	10,61	0.0036
Gender Decision	0,03	0,58	0.4558
FCT: W-P	0,02	0,42	0.5218
Word	0,01	0,24	0.6286
Rhyming	0,00	0,08	0.7871
FCT: P-W	0,00	0,05	0.8245
Semantic	0,00	0,02	0.9003
FCT: P-P	0,00	0,00	1.000

Table 8 and 9: Healthy vs. Neurological Controls: Latencies and Percent Errors

Table 8: Latencies (dF= 1,22)

Task	R^2	F	Prob >
Semantic	0,25	9,95	0.0036
FCT: P-W	0,20	7,60	0.0098
FCT: P-P	0,20	7,49	0.0103
Word	0,18	6,77	0.0143
Rhyming	0,16	5,57	0.0249
FCT: W-W	0,14	4,73	0.0376
FCT: W-P	0,13	4,45	0.0433
Gender Decision	0,12	4,00	0.0545

Table 9: % errors (dF= 1,22)

Task	R^2	F	Prob >
Gender Decision	0,08	2,47	0.1263
Rhyming	0,07	2,41	0.1310
Semantic	0,07	2,23	0.1457
FCT: P-P	0,05	1,72	0.1997
FCT: W-P	0,04	1,26	0.2705
FCT: P-W	0,04	1,14	0.2940
Word	0,01	0,16	0.6912
FCT: W-W	0,00	0,12	0.7344

Apparently latencies and percent errors are differently able to distinguish groups. If this seems first surprising it should be remembered that latencies were analysed only for correct responses so that strategic influences can come into play, e.g. a subject can commit on a task many errors but answer fast on correct trials.

All tasks reach levels of significance to distinguish aphasics from controls with the highest determination coefficient reaching 60%. This can be interpreted as improving the predictive classification of 60% compared to a priori classification.

For latencies the Rhyming and Gender Decision reach highest F-values. For errors all FCT tasks that contain verbal stimuli are best able to separate aphasics from controls. This

corroborates the clinical findings that the Token Test is the best test to separate aphasics from controls, given only errors. In the Token Test latencies are not measured.
The tests being less able to separate aphasics from controls is the lexical-semantic task *Word Comprehension*, the control task *Semantic Classification* and the *Picture-Picture FC task* for latencies and errors. For latencies all tasks reach significant levels for separation of groups, what is not surprising, because aphasics suffer from a brain damage and generally slower reaction can be expected.

No test reaches significance except the FCT Word-Word task for errors in order to distinguish fluent and non-fluent aphasics. In this task non-fluent aphasics commit more errors than fluent aphasics. This is surprising, because Wernicke's aphasics commit more errors than Broca's aphasics in the Token Test (see Huber et al., 1983). It might be suggested that in the FCT version more emphasis is put on the productive nature of the task. This might also explain why the W-P task did not reach significance. In the W-W task non-fluent aphasics might try to verbalize the stimuli on upon presentation of S1 and S2 and therefore might fail on two occasions. Neurological controls responded in all tasks slower than healthy controls. This had to be expected because they are inpatients in a hospital. What discounts the tasks as being tasks for neurological patients in general is the fact that neurological controls did not commit more errors than healthy controls on any of the tasks.

One word of caution: The tables 4-9 might imply that the tests do not correlate. For example the question, if one has to perform all tasks to separate groups reliably from each other, cannot be answered with these tables. In order to do this, multivariate analysis are necessary. As questions of this kind were not central here, these analysis are only reported in Appendix C. There the complete results of the stepwise discriminant analyses are listed.

In sum, the tasks proved suitable for the present aim to compare aphasics and non-aphasics. Even though also neurological controls respond slower, they do not commit more errors than healthy controls. The tasks are not able to separate fluent from non-fluent aphasics, except for the Word-Word FC task. These results suggest that different impairments in aphasic groups lead to comparable impairments in task performance. It remains to be seen if differences between aphasics and controls and within the aphasic group can be found with ERPs. This will be the main topic of the next chapters.

2.4 Feature Comparison Tasks

2.4.1. Aim of the Experiments

The aim of these experiments was to compare event-related potentials (ERPs) of aphasic patients and normal controls in a number of tasks requiring similar cognitive skills as those assumed to be characteristic for the "Token Test", i.e. the analytical isolation, encoding and short term storage of individual features. In the present study, we realized this task, i.e., feature comparison by drawing on earlier research with the Token Test and as stimulated by Kurt Goldstein's notion of an abstract in contrast to a concrete attitude (see also 1.3.1). Different versions of a ”feature comparison task" (FCT) were designed that allowed the recording of event-related potentials (ERPs) during feature encoding, i.e. in response to either a verbal or a pictorial representation of a 'token' stimulus, and during preparation for feature comparison, i.e., prior to the verbal or pictorial representation of another 'token' to be compared with the first one with respect to size, form and color. A left-hemispheric predominance of activity was hypothesized during this task, and it was to be examined whether and to what an extent such a left-hemispheric predominance of cortical activation depends on the verbal or non-verbal representation of the "tokens" in the encoding and in preparing for the later comparison phase.

The scalp distribution of ERPs should add to performance measures in the investigation of dysfunction in aphasia. If it were the comprehension and cognitive handling of words in general which primarily creates difficulties for aphasics, one would expect considerably better performance, if both the first and the second representation of the stimuli to be compared were entirely pictorial. If it were primarily the verbal encoding, one would expect the poorest performance, when the first stimulus is presented as a picture and the second stimulus as a noun phrase verbally defining the object features. If both stimuli are represented as noun phrases, it would allow a pictorial comparison of the graphemic patterns of these lists, so that these conditions would not necessarily impose the highest linguistic demands. Accordingly, the poorest performance was expected for those conditions, in which one of the stimuli to be compared was described verbally, while the other was presented in the pictorial mode. These versions of the task require a shift across modalities by means of verbal encoding, regardless of whether the first or the second stimulus is presented as a picture.
As stated above, earlier studies had shown that the Token Test has similar discriminative power whether the instructions are given verbally or whether neither verbal production nor comprehension is required of the patient. Therefore, the possibility was considered that the

entirely pictorial version of the task would also lead to impaired performance of the aphasics – compared to other groups – and to a similar pattern in the event-related potentials. If this were the case, it might reflect the loss of "abstract attitude" which Kurt Goldstein considered characteristic for brain-damaged subjects in general. But this is not the only possibility: at least after extensive speech therapy, aphasic patients tested in their rehabilitation setting might be prone to work for verbal encoding and processing even if the task could be handled easier and more successfully without inner verbalization simply by comparing the pictorial representations. If this were the case one would expect less lateralisation in controls than in aphasics when both the first and the second stimulus to be compared were presented in the pictorial mode.

2.4.2 Methods

Subjects

Thirty aphasic patients were able to complete at least one of the FCT tasks (see Table 10 for individual characteristics; 19 male, 11 female, mean age 50± 12 years, mean level of education 11±2 years). All patients were able to complete at least one of the four versions of the test and responded correctly in this version significantly above chance.

Twenty-eight of the 30 patients suffered from a left hemispheric cerebrovascular insult, most of them from an infarct of the arteria cerebri media. In addition, one patient suffered from aphasia following a cerebral trauma including subdural bleeding in the temporal-parietal area and compression of the left lateral ventricle; another patient had suffered from a left-temporal skull fracture. Diagnoses of aphasia were determined by the Aachener Aphasie Test (AAT; Huber et al., 1983). The AAT diagnoses were compared with the diagnosis given by the speech therapist and the neurologist in charge. According to the AAT classification guidelines, the diagnosis of aphasia syndromes was given with a probability >75% in patients in accordance with the diagnoses of the speech therapist and the neurologist. Eleven patients were classified as Broca's-, eight as Wernicke's-, nine as Amnestic aphasics, one as conduction and one as global aphasic. In the two patients without cerebrovascular insult (see above) the probability was below 75%.

One patient was diagnosed as Wernicke's aphasia with 53% and amnestic aphasia with 47%, According to the diagnosis as Wernicke's aphasia given by the speech therapist this patient was assigned to the group of Wernicke's aphasics in the present study. In the other patient syndrome classification was 40% Wernicke's and 60% amnestic aphasia in the other. The speech therapist classified this patient as amnestic.

One patient was classified with 48% as Broca and 52% as Amnestic aphasic. According to the speech therapist he was diagnosed as Conduction aphasic.

The time interval since the insult varied between 1 and 99 months around a mean of 23±25 months.

Twenty-six subjects were examined as control subjects (13 male, 13 female); 15 of them were healthy controls, 11 neurological patients with without any indication of a language disorder (e.g. slipped discs). The mean age was 43±11 years, the mean level of education 11±2 years.

In all Ss handedness was evaluated by a modified version of the Edinburgh Handedness Questionnaire (Oldfield, 1971), asking for hand preferences prior to the insult. Twenty-four control Ss were right-handed, while the laterality index indicated left-handedness (-100) in one and ambidexterity (-64) in another control. Two of the 30 aphasics reported to have been left-handed before the insult. For them, the laterality index was –40 and –80, respectively.

Table 10: Clinical and demographical data of patients

								Spontaneous Speech						AAT Subtests					Tasks			
Patient	**Sex**	**Age**	**Handedness**	**Years of Education**	**Months Since Lesion**	**Verbal Output**	**Type of Aphasia**	**Communicative Behaviour**	**Articulation and Prosody**	**Automatic Speech**	**Semantic Structure**	**Phonetic Structure**	**Syntactic Structure**	**Token Test**	**Repetition**	**Written Language**	**Naming**	**Comprehension**	**Picture-Picture**	**Picture-Word**	**Word-Word**	**Word-Picture**
1	M	59	R	9	3	fluent	Amnestic	3	4	5	4	3	4	9	147	72	98	103	+	+	0	0
2	W	47	R	9	3	fluent	Amnestic	4	5	5	4	5	4	12	146	89	92	84	+	-	+	-
3	M	46	L	9	9	fluent	Amnestic	4	4	5	4	4	4	8	140	83	114	94	+	+	+	+
4	M	51	R	13	20	fluent	Amnestic	3	5	5	4	4	4	17	124	86	97	102	+	+	-	+
5	M	48	R	13	20	fluent	Amnestic	3	5	5	3	4	3	8	130	90	103	113	+	+	+	+
6	W	34	R	9	35	fluent	Amnestic	4	4	5	5	4	4	9	115	79	110	118	+	+	+	-
7	M	36	R	9	51	fluent	Amnestic	4	4	5	5	5	5	16	145	70	108	89	+	+	0	-
8	M	62	R	10	74	fluent	Amnestic	3	4	5	4	3	4	20	133	48	98	106	+	-	-	-
9	M	69	R	13	2	fluent	Amnestic	4	4	5	3	4	4	14	134	74	104	108	+	+	-	-
10	M	58	R	9	2	fluent	Cond.	3	2	4	4	2	4	14	125	75	103	98	+	-	-	+
11	W	68	R	9	1	fluent	Wernicke	2	5	5	3	4	3	18	140	81	54	78	0	+	0	-
12	M	50	R	13	1	fluent	Wernicke	3	5	5	3	4	3	5	146	70	62	90	+	+	0	-
13	M	51	R	9	1	fluent	Wernicke	3	5	5	3	3	4	29	96	71	70	72	+	+	-	+
14	M	40	R	9	2	fluent	Wernicke	2	5	5	2	3	4	36	138	54	41	71	+	-	+	-
15	W	40	R	13	3	fluent	Wernicke	3	5	5	3	2	3	22	82	59	66	116	+	+	0	0
16	M	50	R	10	7	fluent	Wernicke	3	5	5	3	3	3	37	108	66	82	91	-	-	+	-
17	M	67	R	13	11	fluent	Wernicke	3	4	5	3	3	3	5	120	77	89	79	+	+	+	+
18	M	34	R	13	25	fluent	Wernicke	2	5	4	4	4	4	30	136	85	83	98	+	+	+	-
19	W	22	R	13	3	n.-fluent	Broca	2	2	5	3	4	1	30	145	70	45	71	+	+	+	+
20	W	51	R	9	7	n.-fluent	Broca	3	5	3	4	2	2	17	116	71	104	90	+	+	+	+
21	M	46	R	13	11	n.-fluent	Broca	3	2	5	4	3	4	5	119	75	115	111	+	+	+	+
22	M	68	R	9	15	n.-fluent	Broca	1	3	5	3	1	2	20	86	65	101	94	-	+	+	-
23	W	52	R	9	18	n.-fluent	Broca	4	5	4	4	4	2	20	142	62	109	115	+	+	-	+
24	W	42	R	9	34	n.-fluent	Broca	2	3	2	3	3	1	10	107	56	90	86	+	+	+	+
25	W	35	L	9	45	n.-fluent	Broca	2	4	4	3	4	1	34	127	29	93	95	+	+	-	-
26	M	57	R	13	47	n.-fluent	Broca	3	4	5	3	4	2	13	140	52	95	115	+	+	+	+
27	W	58	R	9	54	n.-fluent	Broca	2	3	5	3	4	2	17	118	67	105	84	+	+	+	+
28	M	52	R	13	62	n.-fluent	Broca	1	4	4	3	4	1	30	134	60	64	100	+	+	+	+
29	W	39	R	9	99	n.-fluent	Broca	3	4	5	3	4	2	12	133	61	98	99	+	+	+	+
30	M	59	R	10	13	n.-fluent	Global	1	5	5	3	3	1	41	81	16	36	78	+	+	+	+

Maximal values of „spontaneous speech“ is 5, denoting „no dysfunction“. Maximal values of AAT subtests denoting „no dysfunction“: Repetition 150, Written language 90, Naming 120, Comprehension 120. Values of Token test denote number of errors made (max: 50).
Handedness: l left, r right
+ :test is included in analysis
-: test could not be evaluated due to artefacts and/or number of errors made
0: test was not performed

Stimulus Materials and Design

The four versions of the Feature Comparison task (FCT) were presented as two-stimulus reaction time tasks, in which a first stimulus (S1) signals the presentation of a second stimulus (S2) after a 2-sec interval.

The *Word-Picture Task* closely resembled the ”Token Test”: a noun phrase was presented as S1 for 1.5 sec in that vertically aligned words described the stimulus on the three dimensions color (blue or yellow), form (star or circle), and size (large or small; e.g. ”The little yellow star”). The S2 following after an interstimulus interval of 2 sec comprised pictures of two such stimuli, one of which perfectly corresponding to the stimulus described in the S1 and differing from the other stimulus in only one of the three dimensions. Subjects were asked to indicate, by pressing the right or the left of two buttons with their left hand, whether the left or the right picture in the S2 exactly matched the description provided in the S1. The button press terminated the stimulus presentation. The subsequent trial started after 3 sec.

The verbal and pictorial representations in S1 and S2 were systematically combined in the other three versions of the task. In the *Picture-Word Task* the pictorial representation of the S1 (e.g., a small yellow star, S1) was followed by two words describing the two variations of one of the three dimensions (size, color, form; e.g. “blue” – “yellow”). The subject had to decide by pressing the right or the left button with their left hand, whether the left or the right word matched the S1. In the *Picture-Picture Task*, the pictorial representation of the S1 was followed by the pictorial representation of two such stimuli, differing in only one of the three dimensions (color, size, or form), while in the *Word-Word Task* the verbal description of the stimulus was followed again by two words describing one of the alternatives of one of the three dimensions.

Each of the four tasks comprised 48 items. A left-hand response was chosen considering the high probability of right-sided paralysis in the aphasic patients.

The order of the four versions of the task was counterbalanced across subjects during data acquisition. There were no drastic deviancies in the distribution of sequential order among the final groups of subjects accepted for statistical analyses.

Each task version was preceded by practice trials in order to familiarize the subjects with the stimulus material and the demands in a given task and to ensure that the subject had understood the instruction. In every patients it was ascertained that he/she did not have any difficulties matching the critical words (blue-yellow, large-small, circle-star) to the pictorial representations of these features in the stimuli to come. If the patient indicated that he had problems reading the verbal descriptions of the stimuli within 1.5 s the presentation time was prolonged to 2.0 s in the subsequent experimental tasks.

Procedure, Setting, Data acquisition and ERP analysis

Procedure, Setting, data acquisition and ERP analysis was performed as outlined in chapters 2.2.2-2.2.4.

Only artefact-free trials and trials with correct responses (Picture-Picture: Controls 70%; Aphasics 67%; Picture-Word: Controls 66%; Aphasics 65%; Word-Word: Controls 73%; Aphasics 65%; Word-Picture: Controls 71%; Aphasics 63%) went into the ERP analysis.

2.4.3 Results

Performance

Across tasks, aphasics made more errors (GROUP, F(1,50) = 93.6, p< .01) and were slower to respond (GROUP, F(1,50)= 46.8, p< .01) than controls. For errors, the differences between groups vary from F(1,50) = 5.5 in the Picture-Picture to F(1,41) = 70.7 in the Word-Word task. For reaction times, the differences between groups vary from F(1.50) = 15.6 in the Picture-Picture to F(1,49) = 49.5 in the Picture-Word task. The mean values and the F-values for GROUP effects for each of the four tasks are summarized in Table 11. In all groups the correct responses were faster in the Picture-Picture than in the other tasks (TASK, F(3,150)= 37.7, e= .7, p< .01). In this task, Ss also made less errors than in the other tasks (F(3,150)= 30.5, e= .9, p< .01).

Table 11:

Percentage of errors (% errors) and response latency (group mean ± SD of the individual medians in seconds) for correct responses in the three groups for FC tasks

Tasks	**DF**	**F**	**Prob > F**	**Aphasics:**	**Controls:**
			Latency		
Picture-Picture	1,50	15.6	p<.01	0.8±0.3	0.6±0.2
Picture-Word	1,49	49.5	p<.01	1.9±0.6	1.0±0.3
Word-Word	1,42	25.5	p<.01	1.7±0.6	1.0±0.3
Word-Picture	1,39	18.0	p<.01	1.6±1.1	0.7±0.3
			% Errors		
Picture-Picture	1,50	5.5	p<.05	6.0±11	0.8±1.6
Picture-Word	1,49	22.8	p<.01	8.8±5.9	2.7±2.5
Word-Word	1,42	71.0	p<.01	20.1±10.0	2.4±2.7
Word-Picture	1,39	38.5	p<.01	15.2±10.3	2.0±2.4

Post hoc tests determined the interactions GROUP x TASK for reaction time ($F(3.150)= 8.4$, $e= .7$, $p< .01$) and for errors ($F(3,150)= 25.4$, $e= .9$, $p< .01$) to be due to shorter reaction times and less errors of the aphasics in the Picture-Picture than in the Word-Word and Word-Picture tasks.

Mean reaction times did not differ significantly between fluent ($7 \leq N \leq 16$) and non-fluent ($10<N<13$) aphasics in any of the tasks (Picture-Picture: $F(1,25)= 0.7$; $p>.1$; Picture-Word: $F(1,23)= 0.5$; $p>.1$; Word-Word: $F(1,16)= 4.3$; $p<.1$; Word-Picture: $F(1,14)= 2.3$; $p>.1$). Non-fluent aphasics, however, made significantly more errors than fluent aphasics in the Word-Word task (SYNDROME: $F(1,16)= 10.3$; $p<.01$) as they had also shown a tendency to respond slower in this task (see above). In no other task did errors differ significantly between fluent and non-fluent aphasics (Picture-Picture: $F(1,25)= 0.5$; $p>.1$; Picture-Word: $F(1,23) = 0.04$; $p>.1$; Word-Picture: $F(1,14)= 0.7$; $p>.1$).

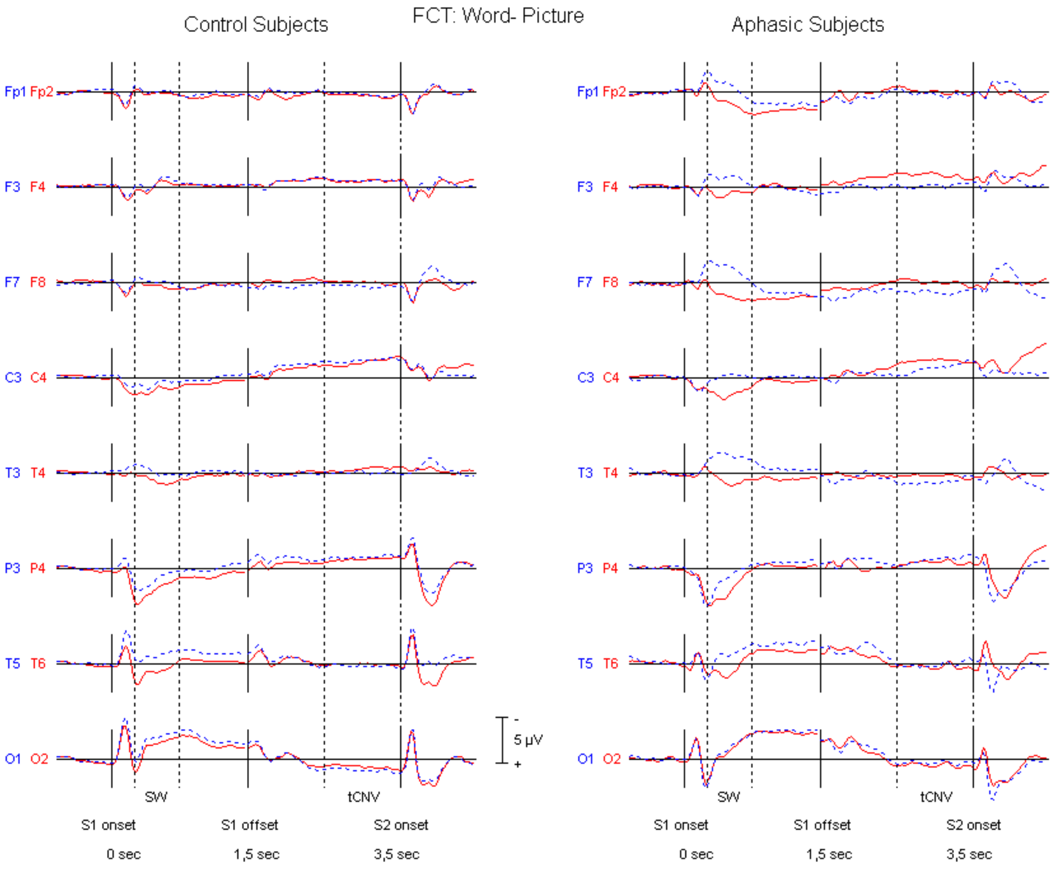
For the patient group the number of errors in the Word-Word Task correlated with the Token Test of the AAT ($r = -.51$, $p< .05$), with the subtest “written language” ($r = -.57$, $p< .05$) and with the syntactic complexity of spontaneous speech ($r = -.67$, $p< .01$). No significant correlation with AAT subtests and the Word-Picture Task (which were designed in close resemblance to the Token Test of the AAT) or the Picture-Word Task were found. Reaction time in the Picture-Picture Task correlated with the “Naming” subtest of the AAT ($r = -.44$, $p< .05$).

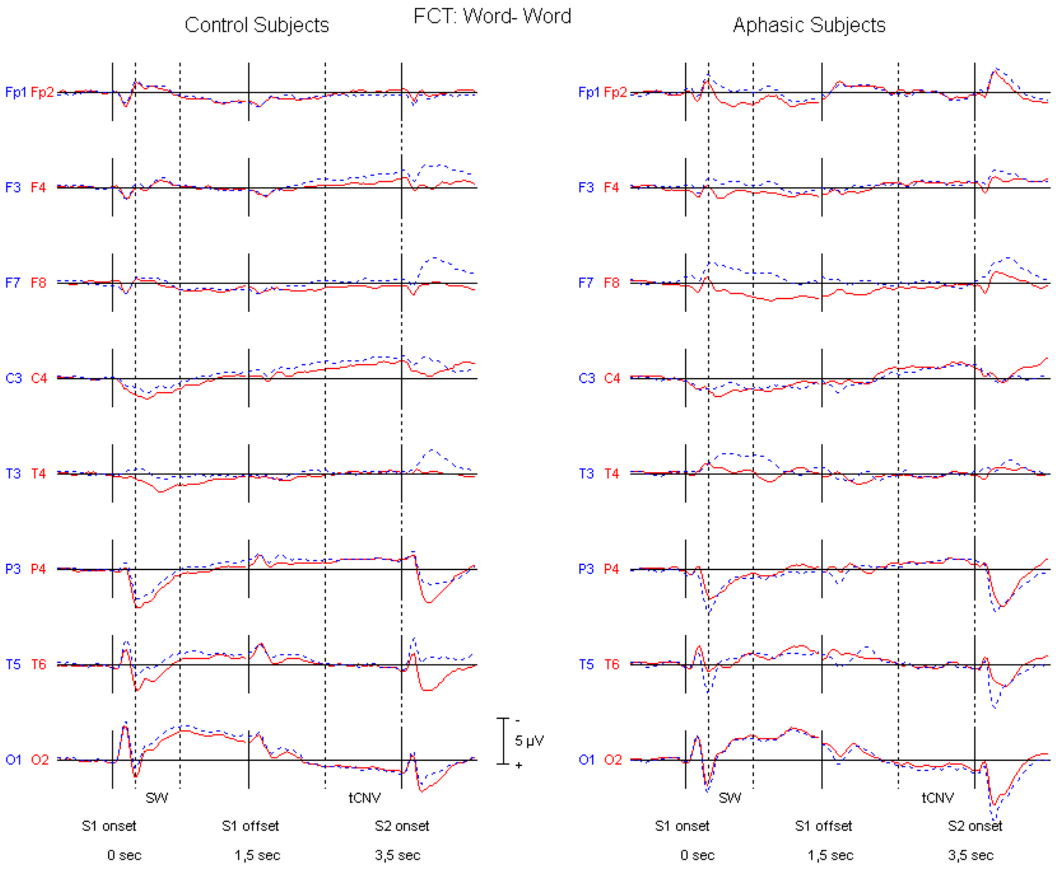
Event-related potentials

Figure 10-13 show the ERP-waveforms as evoked by the S1-S2-sequence in the FC tasks, averaged across subjects from the control group (left) and the group of aphasics (right). Differences between left- and right-hemispheric recording sites were most conspicuous 250 to 750 ms following S1-onset and – somewhat less pronounced – prior to S2-onset. Accordingly, group- and task-specific scalp distributions were analyzed for these two time segments (250-750 ms post-S1-onset, labeled Slow Wave, SW, and 1000 – 0 ms pre-S2-onset, labeled terminal CNV, tCNV).

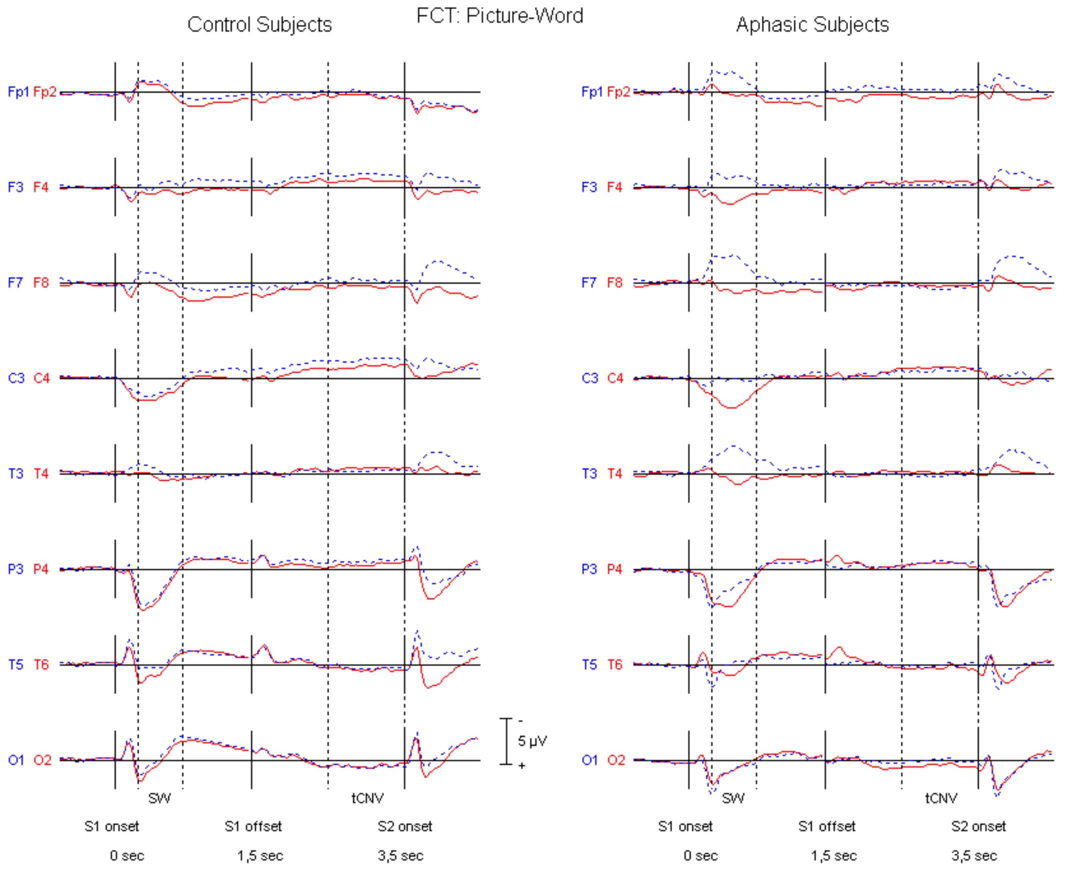
Slow Wave: Figure14 illustrates the scalp distribution of the SW for the four feature comparison tasks in grand means of controls, non-fluent and fluent aphasics. In all groups and all tasks, the SW is characterized by anterior negativity with left-hemispheric focus and centro-parietal positivity with a slight predominance of the right-hemisphere. This pattern is confirmed by a main effect HEMISPHERE in the overall ANOVA comparing the four tasks (F(1,33)= 57.0, p< .001), as well as in separate ANOVAs completed for each task (Picture-Picture: F(1,50) = 19.4; p<.01; Picture-Word: F(1,49) = 37.2; p<.01; Word-Word: F(1,42) = 23.8; p<.01; Word-Picture: F(1,39)= 47.4; p<.01).

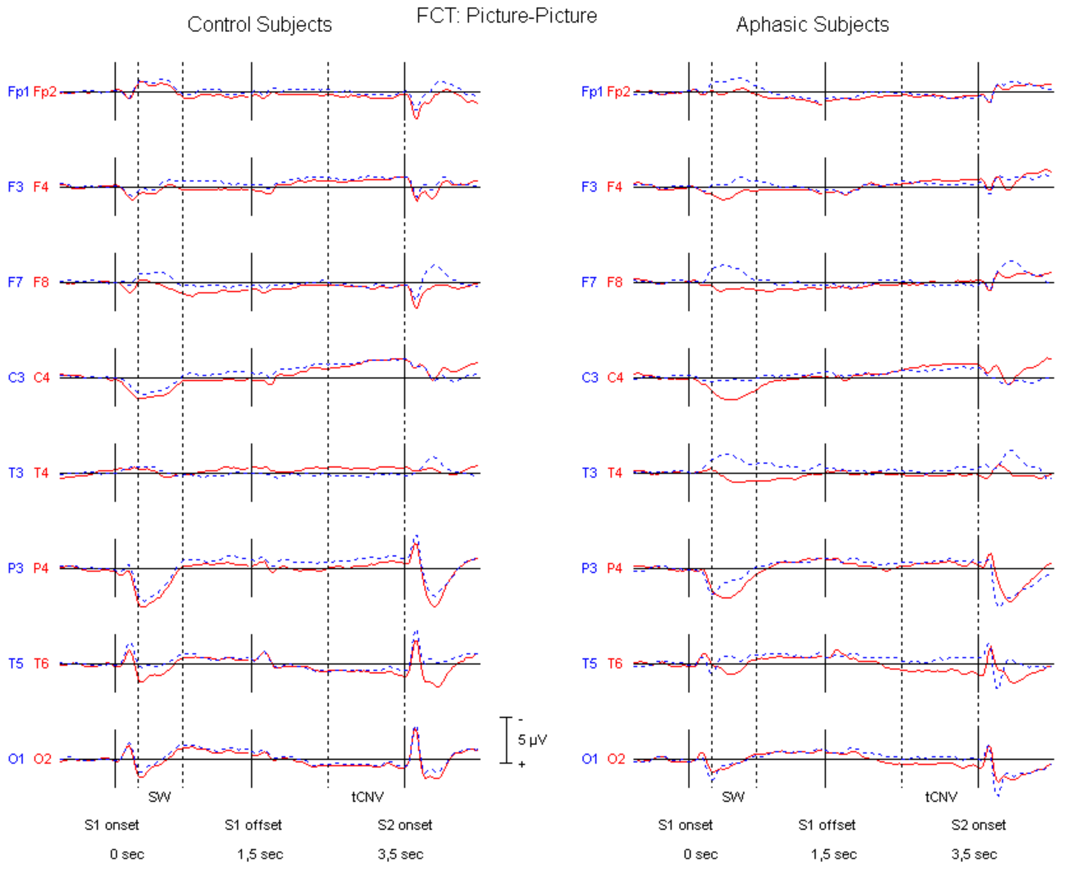
Figures 10 and 11: group averages of the ERP for selected electrode sites (average reference)





Figures 12 and 13: group averages of the ERP for selected electrode sites (average reference)


FCT: Picture-Word


FCT: Picture-Picture

The left-hemispheric negative SW was more pronounced in aphasics than in controls, as indicated by the interaction GROUP x HEMISPHERE in the overall ANOVA (F(1,33)= 5.5; p<.05; post hoc analyses determined the effect HEMISPHERE to be significant for aphasics (F(1,11)= 22.7; p<.01), and for controls (F(1,22)= 29.2; p<.01). Furthermore, the interaction GROUP x HEMISPHERE x GRADIENT (F(1,33)=12.1; p<.01) verified that the more pronounced lateralisation of the negative SW in aphasics was confined to anterior regions. This pattern of more prominent left-anterior negativity in aphasics than in controls was particularly obvious for the two tasks with pictorial S1, the Picture-Word Task (GROUP x HEMISPHERE x GRADIENT (F(1,49) = 10.7; p < .01) and – as a trend – the Picture-Picture Task (GROUP x HEMISPHERE x GRADIENT, F(1,50)= 2.8; p<.1). In contrast, for the two tasks with verbal S1, interactions GROUP x HEMISPHERE x GRADIENT were explained by more pronounced left-hemispheric accentuation of the negative SW in controls over posterior areas (for the Word-Word Task F(1,42)= 7.9, p< .01; for the post hoc analysis of the interaction HEMISPHERE x GRADIENT in the control group, F(1,24)= 10.0, p< .01; for the Word-Picture Task, the respective F-values for the triple-interaction was F(1,39)= 8.3, p< .01, and for the post-hoc interaction within the control group F(1,24)= 5.7, p< .05).

Although this pattern of results suggests group- and task-specific effects, and, in particular, a group-specific SW distribution in tasks with pictorial in contrast to tasks with verbal S1, neither the interaction with the factor TASK in the overall ANOVA reached significance nor the interaction in an ANOVA comparing the two tasks with verbal and the two tasks with pictorial S1 with the within-subjects factor “S1-MODALITY”. This may be due to the powerful and determining left-hemispheric predominance of the SW (effect HEMISPHERE), that prevailed over the task-and group-specific patterns, and / or to the smaller number of data sets of Ss (in particular patients) that accomplished all four tasks and entered the overall ANOVA. Nevertheless, a lack of statistical significance should not invalidate the task- and group-specific effects implied in Figure 2 and the separate analyses of tasks.

Non-fluent aphasics displayed a more conspicuous topography of the SW than fluent aphasics in the Picture-Picture task (SYNDROME, F(1,25)= 5.0, p< .05), with a more pronounced left-anterior negativity and right-posterior positivity (SYNDROME x HEMISPHERE, F(1,25)= 4.7, p< .05). In other tasks, the SW pattern did not differ between the aphasic syndromes.

Figure 14: Potential maps for slow wave for grand means of controls, non-fluent and fluent aphasics (average reference; blue denoting negativity; 0.5µV per contour line)

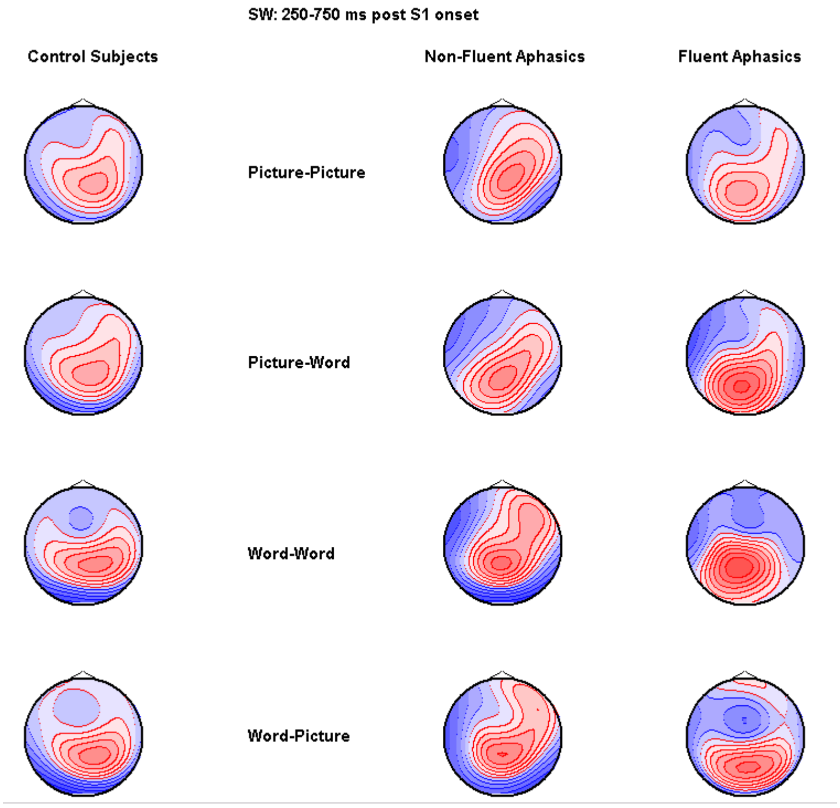
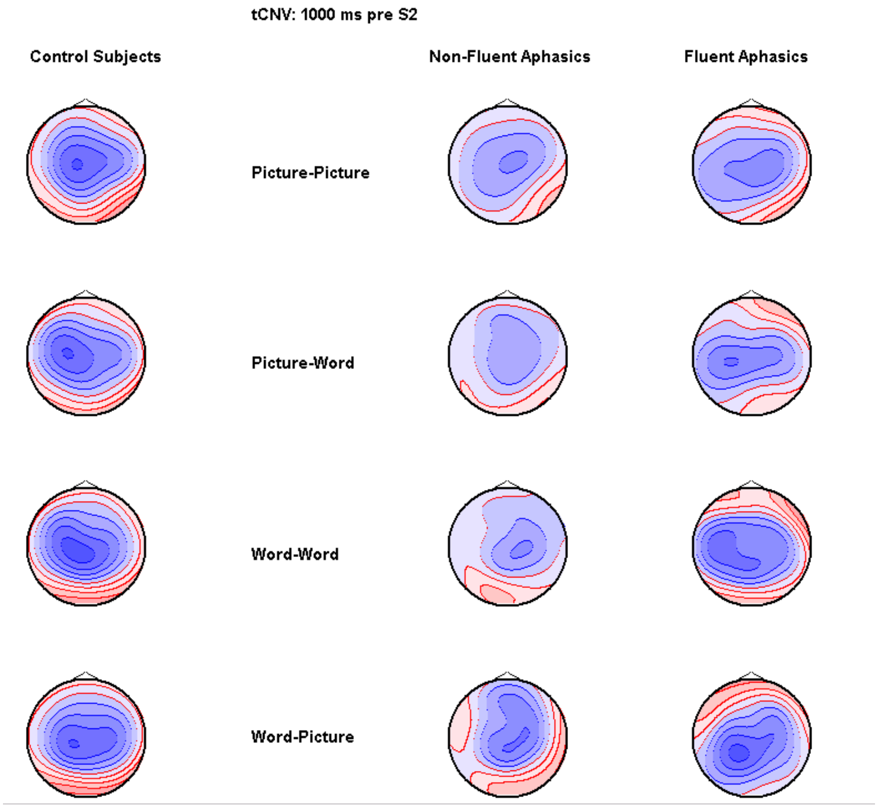


Figure 15: Potential maps for tCNV for grand means of controls, non-fluent and fluent aphasics (average reference; blue denoting negativity; 0.5µV per contour line)



The distribution of event-related activity was also analyzed for the *source space* with minimum norm values.

Interestingly, a significant main effect GRADIENT (F(1,33)=31; p<.01) indicated the focus of activity of the Slow Wave over posterior areas in all tasks and both groups (see Appendix E). When tasks were analyzed in separate ANOVAs, a predominance of the posterior focus was stronger over the right than the left hemisphere in the two tasks with verbal S1 and a reversed pattern over anterior areas (HEMISPHERE x GRADIENT for Word-Word, F(1,42)= 4.3, p< .05; for Word-Picture, F(1,39)= 4.8, p< .05).

However, as mentioned for the analyses of scalp distribution, this task-specific pattern of activity was not confirmed in the overall ANOVA by a main effect or interactions with the factor TASK.

Within the source space no differences were found between fluent and non-fluent aphasics.

Terminal CNV: Figure 15 illustrates the scalp distribution of the tCNV for the four tasks in controls (left), fluent and non-fluent aphasics (right). The terminal CNV in anticipation of an imperative, task-related stimulus is usually most pronounced over central areas (Rockstroh et al., 1989; Birbaumer et al., 1981). This is also true for the tCNV displayed in Figure 15 for all tasks and all groups. In addition, Figure 3 shows the focus of the tCNV in controls to be slightly shifted toward the left hemisphere, but more toward right hemisphere areas in non-fluent aphasics. The ANOVA on all four tasks supported this group-specific pattern by the interaction GROUP x HEMISPHERE x GRADIENT (F(1,33)=9.9; p<.01). Post hoc analyses confirmed the more pronounced left-anterior tCNV in controls compared to aphasics across tasks to be significant (t(33,0)= 2.3, p< .05).

Separate ANOVAs for the different tasks point to task- and group-specific distributions of the tCNV (see also Figure 15). In the two tasks with pictorial S2, aphasics display a right-anterior tCNV (i.e., negativity), while controls show a left anterior tCNV (both groups show positive amplitudes of the tCNV over posterior areas). This group-specific pattern is confirmed by the interaction GROUP x HEMISPHERE x GRADIENT in the Word-Picture Task (F(1,39)= 11.4, p< .01) and for the Picture-Picture Task (F(1,50)= 5.8, p< .05). In both tasks, the post hoc analyses confirmed significance of the anterior asymmetry only in the aphasic group (in the Word-Picture Task: HEMISPHERE x GRADIENT for the aphasics F(1,15)= 9.3, p< .01; in the Picture-Picture Task, the right-anterior negativity and right-posterior positivity resulted in the interaction HEMISPHERE x GRADIENT, F(1,26)= 7.5, p< .01 for aphasics).

Tasks with verbal S2, on the other hand, resulted in small tCNV amplitudes and rather shallow distributions in aphasics, while a left-anterior negativity (tCNV) and posterior positivity still prevailed in controls. This pattern give rise to the interaction– as a trend – GROUP x HEMISPHERE x GRADIENT in the Picture-Word task (F(1,49)= 3.8, p= .06; for the post hoc comparison of asymmetry within the control group, HEMISPHERE x GRADIENT, F(1,25)= 5.8, p< .05).

This task- and group-specific tCNV distribution was not confirmed by an interaction with TASK, S2-MODALITY and GROUP in the overall ANOVA. As suggested for the Slow Wave, this may be due to the smaller number of data sets available for this ANOVA (that required all four tasks to be completed). Furthermore, a strong influence of the broad tCNV distribution with central maximum, which is typical for a tCNV, may have outweighed the contribution of task-specific effects (correlates of cognitive processes) during this interval. Therefore – and the more so – the additional task- and group-specific contributions that still became obvious for the tCNV, merit particular attention.

In general, fluent aphasics display more left-hemispheric, non-fluent more right-hemispheric accentuation of the tCNV maximum. Significant differences in the asymmetry of the tCNV between syndromes were only found in the Word-Word task, in which fluent aphasics displayed a more left-lateral tCNV than non-fluent aphasics (SYNDROME x HEMISPHERE, F(1,17)=4.9; p<.05).

When analyzing the distribution of the tCNV activity in the *source space* by Minimum Norm estimation, a focus of activity was confirmed for the left hemisphere (HEMISPHERE, F(1,33)= 7.0; p<.01). No differences were found between fluent and non-fluent aphasics.

Based on minimum norm values a laterality index was calculated for the SW and the tCNV and correlated with clinical variables such as time since lesion as well as number of errors. There were no significant results pointing towards a change of lateral activity over time or pointing towards a relationship of lateralized activity with performance (for minimum norm maps see Appendix E).

2.4.4 Discussion

All tasks of this study proved to be sensitive to aphasic dysfunctions even if the task did not require the processing of verbal stimuli: aphasic patients made more errors and were slower to respond in all four versions of the task. Differences between tasks were found upon presentation of verbal stimuli where aphasics displayed more impairments. This had been expected from studies with the Token Test (de Renzi & Vignolo, 1962; Huber et al, 1983), as well as non-verbal experimental variants of the test (Cohen et al., 1983).

The task that correlated best with subtests from the AAT was the Word-Word task. It correlated significantly with the Token Test and the subtest ‘Written Language’ as well as ‘Syntactic Complexity of Spontaneous Speech’. This had to be expected because in this task all functions related to processing of verbal material were activated. Unexpectedly, performance in the task that was meant to be most similar to the Token Test, the Word-Picture task, did not show significant correlations with the AAT.

The primary aim of the study was to examine whether and to what extent aphasic patients - who were successful in handling the tasks above chance level - differed from controls in the pattern of cortical activation as indicated by ERPs. Therefore, ERPs were not compared between subjects who succeed or fail in handling the task but between language unimpaired subjects who usually do not have any difficulties with the task and aphasic patients who despite a clearly defined left-hemisphere dysfunction handle these tasks well enough to perform clearly above chance level. This comparison should uncover compensation, restitution or substitution.

As reviewed in chapter 1.2.3, from studies about brain activity in aphasics one could expect that aphasics should show more right hemispheric activity than controls (e.g. Weiller et al., 1995). This could favor an explanation in terms of substitution or “take-over” of function. On the other hand a number of studies showed that aphasics display in the course of their rehabilitation left hemispheric activity similar to controls. This would favor an explanation pointing towards restitution or “regression of diaschisis” (e.g. Heiss et al., 1997; see also chapter 1.2.3). In the present study the negative SW over left hemispheric areas was prominent in all subjects and even more so in aphasic subjects. Consequently, the left hemispheric negativity in all tasks is assumed to reflect what all tasks have in common, namely ‘the analytical isolation and cognitive handling of individual features of concepts’. In aphasics the left hemispheric negativity was even more prominent pointing toward greater effort in fulfilling the demands of the tasks. In a review about the functional categorization of slow waves Ruchkin and co-workers (1988) argued that the amplitude of this component increases with higher tasks demands. This has been replicated in a more recent study (Ruchkin et al., 1997).

Even though this activity pattern was common in both groups, there were also differences between groups across all tasks: it turned out that aphasics show stronger negativity over particularly left anterior regions that is not seen in controls. It seems not plausible that this reflects restitutional processes, because this activity pattern is different from controls**.** It seems more plausible to assume that this activity is related to compensational processes. Ruchkin and co-workers have found in three studies (1992, 1994, 1997), that the slow wave activity was largest over the left anterior scalp when phonological information had to be kept in working memory. This might indicate that aphasics tried to verbalize the stimuli in all tasks, even when not necessarily required.

While the analysis across tasks did not show any task specific results, they were found when tasks were analysed separately (as a consequence substantially more subjects went into the analysis of each task). A pronounced left-hemispheric negative Slow Wave with focus over posterior areas (Wernicke's area) was exhibited by controls in those tasks, in which words comprised the object features to be encoded. If we consider this pattern to indicate that left-temporo-parietal (Wernicke's) activity represents the cortical correlate of phonological encoding (see Levelt, 1998 and above 1.4.2), the lack of this left temporo-parietal focus in aphasics might point to a dysfunction of phonological processes in particular, when reading of words was required for (and involved in) feature encoding. The assumption of impaired verbal feature encoding is supported by the poorer performance of aphasics in these tasks (see Table 11: W-W and W-P, compared to P-P and P-W).
On the other hand, aphasics displayed more pronounced anterior nSW asymmetry than controls in those FC tasks, in which the to-be-encoded object features were presented in the object picture (Picture-Picture and Picture-Word tasks). This is intriguing, since the FCT was supposed to activate frontal (anterior) and left-hemispheric cortical areas, thus of areas assumed to be dysfunctional following the lesion.

The tCNV was examined as a measure of preparation for feature comparison. More anterior left-hemispheric activity during this interval in controls across all tasks suggests that preparation comprised more than motor preparation which would have produced a left central focus. It has been demonstrated that the anticipatory ERP between the warning and imperative stimulus is influenced by working memory and preparatory processes (Ruchkin et al., 1995). The deviance of the tCNV pattern in aphasics are provocative, since the tCNV distribution depended on the type of the S2. Preceding a pictorial stimulus the tCNV was prevailing over right anterior areas in aphasics and left anterior areas in controls. If the S2 consisted of verbal material, the statistical analysis gave less clear-cut results. In aphasics the distribution of the tCNV was very shallow and broadly distributed. In controls inspection of the ERPs suggested again a left anterior tCNV, which was more prominent if the verbal S2 was preceded by a pictorial S1.

We may assume that working memory and retrieval strategies are activated during the tCNV. The left-hemispheric tCNV predominance of controls might indicate this activation. Imaging studies found left-frontal activity particularly when reflective or strategic demands of the (working memory) task increased (Nolde, Johnson, and Raye,1998), or information was maintained over time in the working memory (Cohen, Perlstein et al., 1996), while monitoring or less demanding working memory tasks elicited right-frontal activation. It might be suggested that the shallow tCNV in aphasics in preparation for a verbal stimulus reflects dysfunctional working memory processes for verbal material. However, if the forthcoming stimulus is of pictorial nature aphasics display a right anterior tCNV. This might indicate an activation of spatial working memory (Jonides et al., 1993).

Hardly any differences in brain activity patterns were found between fluent and non-fluent aphasics. Only in the negative SW of the Picture-Picture task non-fluent aphasics displayed stronger left hemispheric activity than fluent aphasics. During the tCNV interval of the W-W task fluent aphasics displayed stronger negativity over left hemispheric areas than non-fluent aphasics. Regarding the larger number of errors of non-fluent aphasics in this task, this may provide further evidence for tCNV reflecting task specific preparatory processes.

The lack of differences between fluent and non-fluent aphasics is in line with the lack of distinction of the Token Test between syndromes. The score a patient receives does not reflect the aphasic syndrome, but the severity of the aphasic disorder. Wernicke aphasics make on the average more errors than Broca and Amnestic aphasics, but from the performance of the Token Test alone one cannot conclude what type of aphasia the patient has (Huber, 1983; p. 130).

The analysis of the source space revealed for the SW mainly posterior activity. Following a verbal S1 stronger left than right activation over anterior areas and a reversed pattern for posterior areas was found. During the tCNV interval activity was stronger over the left hemisphere for aphasics and controls. This corroborates findings from the analysis of ERP amplitudes.

The source reconstruction analysis provides additional interesting information. Obviously activity sources in the present tasks are located in posterior areas, not necessarily in those regions which suggest areas of activity according to potential maps (i.e. anterior). It may be that a) posterior sources project to anterior surface electrodes or b) that anterior activity as described varying with task demands and stimulus modality is less pronounced than posterior activity in distributed association networks. These results suggest for future studies to examine activity sources more closely either by MEG or with dipole localization (Scherg, 1990).

In overall analyses no main effects or interactions with the factor TASK were found. This may be due to the powerful and determining left-hemispheric predominance of the SW, that prevailed over the task-and group-specific patterns, and / or to the smaller number of data sets of Ss (in particular patients) that accomplished all four tasks and entered the overall ANOVA.

Nevertheless, a lack of statistical significance should not invalidate the task- and group-specific effects implied in Figure 2 and the separate analyses of tasks.

In sum, the results suggest that aphasics show impaired performance in tasks emphasizing analytical isolation of features even when no verbal stimuli are presented. These tasks correlate with a negative slow wave over left hemispheric areas. In aphasics the slow wave is most prominent over left anterior regions, which was interpreted as a reflection of compensatory processes.

2.5 Gender Decision and Semantic Classification

2.5.1 Aim of the experiments

As described in chapter 1.2 the retrieval of a word form proceeds in two steps (Levelt, 1989): First a lemma is selected and subsequently the associated word form is retrieved. The syntactic properties, such as gender are stored at the lemma level (see Figure 2). According to the model, activation spreads immediately from an activated lemma to its gender node which is an independent process of the activation of the word form. Consequently activating the gender of a noun can be used to investigate lemma access. Jescheniak and Levelt (1994) examined this possibility to investigate lemma access with a gender decision task. Snodgrass pictures were presented to Dutch subjects who had to decide on the singular definite article of the noun that labels the object. The series of objects was presented three times. From the decreasing reaction times across presentations Jescheniak and Levelt suggested that during the first presentations of the objects subjects silently generated the pictures' names in full noun phrases (i.e. article plus noun, e.g. 'the cat') and then monitored for the article. On later presentations they were able to derive gender information without accessing the word form. A frequency effect was clearly visible on the first presentation, but disappeared on subsequent presentations. The authors concluded that the frequency effect arises on a later processing level, the word form level.

In the present study the gender decision task was employed to trace lemma access. A semantic classification task was used as a control task that did not require lemma or word form access. It was expected that stronger left hemispheric activity occurred in response to the gender decision task compared to the semantic task. There seems to be only one brain imaging study employing lemma access, namely the PET study by Levelt (1998; see above). As shown above this study found activity of the right parietal cortex during the assumed critical time window of lemma access (150-275 msec). This unexpected finding was related to attentional efforts.

2.5.2 Methods

Subjects

Nineteen patients completed both tasks above chance level so that their performance and ERP data were accepted for statistical analysis (see Table 12 for individual characteristics; 6 female, 13 male, mean age 49± 11 years, mean level of education 11±2 years).

Seventeen of the nineteen patients had suffered from a left hemispheric cerebrovascular insult. One patient suffered from aphasia following a cerebral trauma including subdural bleeding in the temporal-parietal area and compression of the left lateral ventricle; another patient had suffered from a left-temporal skull fracture. Diagnoses of aphasia were determined by the Aachener Aphasie Test (AAT; Huber et al., 1983). The AAT diagnoses were compared with the diagnosis given by the speech therapist and the neurologist in charge. According to the AAT classification guidelines, the diagnosis of aphasia syndromes was given with a probability >75% in patients in accordance with the diagnoses of the speech therapist and the neurologist. Eight patients were classified as Broca's-, five as Wernicke's-, and six as Amnestic aphasics.

In the two patients without cerebrovascular insult (see above) one patient was diagnosed as Wernicke's aphasic with 53% and amnestic aphasia with 47%. According to the diagnosis as Wernicke's aphasia given by the speech therapist this patient was assigned to the group of "fluent aphasics" in the present study. In the other patient syndrome classification was 40% Wernicke's and 60% amnestic aphasia in the other. The speech therapist classified this patient as amnestic.

The time interval since the insult varied between 1 and 62 months around a mean of 20±19 months.

Twenty-five subjects were examined as control subjects (13 female, 12 female); 14 of them were healthy controls, 11 neurological patients without any indication of a language disorder. The mean age was 43±12 years, the mean level of education 11±2 years.

In all Ss handedness was evaluated by a modified version of the Edinburgh Handedness Questionnaire (Oldfield, 1971), asking for hand preferences prior to the insult. Twenty-three control Ss were right-handed, while the laterality index indicated left-handedness (-100) in one and ambidexterity (-64) in another control. One of the nineteen aphasics reported to have been ambidextrous before the insult. For this patient, the laterality index was –40.

Table 12: Clinical and demographic data of patients

								Spontaneous Speech						AAT Subtests				
Patient	Sex	Age	Handedness	Years of Education	Months Since Lesion	Verbal Output	Type of Aphasia	Communicative Behaviour	Articulation and Prosody	Automatic Speech	Semantic Structure	Phonetic Structure	Syntactic Structure	Token Test	Repetition	Written Language	Naming	Comprehension
1	M	46	R	13	11	non-fluent	Broca	3	2	5	4	3	4	5	119	75	115	111
2	M	52	R	13	62	non-fluent	Broca	1	4	4	3	4	1	30	134	60	64	100
3	W	42	R	9	34	non-fluent	Broca	2	3	2	3	3	1	10	107	56	90	86
4	M	57	R	13	47	non-fluent	Broca	3	4	5	3	4	2	13	140	52	95	115
5	W	58	R	9	54	non-fluent	Broca	2	3	5	3	4	2	17	118	67	105	84
6	W	52	R	9	18	non-fluent	Broca	4	5	4	4	4	2	20	142	62	109	115
7	W	51	R	9	7	non-fluent	Broca	3	5	3	4	2	2	17	116	71	104	90
8	W	22	R	13	3	non-fluent	Broca	2	2	5	3	4	1	30	145	70	45	71
9	M	51	R	13	20	fluent	Amnestic	3	5	5	4	4	4	17	124	86	97	102
10	M	48	R	13	20	fluent	Amnestic	3	5	5	3	4	3	8	130	90	103	113
11	M	36	R	9	51	fluent	Amnestic	4	4	5	5	5	5	16	145	70	108	89
12	M	46	L	9	9	fluent	Amnestic	4	4	5	4	4	4	8	140	83	114	94
13	M	59	R	9	3	fluent	Amnestic	3	4	5	4	3	4	9	147	72	98	103
14	M	69	R	13	2	fluent	Amnestic	4	4	5	3	4	4	14	134	74	104	108
15	M	34	R	13	25	fluent	Wernicke	2	5	4	4	4	4	30	136	85	83	98
16	M	51	R	9	1	fluent	Wernicke	3	5	5	3	3	4	29	96	71	70	72
17	M	67	R	13	11	fluent	Wernicke	3	4	5	3	3	3	5	120	77	89	79
18	M	50	R	10	7	fluent	Wernicke	3	5	5	3	3	3	37	108	66	82	91
19	W	40	R	13	3	fluent	Wernicke	3	5	5	3	2	3	22	82	59	66	116

EM

BED

Maximal values of „spontaneous speech“ is 5, denoting „no dysfunction“. Maximal values of AAT subtests denoting „no dysfunction“: Repetition 150, Written language 90, Naming 120, Comprehension 120. Values of Token test denote number of errors made (max: 50).
handedness: l left, r right

Stimulus Material and Design

Each task comprised 54 stimuli that were taken from the Snodgrass (1980) series (stimuli together with lemma frequencies are listed in appendix D). Stimuli consisted of concrete objects. The corresponding singular definite article for each word labelling an object was either masculine (“der”) or feminine (“die”). Subjects had to respond with the left index finger to masculine gender and with the left middle finger to feminine gender. A left-hand response was chosen considering the high probability of right-sided paralysis in the aphasic patients. The button press terminated the stimulus presentation and the subsequent trial started after 3 sec. By randomizing the order of stimuli three versions of the gender decision task were produced that were presented in counterbalanced order to subjects. The gender decision task was presented three times, the semantic classification task once.

Procedure, Setting, Data acquisition and ERP analysis

Procedure, Setting, data acquisition and ERP analysis was performed as outlined in chapters 2.2.2-2.2.4 with two exceptions. The continuous data were epochized with 1 sec preceding stimulus onset and two seconds following stimulus onset. Data were only filtered between DC and 5 Hz..

In twelve of the nineteen aphasics the third presentation of the gender decision task was not performed and therefore for all subjects the second presentation was chosen for analysis.

For artefact-free trials and trials with correct responses (Gender decision: Controls 67%; Aphasics 52%; Semantic Classification: Controls 63%; Aphasics 56%;) the distribution of the average amplitude was determined for the negative slow wave between 300 and 600 msec after stimulus onset.

2.5.3 Results

Performance

Aphasics were slower to respond than controls in both tasks (GROUP: F(1,42)= 42.2; p<.01). In both groups the latencies were longer in the gender decision task compared to semantic classification (TASK: F(1.42)= 44.4; p<.01). The interaction TASK*GROUP indicated that aphasics had longer response times especially in the gender decision task (F(1,42)=26.6; p<.01). A similar pattern was found for number of errors. Aphasics made more errors than controls in both tasks in both tasks (GROUP F(1.42)= 6.9; p<.01) and both groups made more errors in the gender decision task (TASK: F(1.42)= 4.6; p<.04). The interaction TASK*GROUP fell short of significance (F(1,42)= 2.9; p<.09).

When latencies and number of errors were compared between syndromes (fluent vs. non-fluent aphasics) no significant differences for this factor or the interaction SYNDROME*TASK were found.

When latencies of the first and second presentation were compared it was found that aphasics responded slower in both presentations (GROUP F(1,42)= 48.7; p<.01), but both groups became faster on the second presentation (REPETITION F(1,42)=4.4; p<.05).

Aphasics made more errors than controls in both presentations (GROUP F(1,42)= 12.3; p<.01). However, neither the factor REPETITION nor the interaction GROUPxREPETITION became significant. Table 13 summarises these results.

Table 13:

Percentage of errors (% errors) and Response latency (group mean ± SD of the individual medians in seconds) for correct responses in the three groups for the *gender decision (both presentations)* and the *semantic classification* task

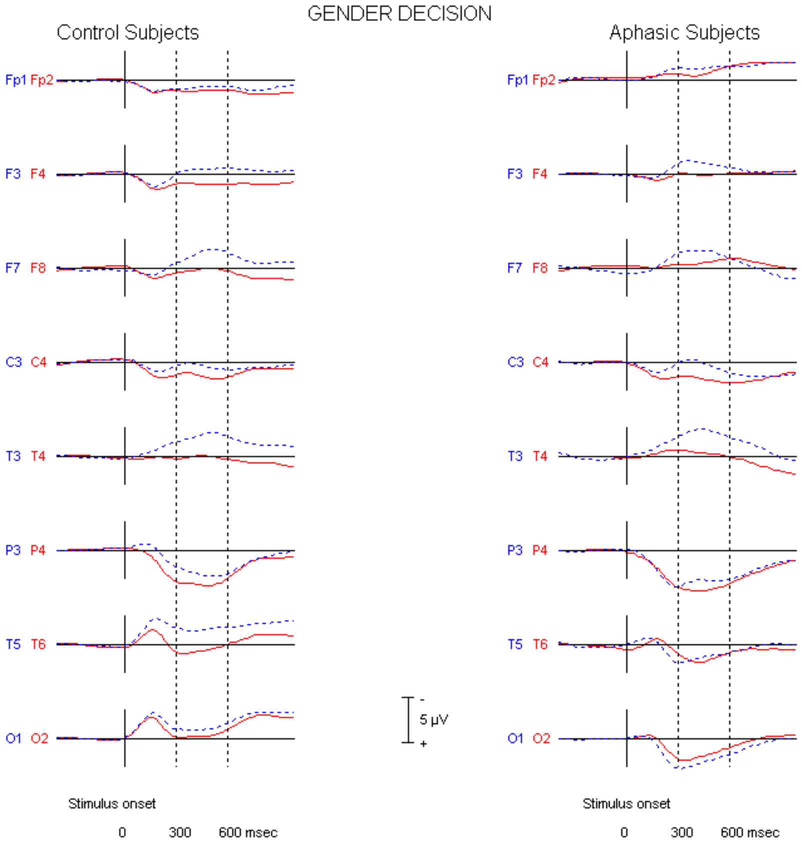
	Gender decision (first presentation)		**Gender decision (second presentation)**		**Semantic classification**	
	Response Latency	*Mean of % errors*	*Response Latency*	*Mean of % errors*	*Response Latency*	*Mean of % errors*
Aphasics	3.1±1.5	13.3±11.7	2.7± 1.4	13.2± 15.1	1.1± 0.3	5.7± 7.1
Controls	1.1±0.4	3.5±3.3	1.0± 0.2	3.9± 3.6	0.8± 0.2	3.0± 10.6

Event Related Potentials

Figure 16 and 17 display ERP-waveforms as evoked by the stimulus presentation for the gender decision and the semantic classification tasks, averaged across subjects from the control group and the group of aphasics. Differences between left- and right-hemispheric recording sites were most conspicuous 300 to 600 ms following stimulus onset. Accordingly, group- and task-specific scalp distributions were analyzed for this interval. Figure 18 illustrates the scalp distribution for both tasks in controls, non-fluent and fluent aphasics. While controls exhibit the expected left hemispheric asymmetry in the gender decision task and bilateral distribution of negativity in the semantic task, aphasics show the left-anterior predominance of activity in both tasks. This pattern is confirmed by the interaction GROUPxHEMISPHERExTASK (F(1,42)= 8.5; p<.01) with more pronounced negativity over the left hemispheric areas for aphasics in the semantic task (HEMISPHERE for aphasics in the semantic task: F(1,18)= 13.1; p<.01). In both task aphasics displayed stronger left anterior negativity than controls demonstrated by the interaction GROUPxHEMISPHERExGRADIENT (F(1,42)= 6.1; p<.02; for aphasics GRADIENTxHEMISPHERE F(1,18)= 3.5; p<.07).

Common between both tasks and groups was a stronger left than right negativity over areas of the left hemisphere for both tasks (HEMISPHERE (F(1,42)= 20.7; p<.01). Differences between tasks were found in that the semantic task correlated with generally more negativity (TASK (F(1,42)= 8.1; p<.01)). A significant interaction TASKxGRADIENT (F(1,42)= 4.9; p<.05) indicated that more pronounced negativity was found over posterior than anterior areas in the semantic task while the opposite pattern was obvious for the gender decision task.

Figure 16 and 17: group averages of the ERP for selected electrode sites (average reference)


GENDER DECISION

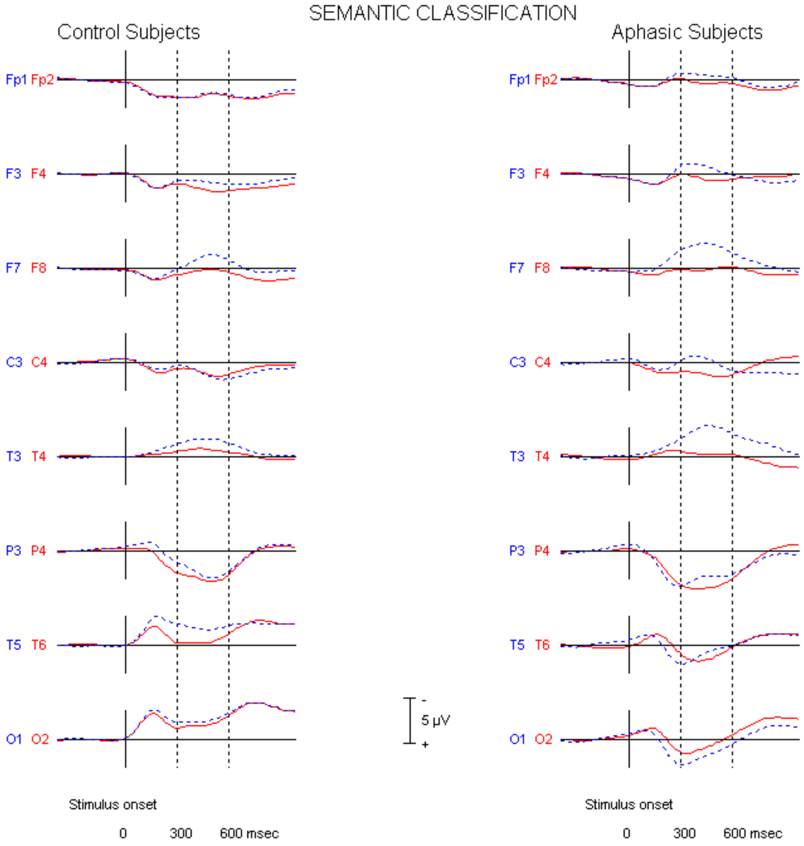
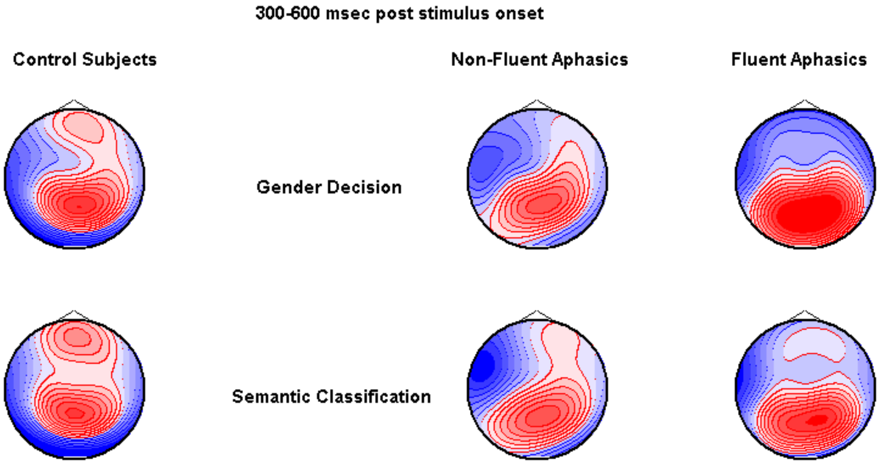

SEMANTIC CLASSIFICATION

Figure 18: Potential maps for slow wave of grand means across groups (average reference; blue denoting negativity; 0.5µV per contour line)



Comparing aphasic syndromes revealed that the strong left anterior negative SW was especially prominent in non-fluent aphasics (GRADIENTxHEMISPHERExSYNDROME (F(1,17)= 4.9; p<.04) (for non-fluent aphasics: GRADIENTxHEMISPHERE: F(1,8)= 22.3; p<.01)).

Analysis within the *source space* indicated mainly activity over posterior regions (GRADIENT (F(1,42)= 30.7; p<.01)). There were no further main effects or interactions with the factor GROUP or SYNDROME (for minimum norm maps see Appendix E).

2.5.4 Discussion

The gender decision task was chosen as a possibility to examine lexical access in comparison to a semantic classification task.

As predicted by Levelt's model subjects responded faster and made less errors in the semantic classification task, because this task can be solved on the conceptual stratum and no additional processing step has to be taken. Also as predicted from Jescheniak and Levelt (1994) subjects responded faster on the second presentation of the gender task.

As expected aphasics' performance was especially impaired on the gender decision task. Interestingly both groups did not make less errors on the second presentation of the gender decision task, although they became faster. It might be speculated that subjects had difficulties with specific items that did not become resolved on a second presentation. Controls hardly made any errors at all and so it is suggested that their performance level was already at ceiling level.

The improvement in performance from first to second presentation replicated the finding by Jescheniak and Levelt (1994). The response latencies of the second presentation in the Jescheniak study were considerably shorter than in the present study, but on the average the stimulus material of the present study had lower lemma frequencies and longer response latencies had to be expected (mean lemma frequency (1/million words): 56.0; Jescheniak study: 6.0 for low frequent words; 150.7 for high frequent words).
However it is safer to say, that the present study does not allow to verify subjects strategies, i.e. one cannot be sure if subjects did not generate the pictures' names in full noun phrases and then monitor for the article in their internal speech.

Badecker (1995) described the amnestic aphasic called Dante (see above: 1.3.2) who made hardly any errors in gender decision, but showed poor performance in naming. Even though the statistical analysis shows that aphasics made generally more errors than controls in the gender decision task, the inspection of single subject data provides an interesting result. Nine out of 19 patients committed only one or two errors in the second presentation (see Table 12; patients 1, 3, 5, 9, 12, 13, 14, 15, 16; three of these nine patients were classified as Broca aphasics, two as Wernicke's and four as Amnestic aphasics). This is interesting in the light of the naming performance in the AAT (max. score 120) of e.g. patient 15 (naming score: 83) or patient 16 (naming score: 70). One may speculate that these patients did not generate whole noun phrases, but were successful in the task, because they accessed only the gender node in the lemma level. Thus Badecker is supported at least by some of the present data and even extended in so far as not only Amnestic aphasics display the ability to retrieve a noun's gender despite impaired naming performance. Future research has to uncover what this heterogeneous group of aphasics has in common to produce this pattern of performance.

The analysis of the ERP patterns revealed that more negativity (i.e. less positivity) was found in the semantic task over the whole cortex. This is in line with findings by Pulvermüller (for an overview: 1996) who showed that semantic representations are widely distributed in cortical networks. The semantic task also showed more pronounced negativity over posterior areas. It is tempting to say that this corroborates findings by Levelt (1998) and Salmelin (1994) who found in their MEG studies that the access of lexical concepts is co-varied with more activity over occipital areas. The semantic classification task puts more demand on the activation of the exact meaning of a presented object than the gender decision task. It should be kept in mind, however, that in the MEG studies the occipital activation is taking place much earlier (0-150 msec). One way to find out if posterior activity is related to activation of lexical concepts would be to develop similar task like the present one, but with harder demands on the semantic nature of the task.

Both groups showed in both tasks stronger negativity over the left hemisphere. This suggests that this activity is related to naming processes, if subjects possibly generate complete noun phrases during the task. This is less probable for controls in the semantic task and in this task we find a difference to aphasics, who show stronger negativity over left hemispheric areas. It is an often observed clinical finding that aphasics verbalize even in situations when it is not required. This might also explain why non-fluent aphasics showed stronger negativity over left hemispheric areas than fluent aphasics. Another possibility is that non-fluent aphasics have to activate left hemispheric areas more strongly to reach a comparable performance as fluent aphasics. It should be remembered that no difference was found between those groups in performance.

The most striking difference between aphasics and controls is the prominent left anterior negativity of aphasics in both tasks, i.e. aphasics obviously activated the same areas in very different speech-related tasks. This pattern is neither related to performance nor to elapsed time since lesion as became obvious by two further ANOVAS. If the aphasic group is divided into those who perform well in the gender decision task (two errors or less) and those who do not, no significant differences in brain activity can be found in these two groups. When aphasics with longer and shorter time since lesion (Median = 11 months) were divided into early and late aphasics also no significant differences were found.

In sum, it seems that the aphasia specific pattern of activity is not related to performance, not to restitutional or substitutional factors (in this case one would have expected a difference between early and late aphasics) and to syndrome (the left anterior negativity was not more prominent in fluent or non-fluent aphasics). The latter fact also makes it implausible that this activity is related to the brain lesion. As pointed out in chapter 1.2.2 Broca's aphasia arises due to anterior and Wernicke's to posterior lesions. In Amnestic aphasics (that are not former Wernicke’s aphasics) generally no focused locus of lesion is found.

It might be speculated that the left anterior negativity pattern is due to compensatory efforts to cope with the impaired functions. This activity might lead in one task (semantic classification) to a relatively successful performance, while it might impair performance in a different task (gender decision). One may speculate that representation of the stimulus in working memory might improve performance in the semantic task, but that it is not helpful if one has to generate the singular definite article of the noun that labels the object.
A left anterior negative slow wave has been found under conditions, when phonological information has to be kept in working memory (Ruchkin et al., 1992, 1994, 1997).
This assumption is supported by functional neuroimaging findings. Reviewing this findings with reference to the role of left prefrontal cortex in language and memory Gabrieli (1998) concluded, that “left prefrontal activation occurs in conditions that require a greater amount, a longer duration, or more selection of semantic knowledge held in working memory”. The activation of posterior left prefrontal cortex in verbal working memory tasks has been demonstrated in a PET study by Paulesu and co-workers (1993). From this it can be predicted that the left anterior negativity in the semantic task will get even more pronounced when working memory processes are more stressed for example by a more difficult semantic classification task.

With the employed tasks so far the conceptual and lemma levels were investigated and the most prevailing difference between aphasics and controls was a prevailing left anterior negativity in the patient group. In the next part the last two tasks will be analysed: Word Comprehension and Rhyming. Particularly the Rhyming task is of interest, because there pictures are presented and subjects have to generate the corresponding verbal labels to respond correctly. It will be a point of major interest to see if control subjects do show the prominent left anterior negativity as well.

2.6 Word Comprehension and Rhyming

2.6.1 Aim of the experiments

In this part two experiments are compared: *Word Comprehension* and *Rhyming* (see Figures 8 and 9). As shown in the theoretical chapter on speech production the first task focuses on conceptual processes and lexical-semantic access. By presenting a word that subjects have to read a lexical concept is activated. After an interval subjects are presented an object (which activates again a lexical object, the same or a different one) and the task is to decide if the two activated concepts correspond (i.e. are the same or different). As outlined above aphasics show conceptual impairments. However, these impairments become especially prominent when specific features of concepts have to be isolated, what is not required in the *Word Comprehension* task. In the analysis across all tasks (chapter 2.3) it was shown that this is a task where aphasics do fairly well compared to the *Rhyming* task.

In the *Rhyming* task subjects are presented two objects separated again by a short interval and they have to decide if the common verbal labels of the objects rhyme. To perform this task it is necessary to produce after a visual analysis of the presented object the corresponding common word form, i.e. all stages of lexical access have to be performed (excluding articulation). It was expected and confirmed by analysis of performance values that aphasics perform worse on this task than on the *Word Comprehension* task: additionally to the activation of a concept the corresponding word form has to be activated, i.e. there are more possible sources of errors. What both tasks have in common is a demand on working memory to bridge the temporal gap between the presented objects. However, in one task the demand is more of a semantic nature (when concepts have to be compared), while in the other task the demand is more of a phonological nature (when word forms have to be compared).

2.6.2 Methods

Subjects

Thirty aphasics (12 female, mean age 49.5± 11.2 years) were able to complete at least one of the tests (see also Table1 for specific information). Data were analyzed only for those patients who had recovered to such an extent that they responded significantly above chance and had answered correctly to so many items that we could compare the scalp distribution of their SP patterns to these items with that of control subjects. All patients but two suffered from a left hemispheric cerebrovascular insult, most of them from infarcts of the arteria media. One patient suffered from aphasia following a cerebral trauma including subdural bleeding in the temporal-parietal area and compression of the left lateral ventricle; another patient had suffered from a left-temporal skull fracture.It was assured the diagnosis of aphasia syndrome given by the speech therapist and the supervising neurologist was in accordance with the Aachener Aphasie Test. According to the standard rules from a non-parametric discriminant analyses for the AAT 13 patients were classified as Broca's-, 5 as Wernicke's-, and 9 as Amnestic aphasics, while 3 of the patients clinically diagnosed as aphasics did not reach the criteria for classification according to the AAT at time of the investigation. These patients though had been classified as aphasic at the beginning of their disorder. In the two patients without a left hemispheric infarct the AAT classification was below 75%. One patient was diagnosed as Wernicke's aphasia with 53% and amnestic aphasia with 47%, According to the diagnosis as Wernicke's aphasia given by the speech therapist this patient was assigned to the group of Wernicke's aphasics in the present study. In the other patient syndrome classification was 40% Wernicke's and 60% amnestic aphasia in the other. The speech therapist classified this patient as amnestic. The time interval since the critical insult varied between 1 and 140 months around a mean of 28±31 months. At the time of the experimental investigation seventeen of the 30 patients were classified as fluent Wernicke's- or Amnestic aphasics according to AAT (4 females, mean age 48±15 years, mean years of education 11±2 years, mean time since lesion 24±34.8 months), thirteen were non-fluent and classified as Broca's-aphasics according to AAT criteria (8 females, mean age 49±12 years, mean years of education 10±1.9 years, mean time since lesion 34±27 months).

Table 14:

Clinical and demographic data on patients

								Spontaneous Speech						AAT Subtests					Tasks	
Patient	**Sex**	**Age**	**Handedness**	**Years of Education**	**Months Since Lesion**	**Verbal Output**	**Type of Aphasia**	**Communicative Behaviour**	**Articulation and Prosody**	**Automatic Speech**	**Semantic Structure**	**Phonetic Structure**	**Syntactic Structure**	**Token Test**	**Repetition**	**Written Language**	**Naming**	**Comprehension**	**Picture-Picture**	**Picture-Word**
1	M	36	R	9	51	fluent	Amnestic	4	4	5	5	5	5	16	145	70	108	89	+	o
2	F	34	R	9	35	fluent	Amnestic	4	4	5	5	4	4	9	115	79	110	118	+	-
3	M	51	R	13	20	fluent	Amnestic	3	5	5	4	4	4	17	124	86	97	102	+	+
4	M	48	R	13	20	fluent	Amnestic	3	5	5	3	4	3	8	130	90	103	113	+	+
5	M	46	L	9	9	fluent	Amnestic	4	4	5	4	4	4	8	140	83	114	94	+	-
6	M	59	R	9	3	fluent	Amnestic	3	4	5	4	3	4	9	147	72	98	103	+	-
7	M	51	R	9	1	fluent	Amnestic	3	5	5	3	3	4	20	117	81	91	97	+	-
8	M	69	R	13	2	fluent	Amnestic	4	4	5	3	4	4	14	134	74	104	108	+	+
9	F	47	R	9	3	fluent	Amnestic	4	5	5	4	5	4	12	146	89	92	84	+	+
10	M	68	R	13	61	fluent	Mild aphasia	4	4	5	4	4	5	4	147	87	101	117	+	+
11	F	51	R	9	13	fluent	Mild aphasia	4	5	5	4	5	5	3	143	85	94	97	+	-
12	M	50	R	9	140	fluent	Mild aphasia	4	4	5	4	4	4	1	147	83	113	113	+	+
13	M	34	R	13	25	fluent	Wernicke	2	5	4	4	4	4	30	136	85	83	98	+	o
14	M	50	R	13	1	fluent	Wernicke	3	5	5	3	4	3	5	146	70	62	90	+	-
15	M	67	R	13	11	fluent	Wernicke	3	4	5	3	3	3	5	120	77	89	79	+	+
16	M	50	R	10	7	fluent	Wernicke	3	5	5	3	3	3	37	108	66	82	91	+	+
17	F	40	R	13	3	fluent	Wernicke	3	5	5	3	2	3	22	82	59	66	116	+	o
18	M	46	R	13	11	non-fluent	Broca	3	2	5	4	3	4	5	119	75	115	111	+	+
19	M	52	R	13	62	non-fluent	Broca	1	4	4	3	4	1	30	134	60	64	100	+	+
20	F	56	R	9	21	non-fluent	Broca	2	3	5	3	4	2	35	111	75	82	92	+	-
21	F	35	L	9	45	non-fluent	Broca	2	4	4	3	4	1	34	127	29	93	95	+	-
22	F	39	R	9	99	non-fluent	Broca	3	4	5	3	4	2	12	133	61	98	99	+	-
23	M	68	R	9	15	non-fluent	Broca	1	3	5	3	1	2	20	86	65	101	94	+	-
24	F	42	R	9	34	non-fluent	Broca	2	3	2	3	3	1	10	107	56	90	86	+	+
25	M	57	R	13	47	non-fluent	Broca	3	4	5	3	4	2	13	140	52	95	115	+	-
26	F	58	R	9	54	non-fluent	Broca	2	3	5	3	4	2	17	118	67	105	84	+	+
27	F	52	R	9	18	non-fluent	Broca	4	5	4	4	4	2	20	142	62	109	115	+	-
28	M	57	R	9	30	non-fluent	Broca	2	4	4	3	4	1	30	92	41	87	89	+	o
29	F	51	R	9	7	non-fluent	Broca	3	5	3	4	2	2	17	116	71	104	90	+	+
30	F	22	R	13	3	non-fluent	Broca	2	2	5	3	4	1	30	145	70	45	71	+	-

EMBEDMaximal values of „spontaneous speech“ is 5, denoting „no dysfunction“. Maximal values of AAT subtests denoting „no dysfunction“: Repetition 150, Written language 90, Naming 120, Comprehension 120. Values of Token test denote number of errors made (max: 50).
Handedness: l left, r right
+ :test is included in analysis
-: test could not be evaluated due to artefacts and/or number of errors made; : test was not performed

Nineteen (7 female) subjects served as control group (10 of these subjects were healthy controls, 9 were patients without any indication of a brain lesion (e.g. slipped discs). The mean age was 46±10.4 years, the mean level of education 11±1.9 years.

In all Ss handedness was evaluated by a modified version of the Edinburgh Handedness Questionnaire (Oldfield, 1971). For aphasic patients, premorbid handedness was determined. All control Ss were right-handed. Two of the 30 patients reported to have been left-handed before the insult.

Stimulus Materials and Design:

Both tasks were presented as two-stimulus reaction time paradigms, in which a first stimulus (S1) signals the presentation of a second stimulus (S2) after a 2-s interval (see Figure 3 for *Word Comprehension* and Figure 4 for *Rhyming*). In both tasks, subjects were asked to press a button with the index finger of their left hand for a match between S1 and S2 or an adjacent button with the left middle finger for a mismatch. Matching and non-matching stimulus pairs were pseudorandomly distributed across the trials. Both stimuli (S1, S2) were presented for 1 s with an interval of 2 s between S1 and S2. The next trial starting 3 seconds after the button press in response to the preceding trial. The order of presentation of *Rhyming* and *Word Comprehension* task varied systematically across subjects. In the *Rhyming* task line drawings of a concrete object (e.g., dog, chair, fork) with high interindividual consistency in the naming response through high-frequency nouns from the Snodgrass & Vanderwart (1980) series were presented as S1 and as S2, in the *Word Comprehension* task they constituted the S2. In the *Rhyming* task subjects had to indicate by pressing the respective button, whether the most common verbal labels for the objects rhymed (e.g., cat- hat) or not (e.g., cat - pen). In the *Word Comprehension* task they had to decide whether the word presented as S1 corresponded with the object presented as S2. Subjects were verbally instructed about each task. Practice trials assured that instructions were adequately understood.

Procedure, Setting, Data acquisition and ERP analysis

Procedure, Setting, data acquisition and ERP analysis was performed as outlined in chapters 2.2.2-2.2.4.

For artefact-free trials and trials with correct responses (Word Comprehension: Controls 72%; Aphasics 61%; Rhyming: Controls 61%; Aphasics 45%) the distribution of the average amplitude was determined for the following ERP components: (1) Slow Wave (500 - 1000 ms following S1-onset), initial CNV (iCNV: 1000 – 2000 ms after S1-onset), terminal CNV (tCNV: 2000 – 3000 ms after S1-onset or 1-s preceding S2-onset, respectively).

2.6.3 Results

The results are based on data from subjects who did respond better than chance on a given task, and whose ERP recordings from correctly answered items were not contaminated by artefacts. Data sets suitable for analysis were available for the *Rhyming* task of 13 aphasics and 19 controls (ten healthy Ss and nine neurological patients with disorders not affecting the brain, e.g. slipped discs) for the *Word Comprehension* task of 30 aphasics and 19 controls.

Performance

Performance data are summarized in Table 15. Since healthy Ss and neurological control subjects did not differ in their average performance level (Errors: *Word Comprehension* F(1,17) = 1.2, p>0.3; *Rhyming* F(1,17) = 0.8, p>.3; mean of median Response Latencies: *Word Comprehension* F(1,17) = 1.14, p> .1; *Rhyming* F(1,17) = .6 , p> .1), the two control groups were combined for further comparisons. Fluent and non-fluent aphasics also made about the same number of errors and were comparable in response latencies (F(1,12) < 1, p> .1) Combined, the two groups of aphasics made more errors than the control groups in both *Word Comprehension* (F(2,46)= 6.4, p< .01) and *Rhyming* (F(2,29)= 15.9, p< .001); they also were slower than the control groups in their correct responses both in *Word Comprehension* (F(2,46)= 8.8, p< .01) and in *Rhyming* (F(2,29)= 37.1, p< .001).
Confining the analysis to those subjects, who accomplished both tasks well above chance and with little artefacts in their ERPs, significant main effects for TASKS confirmed that the *Rhyming* task was more difficult than the *Work Comprehension* task (Errors: F(1,29)= 98.7, p< .001; Response Latencies: F(1,29)= 164.2, p< .001), and significant interactions SYNDROME * TASK (Errors: F(2,29)= 15.5, p< .001; Response Latencies: F(2,29)= 34.9, p< .001) resulted from larger differences between tasks in the performance of aphasics than that of the controls .

Table 15:

Percentage of errors (% errors) and Response latency (group mean ± SD of the individual medians in seconds) for correct responses in the three groups for the *Word Comprehension* and the *Rhyming* task

	% errors		**Latency**	
	Word Comprehension	*Rhyming*	*Word Comprehension*	*Rhyming*
Controls	2.7 ± 2.5	8.5 ± 6.3	0.9 ± 0.23	1.2 ± 0.4
Fluent aphasics	7.4 ± 5.2	23.0 ± 9.9	1.2 ± 0.4	3.2 ± 0.7
Non-fluent aphasics	6.3 ± 4.1	30.8 ± 15.4	1.2 ± 0.3	2.7 ± 0.9

Event-Related Potentials and Cortical Activity Patterns

Figure 19 illustrates group averages of the ERP for selected electrode sites, Figure 20 presents spline interpolated amplitude maps from the event-related potentials during three time windows: Slow Wave: 500 – 1000 ms, iCNV:1000 – 2000 ms and tCNV: 2000 – 3000 ms post S1-onset.

Figure 19: group averages of the ERP for selected electrode sites (average reference)

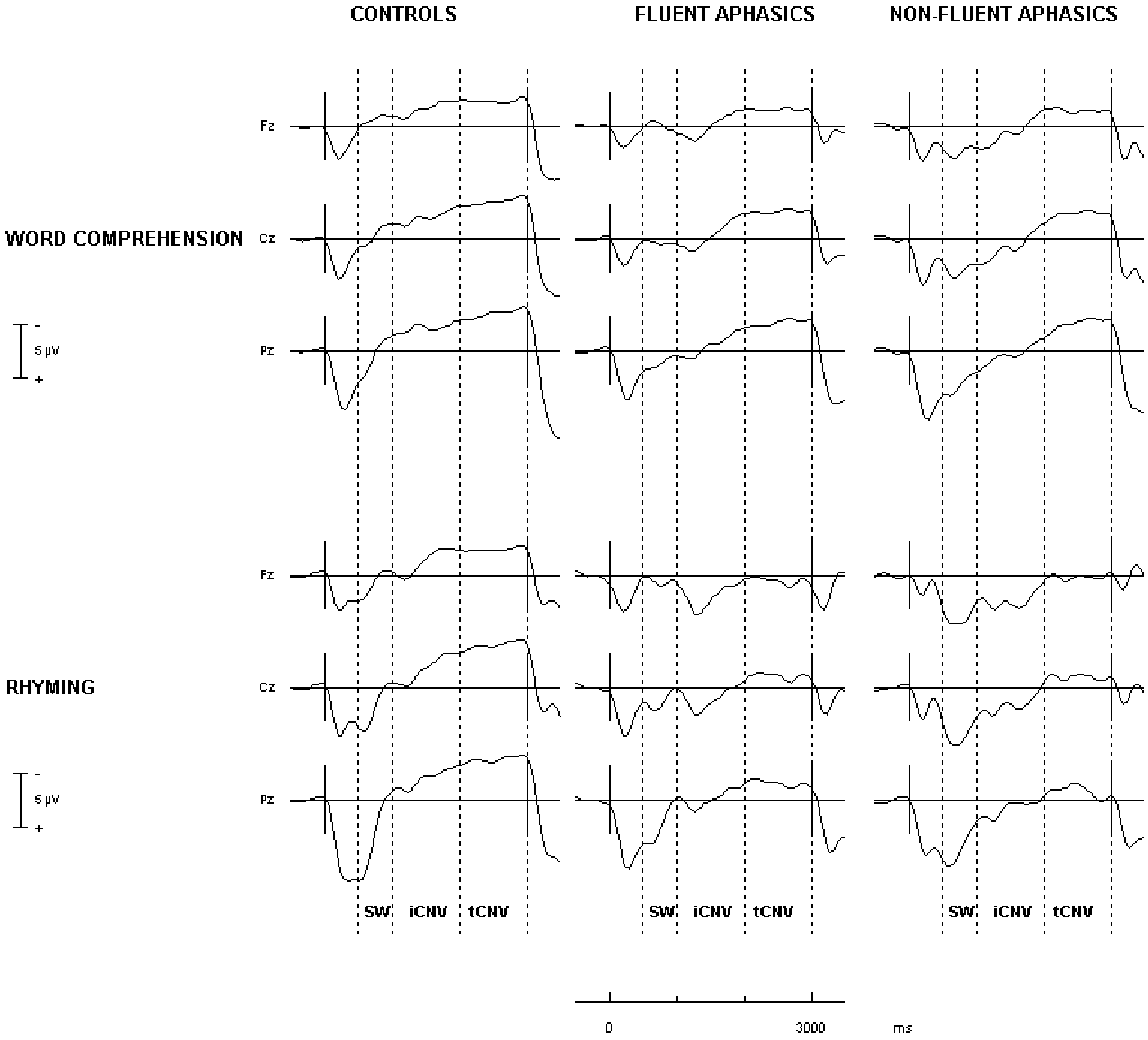
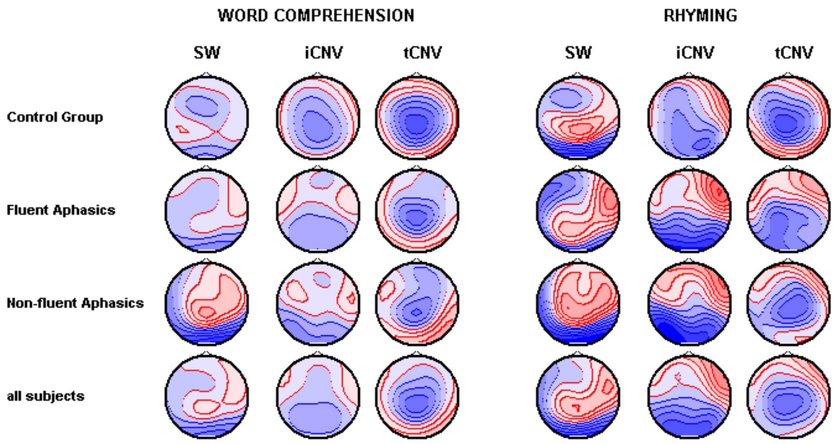


Figure 20: Potential maps for slow wave of grand means across groups (average reference; blue denoting negativity; 0.5µV per contour line)



In the *Word Comprehension task*, the Slow Wave was more negative across groups over the left than over the right hemisphere (HEMISPHERE: F(1,46) = 5.7, p< .05). In fact, the polarity of the Slow Wave over right anterior areas was even slightly positive relative to the average reference. The same pattern was found for the subsequent iCNV (HEMISPHERE: F (1,46) = 3.9, p< .05). The iCNV had its largest negativity over posterior areas (GRADIENT: F(1,46) = 5.2, p< .03), again with small positivity relative to average reference over frontal areas. The tCNV showed an extensive negativity over anterior (F(1,46) = 4.4, p< .05), in particularly over right-anterior areas (HEMISPHERE * GRADIENT: F(1,46) = 7.0, p< .01; GRADIENT: F(1,46) = 4.4, p< .05). In the *Word Comprehension* task groups did not differ significantly in any of these amplitude measures; there was only a tendency for larger amplitudes of the negative Slow Wave in non-fluent aphasics during the presentation of the S1 than in the two other groups (SYNDROME: F(2, 46) = 2.9, p= .06).

In the *Rhyming* task again the amplitudes of the Slow Wave were more negative across groups over the left than over the right hemisphere (HEMISPHERE: F(1,29) = 15.4, p< .001). However, the interaction GRADIENT * HEMISPHERE (F(1,29) = 5.4, p< .03) indicates that this negativity is more pronounced over left posterior areas (F(1,31) = 4.0, p< .05), while a positive Slow Wave prevails over right anterior areas (F(1,31)= 8.1, p< .01). This pattern of right-anterior positivity with some left-anterior and considerable left-posterior negativity was most pronounced among the fluent aphasics (GRADIENT * HEMISPHERE *

SYNDROME : F(2,29) = 3.7, p< .05). This pattern of the Slow Wave (500-1000 ms) extends to the iCNV (1000-2000 ms post-S1 onset) with a main effect for HEMISPHERE (F(1,29) = 8.9, p< .01) and significant interactions for HEMISPHERE * GRADIENT (F(1,29) = 4.1, p< .05) as well as for HEMISPHERE * GRADIENT * SYNDROME (F(2,29) = 5.8, p< .01). Again, the positivity over right anterior areas concomitant with a pronounced negativity over posterior areas was most pronounced in the fluent aphasics.

In the third second, prior to the imperative stimulus (S2), larger amplitudes of the tCNV were found in the fluent aphasics over posterior areas compared to the two other groups (GRADIENT * SYNDROME: F(2,29) = 3.8, p< .04). There were no other significant effects for the tCNV.

Overall, it appears that the differential pattern found significant in the *Rhyming* task with a right-anterior positivity and a pronounced posterior negativity of the fluent aphasics during 500 – 2000 ms after S1 onset is not all too different from the pattern found with attenuated differences also in the *Word Comprehension* task (see Fig. 13). Also in the *Word Comprehension* task this pattern is recognizable at best among the fluent aphasics; among the non-fluent aphasics it is evident in the time window 500-1000 ms after stimulus presentation.

These results from the scalp amplitudes are largely confirmed by an analysis of the sources of activity as estimated by the Minimum Norm (MN) solution.

For *Word Comprehension* the main source of activity during the SW interval was determined in posterior areas (GRADIENT: F(1,46) = 5.9; p< .02). For the iCNV an interaction SYNDROME * HEMISPHERE (F(2,46) = 3.2, p< .05) resulted from a larger difference between the right and the left hemisphere in the control group (F(1,18) = 6.6, p< .02) than was found in fluent and non-fluent aphasics. No significant effects were found for the tCNV.

In the *Rhyming* task a more prominent left anterior source of activity was found for controls than for aphasics for the iCNV (GRADIENT * HEMISPHERE *SYNDROME: (F(2,29) = 7.1 p< .01; for the post hoc analysis within the control group GRADIENT*HEMSIPHERE: F(1,18) = 24.1, p< .001). During the tCNV interval the main source of activity was located in the left posterior cortex (GRADIENT * HEMISPHERE: F(1,29) = 9.9, p< .01). The interaction GRADIENT * HEMISPHERE * SYNDROME (F(2,29)= 6.4, p< .01) indicates somewhat stronger right than left-anterior activity in the aphasic groups (HEMISPHERE at anterior sites within the aphasics: F(1,12) = 14.8, p< .01).

A laterality index was calculated for each subject and time segment per task as the differences between the MN indices of all left- minus right-hemispheric electrodes divided by their sum. Indices are summarised in Figure 21 for the means across groups and in Figure 22 for individual subjects (negative values denote more right than left-hemispheric activity). While no differences between the groups of aphasics are apparent at any time for the *Word Comprehension* task, in the *Rhyming* task the fluent aphasics display more right- than left-hemispheric activity during the Slow Wave (F(2,28)= 3.5, p< .04) and the iCNV (F(2,28)= 3.6, p<.04) For minimum norm maps see Appendix E.

In fluent aphasics, the right-hemispheric predominance covaried with the time elapsed since the lesion, that is, aphasics with short time since lesion exhibited the right-hemispheric predominance, while patients with long time elapsed since the insult displayed a left-hemispheric predominance of activity (rho = -.87 for the asymmetry of the Slow Wave and rho= -.72, for the asymmetry of the iCNV; see also Figure 23).

Figure 23: Laterality Index * Time since Lesion

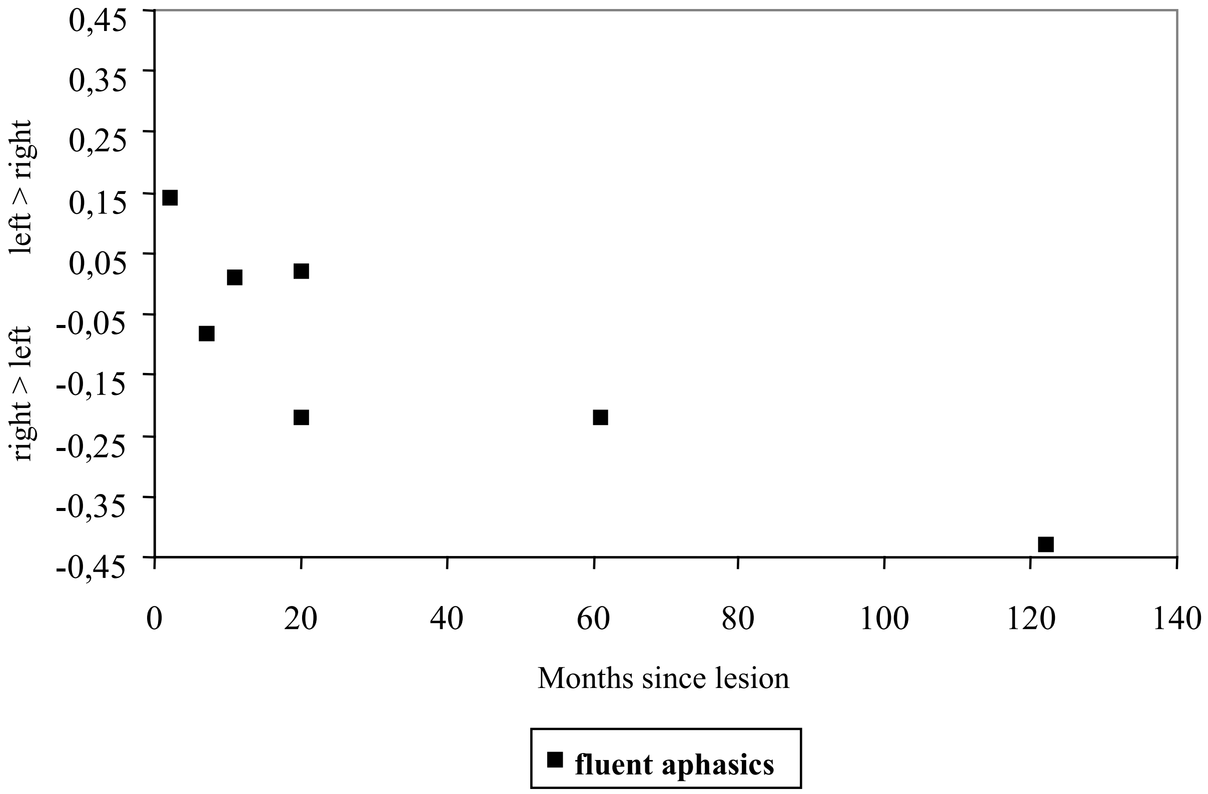


Figure 21: Laterality indices for means of groups

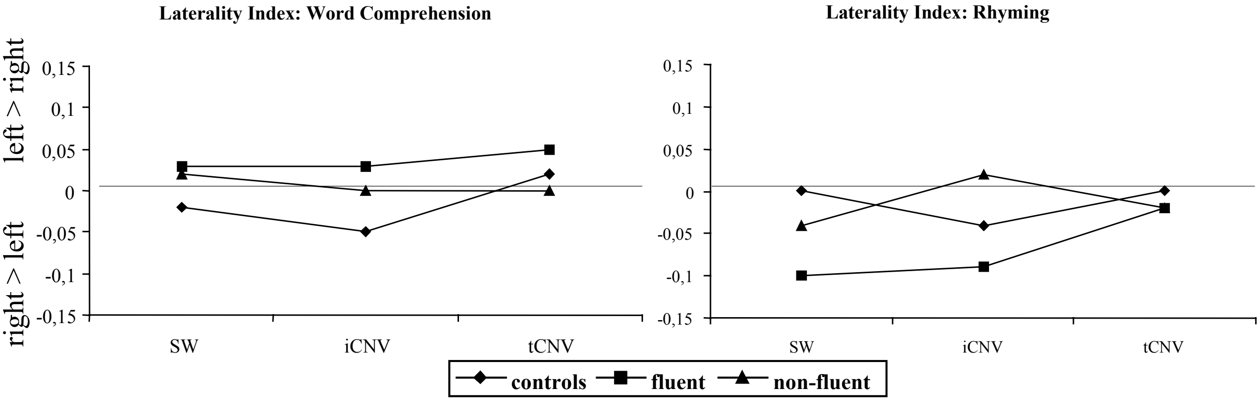
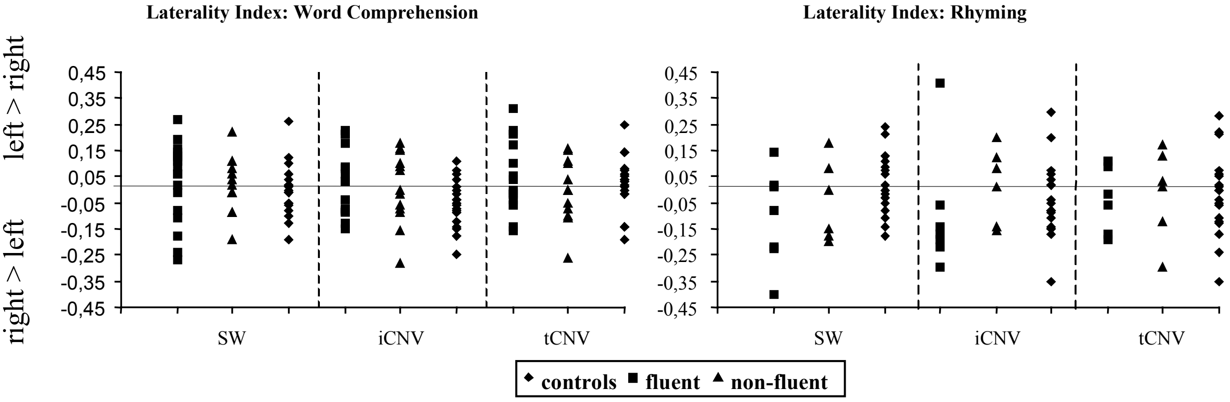


Figure 22: Laterality indices for individual subjects



2.6.4 Discussion

Two tasks - a *Word Comprehension* and a *Rhyming* task – were designed to activate language-related processes in aphasic patients. In particular, lexical access and phonological encoding were challenged by the task. In addition, verbal working memory was required as the long interstimulus intervals required to keep the result of S1-induced lexical access or phonological encoding in memory. In the Word Comprehension Task - focusing on conceptual processing and lexical access (Levelt, 1989) - subjects had to indicate whether the picture of an object corresponds to the meaning of a word presented earlier, thus requiring that the meaning of the word is kept in working memory until the picture is presented. In the Rhyming task subjects had to indicate whether the common label for an object depicted on a screen rhymes with the label for the object presented two seconds before. In contrast to the Word Comprehension task this task puts very little demands on conceptual processing, it also requires lexical access and also requires to keep in working memory the phonological code for the verbal label of the object presented to compare it later with the name for the second object.

As had to be expected, in both tasks aphasic patients performed significantly worse than subjects without any indication of brain lesion. They made more errors and had longer response latencies for correct responses. Differences between aphasic patients and controls in performance were more pronounced in the *Rhyming* than in the *Word Comprehension* task. This holds both for the Broca's-Aphasics with non-fluent as for Wernicke's- and Amnestic Aphasics with fluent speech. Aphasics performed worse in the Rhyming than in the Word Comprehension task. This suggests that the functions required by the Rhyming task were more vulnerable to the impairment of aphasic patients.

The performance in the present tasks closely corresponds to the performance level in the subtests of the AAT. The percentage correct responses from the Word Comprehension task correlate rho = .67 ($p< .05$) with Language Comprehension, the percentage correct responses from the Rhyming task correlate with Token Test rho = -.70 ($p< .05$), with Language Comprehension rho = .63 ($p< .05$), and with Naming rho = . 74 ($p< .05$). No correlations were found for response latencies. Among the non-fluent aphasics a correlation was found between performance and the time elapsed since the insult: rho = .83 ($p< .05$). These correlations together with the reported group differences in performance indicate, that the present tasks were highly sensitive to aphasic impairments. The differences between groups and between tasks suggest that the two tasks are suitable for examining the intended language-related processes.

The cortical activation of the patients during the performance on those items to which they correctly responded was compared with the cortical activation of controls dealing with these items. This comparison was based on the topographical patterns of scalp potentials and on the Minimum Norm estimation of sources of activity at the level of the cortex.

As expected, control subjects showed more left-hemisphere activity in the Rhyming than in the Word Comprehension task. In a picture recognition task similar to the present Word Comprehension task, Levelt et al. (1998) determined prominent activation during the stage of phonological encoding (i.e., 200-350 ms after picture onset) in the left posterior temporal lobe from magnetoencephalographic recording. Furthermore, imaging studies suggest left-anterior activation during encoding of word lists and verbal working memory (Gabrieli, 1998), while retrieval of verbal material was found to activate right-posterior regions. Thus, the pattern observed in controls may be interpreted to indicate the expected encoding processes.

Aphasics did not differ from controls in the *Word Comprehension* task. In the *Rhyming* task, on the other hand, the cortical activity of the Wernicke's- and Amnestic Aphasics was estimated to have a clear right-hemispheric predominance of activity during 500-2000 ms after presentation of the first picture. This cortical activity was reflected in a prolonged positivity over right anterior scalp areas together with an extended negativity over posterior scalp areas.

The similarity of patterns between groups in the *Word comprehension* task, in which aphasics also displayed better performance than in the Rhyming task, might be interpreted as indicating restitutional processes, i.e. recovery of function. In the Rhyming task, the pronounced right-anterior positivity in aphasics - contrasting with predominantly left-hemispheric negativity in controls - might point to a compensation for left-hemispheric dysfunctions. On the other hand, the surprisingly high correlation of rho = .87 between the laterality index for cortical activity in this time window with the time elapsed since lesion might indicate that this interplay between the hemispheres in handling the task demands of phonological encoding and preservation varies over the course of recovery. The tendency for right-hemispheric activation with increasing time since lesion is in line with findings from other ERP and imaging studies (e.g. Weiller et al., 1995; Thomas et al., 1997).

The right-anterior positivity was particularly pronounced in fluent aphasics. For these subjects the Rhyming task may have challenged particularly impaired language dysfunction, like access to "phonological representations corresponding to the underlying representation of the lexical item" (Blumstein, 1995; p.918). As has been already suggested by other authors the enhanced right hemispheric activity might be an indicator for cortical reorganization in aphasics in the sense of substitution. In contrast, non-fluent aphasics (Broca's) are impaired to access "phonetic representations corresponding to the articulatory parameters of an utterance" (Blumstein, 1995; p.918). It might be suggested that the representation of phonetic features are exclusive functions of the left hemisphere, that cannot be compensated by the right hemisphere.

Alternative explanations for the pattern of activity in controls and in aphasics are possible. One might speculate that fluent aphasics might rely more than Broca's aphasics on prosodic functions of the right hemisphere in preserving the phonological codes for the words to be kept in working memory. Both tasks implied that a verbal code or a verbal label of a picture were kept in verbal working memory. Verbal working memory is considered to activate left-anterior areas (Gabrieli, 1989). Thus, the left-hemispheric preponderance of activity might be considered an indication of working memory following phonological encoding. The pattern of activity observed in aphasics might point also to an impairment of working memory. However, verbal working memory was similarly required in both tasks, while the scalp distribution of activity differed between groups only in the Rhyming task. It can be suggested that this reflects an impairment of aphasics to keep a phonological code in memory which was especially challenged by the Rhyming task. It can only be speculated whether and to what extent higher demands on verbal working memory in the Rhyming task particularly challenged impaired functions in (fluent) aphasics contributing to the poorer performance and the smaller left-hemispheric negativity in this group.

3. General Discussion

In the present study several approaches to the study of language were brought together, from cognitive science, from neuropsychology and from brain imaging. It was shown, how a cognitive model of speech production can be applied to the study of aphasia with ERP methodology. The topic of speech production is especially demanding for ERP studies, because articulatory movements have high impact on the EEG and make a sensible registration impossible. It was shown, however, that articulation is only the last part in the course of speech production and that all earlier levels can be subject of ERP investigations.

Based on performance data, evidence was presented that showed if and to what degree aphasics are impaired on tasks requiring processing on different levels of speech production.

When only lexical-semantic decisions were required (Word Comprehension and Semantic Classification) or only pictures were presented for feature comparison (P-P task), they succeeded better than in the other tasks of the present series. Together with theoretical considerations one might regard these tasks as control conditions. It has been shown, however, that from these considerations alone on cannot conclude that aphasics perform in the same way as controls. Evidence suggests that aphasics use different strategies to solve tasks like these. Such an observation would be hard to obtain without brain imaging methods.

Throughout all tasks it has been demonstrated that different patterns of activity can be measured depending on the investigated time interval. This demonstrates the importance of methods with good resolution in the time domain for research in the area of higher cognitive processes.

The major point of interest was to elaborate findings from other studies which demonstrated stronger right hemispheric activity in aphasics. To find out in which stage of language process such activity can be found the task series was developed. Evidence was presented that suggests that a brain activity in aphasics compared to controls can be a consequence of different processes: restitution, compensation and substitution.

In the Word Comprehension task no difference between aphasics and controls was found. It was suggested that this in an indication for recovery of function or restitution. However, we cannot exclude that this task was so easy for aphasics that their brain activity was ever different from controls. One could validate this with future studies by imposing higher task demands on the subjects, that would make the decision, if word and picture correspond, more difficult.

In the FC tasks, as well as the gender decision and semantic classification tasks, the observed brain activity was similar to controls and even more enhanced negativity was found over left hemispheric areas, especially over left anterior areas. It was suggested that this is due to different strategies that aphasics develop to compensate their impairments. One possibility is that aphasics try to verbalise internally under conditions when it is not required. Such a finding is supported by several studies demonstrating a left anterior negativity under conditions that require an activation of verbal working memory (Ruchkin et al., 1992, 1994, 1997). However, if aphasics would always do so, it is surprising that they performed relatively well under conditions that were designed especially not to encourage verbalising, such as the FC P-P task or the semantic classification task. Additionally, according to this hypothesis it is astonishing that the activity pattern from the Word Comprehension task did not suggest such a verbalisation strategy, because no difference in brain activity to controls could be found. In the case of the Rhyming task when the task required verbalisation, i.e. the production of a word form, the most prominent pattern in aphasics was the prevailing positivity over right anterior areas and not left anterior negativity.

It is suggested that the activity pattern of the different tasks results from an interaction of working memory processes for phonological and semantic information. Evidence by functional brain imaging studies demonstrates activity of the left prefrontal cortex under conditions where representation of semantic knowledge in working memory is necessary (Gabrieli, 1998). It is a matter of future research to show under what conditions aphasics might adhere to a strategy using enhanced semantic information and under which conditions they verbalise internally.

Evidence for stronger right hemispheric activity in aphasics has been found in the Rhyming task. This corroborates findings that have been made in other studies (Weiller et al., 1995; Thomas et al., 1997). In the study by Weiller only Wernicke’s aphasics have been investigated and in the study by Thomas stronger left hemispheric activity remained prominent over time only in Wernicke’s aphasics. In the present study it was shown that the right hemispheric activity increased over time only in fluent aphasics. Interestingly this corresponds with a proposal by Kinsbourne that “a dissipation of left-to-right cross inhibition... must be a gradual process” (Kinsbourne, 1998).

A further point merits attention. In the study by Weiller subjects had to generate nouns and in the study by Thomas subjects had to generate synonyms. Both tasks require the production of word forms like in the present Rhyming task. It is suggested, that right hemispheric activation in aphasics is most likely to be found under conditions when access of word forms is required.

Consequently, it is followed that evidence for substitutional processes has only been found in the Rhyming task. It is a matter of future research to find out if this is due to language functions that are located within the right hemisphere, that are released by a lesion to the left hemisphere (York et al. 1995) or if the right hemisphere is able to develop functions that were not present before.

Methodological Suggestions for Future Studies

In the present studies focus was mainly put on the SW, the component following the presentation of a warning stimulus, and the tCNV, the component in anticipation of an imperative stimulus. In the presentation of the ERP curves it became obvious that these components showed the strongest lateralization and were thus most apt to investigate changes of lateralization in patients. The studies of Levelt (1998) and van Tourenhout (1998) did emphasise however that conceptual processes and lemma access take place earlier than the investigated time intervals of the present studies. This fact has to be acknowledged and it is recommended for future studies that the EEG is registered without low pass filters and high sampling rate. In our studies the filter was set to 30 Hz with 100 Hz sampling rate and so frequencies higher than this were not recorded. It cannot be excluded that early lateralized effects would have appeared without this filter and a higher sampling rate.

The best method for the investigation of very fast processes to date is MEG. Using whole head MEG would have the additional advantage that the localization of sources of activity is possible with greater confidence. In the present studies the influence of brain noise was reduced by averaging over relatively large areas of the scalp. This had probably the strongest influence on the analysis within source space. For future studies with more sensors it is recommended to use higher spatial resolution.

Overlooking all studies it became obvious that many subjects did not reach the statistical analysis due to artefacts of the EEG. In this thesis only three EOG coefficients were used for artefact correction. The use of additional coefficients would highly improve data quality, including artefacts resulting from articulatory movements. This is possible with very recent developments of EEG analysis software (Ille et al., 1997).

Suggestions for future task developments

In the Rhyming task it was shown that aphasics displayed a shift of activity towards the right hemisphere which was especially prominent in fluent aphasics. However, in this task the processes of naming and rhyming are confounded. To further investigate the interesting finding from this task, it would be advantageous to disentangle these two processes. This was done in a recent Diplomarbeit on Rhyming (Schampel, 1998) by presenting verbal stimuli as S1 and S2. To avoid the possibility of employing an orthographic strategy, the S1 was presented visually and the S2 auditorily. This task was only performed by healthy subjects, but again a stronger left hemispheric activity with lower variance between subjects was prevailing in the Rhyming task compared to a semantic control task. It is a matter of further research to employ this task with aphasics.

In this thesis it became evident that stronger left hemispheric activity was prominent in all tasks to a certain degree with aphasics showing more negativity over left anterior areas. Based on the introductory part one can argue that all employed tasks are language related tasks and that no real control condition was used. To find out if the left hemispheric activity is always present and if the left anterior negativity in aphasics really does not vary between tasks, it would be desirable to develop tasks that evoke stronger activity over the right hemisphere. In the language domain it has been suggested that the right hemisphere hosts functions related to emotional aspects of language (for an overview of right hemispheric language functions and their relation to aphasia see Goodglass, 1993). Several investigators found that the interpretation of emotional aspects of language is significantly more impaired in patients with right hemisphere lesion than in patient with left hemispheric lesions (Heilman et al., 1975; Tucker et al., 1977).

It was also suggested that the right hemisphere has a superiority for sentence prosody as shown in healthy subjects (Blumstein and Cooper, 1974). Ross (1981) reports that posterior right hemisphere lesions interfere with the interpretation of the emotional tone of sentences, as it is extracted from the speaker's intonation, whereas lesions deep in the anterior portion of the right hemisphere may abolish the ability to control the production of speech intonation.

In the present studies evidence was presented that the slow wave following the presentation of a stimulus is a valuable component for language investigations. For future studies in the language domain it is suggested to investigate this component with tasks that put more demand on language specific functions and less demand on more general functions such as working memory, that is required in S1-S2 designs.

Suggestions for further investigations with patients

As already mentioned, the Rhyming task lets suggest that the stronger right than left hemispheric activity increases over time. It would be favourable to see how the brain activity develops in aphasics over time especially with reference to improvement or worsening of the symptoms. It is a matter of present research in our laboratories to reinvestigate the early aphasics (time since lesion shorter than one year) with the same tasks and setting.

To explore the possibilities of functional reorganization in aphasics a single case study approach is proposed. It has been shown that substitutional processes depend on extensive training (for a review see Sterr et al., 1999), which is often not possible in normal clinical settings. It seems worth trying to provide some patients with as much training as possible and investigate them before and after extensive training periods. Highly desirable would be cases that are selectively impaired on certain functions and training should be supplied especially for these functions. This would also allow to investigate ERPs with respect to specific aphasic symptoms. In the present thesis only fluent and non-fluent aphasics were compared because a further division of groups would have made a statistical comparison due to small group sizes unreliable.

Additionally the influence of lesions on the ERP merits attention. In the present study no control group with right hemispheric lesions was presented. Evidence suggests that the peracute, mostly cytotoxic, edema is resolved within two weeks (O'Brien, 1995). Furthermore, extracellular edema, known to be longer-lasting, due to a disrupted blood-brain barrier (O'Brien et al., 1974), have little effect on electric activity and evoked responses (Sutton et al., 1980).

Outlook

In this thesis the attempt was taken to integrate several ways to study language. The goal of the future should be to go one step further. In close collaboration with therapists a combined approach should be taken in order to investigate scientifically for which patient under which condition processes of substitution, restitution or compensation are recommended to improve rehabilitative steps. The present thesis offered an example how brain imaging studies can help to evaluate such an approach. A large amount of recent research showed that cortical reorganization is possible and clinical observations provided evidence that recovery from brain lesions is possible even after considerable time following the onset of the disease (Geschwind, 1985). The ontogenesis of human brain and language lasts for the whole life-span of every individual, it ends only with death.

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Appendix A: From waveforms to maps and sources

Bioelectric signals recorded at the level of the scalp have temporal and spatial dimensions. Temporal in so far as they are sampled in time at the rate of the Analog-Digital converter and spatial in so far as they are recorded at certain locations, where electrodes are placed on the scalp. The usual initial presentation of the data, as it is also done in this thesis, is by means of multiple waveforms displaying voltage as a function of time at each of the recorded electrodes. However, the more electrodes one uses the harder the scalp distribution of the recorded potentials is to interpret. A more suitable method for the spatial domain are maps where voltage levels over the different regions of the scalp are plotted, which are read much as geographical maps with higher and lower values (representing in geographical maps height and in ERP maps voltage levels). The values are scaled with surrounding contour lines that allow to determine the exact value. The spacing between these lines give an impression of the amount of change between two points, i.e. lines lying close together display a fast change in height or voltage. Colours or grey values are generally used to denote positivity and negativity.

These scalp distribution maps are displayed as a two-dimensional projection of the concave scalp surface. Here we chose an azimuthal equidistant projection, where the scale is linear along all contour lines radiationg from the 'pole' positioned at the centre of the map (Cz). The projection can be extended below the equator to show data from the lower hemisphere. In this thesis the projection of all maps extends 20° below this line. To get continuous smooth contour lines values between electrode positions (where accurate measurements were obtained) are interpolated. In this thesis a three-dimensional interpolation was chosen using a spherical spline algorithm by Perrin et al. (1987, 1989). This method is thought to be the most appropriate one (Picton et al., 1995). To improve this method exact electrode positions on the specific head form of the subject were taken into account by registrating these positions three-dimensionally using a 3D digitizer (Polhemus).

Even though maps are impressive and easy to read one has to recognize that maps of potentials are not maps of sources. As reflected by the underdeterminancy of the inverse problem (for a closer description the reader is referred to e.g. Scherg, 1990) each bioelectric or biomagnetic pattern of activity measured at the scalp can be caused not only by a single possible configuration of generating sources, but infinitely many possible configurations are possible.

Many methods have been proposed to calculate the underlying electric brain sources (these electric generators are often described as dipoles thereby describing them with a fixed location and a specific orientation) from the measured scalp potential (for an overview the reader is again referred to Picton et al. (1995)).

In the present study a method was preferred that requires no a priori hypothesis about the number, extent and locations of active sources. As pointed out in the theoretical part, one can in complex cognitive tasks, such as most language related tasks, never assume that only one cognitive component is activated. Especially in language related tasks authors generally agree that multiple cognitive processes, that are highly interconnected, are active almost simultaneously. Additionally, in practice one encounters (especially in clinical studies) large brain noise, resulting in statistical uncertainties in the model, and insufficient data (i.e. a limited amount of employed sensors), resulting in smoothing of spatial details. To deal with these problems in the present thesis the "Minimum Norm Method" (Grave de Peralta Menendez, 1997) was used as a method of source reconstruction.

Based on a specific head model (in our case four spherical shells for brain, CSF, scull and scalp), the actual electrode configuration and the source model, every dipole strength is estimated by multiplying the data with a spatial filter vector that has optimal resolution properties. This filter aims at filtering out activity from just one dipole and suppressing activity from all the other ones.

Assuming that the whole brain might be active the electrically active brain volume is modelled with 665 locations with three orthogonally (one radial and two tangential) oriented dipoles on each location (in other terms 665 regional dipoles) placed on four concentric shells with different radii. Given this large amount of nearly spaced dipoles with fixed locations together with the physical relationship between each of these sources and the measured potential, this method yields the closest mapping of the potential to the underlying brain sources without any a priori information. As not only a few isolated dipoles are taken as model, the requirements for its application are met even in the presence of noisy data. The output of the method are current density values on almost every location on the scalp.

Pitfalls of the method are that the contribution of deeper sources is underestimated compared to more superficial ones and that the contribution of tangential sources is underestimated compared with radial ones. In addition, the solution for a single point source is widely blurred. However, these problems are generally inherent in the measurement of potentials at the surface of the head.

To handle the large amount of data statistically for all dipoles, we focused only on the dipole strengths for locations over which an electrode was positioned. As a compromise between sensitivity to deeper sources and “smearing” of activity the use of the third shell was chosen after visually inspecting the calculated activity on each shell.

Appendix B: Eye Artefact Correction

A very important step in the analysis of ERPs that were recorded in patients is the correction for eye artrfacts. Blinks can be found in almost every trial and make it impossible to exclude artefacts without loosing the whole data set. We employed in all experiments the MSEC (multiple source eye correction) eye artefact correction method introduced by Berg and Scherg (1994). As pointed out by the authors this method is significantly better than traditional methods. Traditional methods consisted of estimating a transmission coefficient with regression methods (i.e. amplitude relationships between EOG (Electrooculogramm) and each EEG channels) and subtracting the estimated potion of the EOG from the EEG. This has the disadvantage that also some proportion of the EEG is subtracted and thus the EEG topography is changed.

The crucial point of the MSEC method is taking into account the assumption that the measured potential at an electrode is the linear sum of the contributions (source components) from brain and eye sources (but also from other possible sources of artefacts such as muscles). So the first step in this method is to determine independently source vectors for eye and brain activity. Such a vector contains the relative amplitude at each electrode due to a source process. Together with the temporal information (i.e. amplitude at each electrode as a function of time) of each vector a source component is defined. For eye movements these source components are estimated based on empirical data. In a calibration run taking place at the beginning of each session each subject had to perform 40 horizontal (20 to the left and 20 to the right of the screen), 40 vertical (20 up and 20 down) eye movements and 20 blinks. Locations where subjects had to look at, were marked at a distance of about 15° to the middle of the screen. Subjects performed these saccadic movements following the presentation of an arrow pointing towards the mark to look at. The EEG of these movements were averaged 200 msec before the beginning of a movement and 400 msec after. These averages were baseline corrected for 100 msec before a movement and transformed to average reference. The source component is then established by applying independently a principal component analysis (PCA) to horizontal (left-rightward movement) and vertical (up-downward movements) movements as well as blinks. The first vector of each PCA was used which explains generally at least 98% of the variance.

To model the brain activity 4 regional dipole (i.e. 12 dipoles) sources were placed in the head. The locations of these dipoles are not necessarily at the locations of the EEG generators of the to-be-corrected ERPs, but are distributed in such a way to describe sufficiently well most of the EEG.

Eye correction is then performed by subtracting from artefact contaminated data the source components of the EOG, but simultaneously specifying the contribution of brain source components and leaving these ‘untouched’. The method can be applied to the averaged means of each subject, but was performed on each trial (i.e. before averaging). As a result of the MSEC method the EOG electrodes can be used as EEG electrodes in the artefact-free corrected data.

Appendix C: Summaries of the Stepwise Discriminant Analysis

Aphasics vs. Controls: Latencies

Step	Variable entered	R^2	F	Prob > F	Average Squared Canonical Correlation
1	Rhyming	0.5964	79.804	0.0001	0.59
2	Gender Decision	0.1313	8.011	0.0066	0.64
3	FCT: P-W	0.1299	7.766	0.0074	0.69
4	FCT: P-P	0.0781	4.320	0.0427	0.71

Aphasics vs. Controls: %errors

Step	Variable entered	R^2	F	Prob > F	Average Squared Canonical Correlation
1	FCT: W-W	0.6013	79.916	0.0001	0.60
2	FCT: W-B	0.0883	5.035	0.0291	0.63

Fluent vs. non-fluent Aphasics: Latencies

Step	Variable entered	R^2	F	Prob > F	Average Squared Canonical Correlation
No Variables can be entered					

Fluent vs. non-fluent Aphasics: % errors

Step	Variable entered	R^2	F	Prob > F	Average Squared Canonical Correlation
1	FCT: W-W	0.3254	10.613	0.0036	0.32

Healthy vs. neurological controls: Latencies

Step	Variable entered	R^2	F	Prob > F	Average Squared Canonical Correlation
1	Semantic Classification	0.2491	9.954	0.0036	0.24

Healthy vs. neurological controls: %errors

Step	Variable entered	R^2	F	Prob > F	Average Squared Canonical Correlation
1	Gender Decision	0.0770	2.420	0.1306	0.07

Appendix D: Stimulus Material for Gender Decision and Semantic Classification

Word frequencies were taken from the German version of Celex. Celex is the lexical database developed for English, Dutch and German at the University Nijmegen. The counts refer to the token lemma frequency in a million words. In this context lemma reflects the abstract representation that underlies an inflectional paradigm. So the lemma for *Bär* not only represents the word form *Bär*, but also all inflections like e.g. *Bäres*, *Bären* etc. Thus, the lemma frequency of *Bär* corresponds to the sum frequency of all listed word forms.

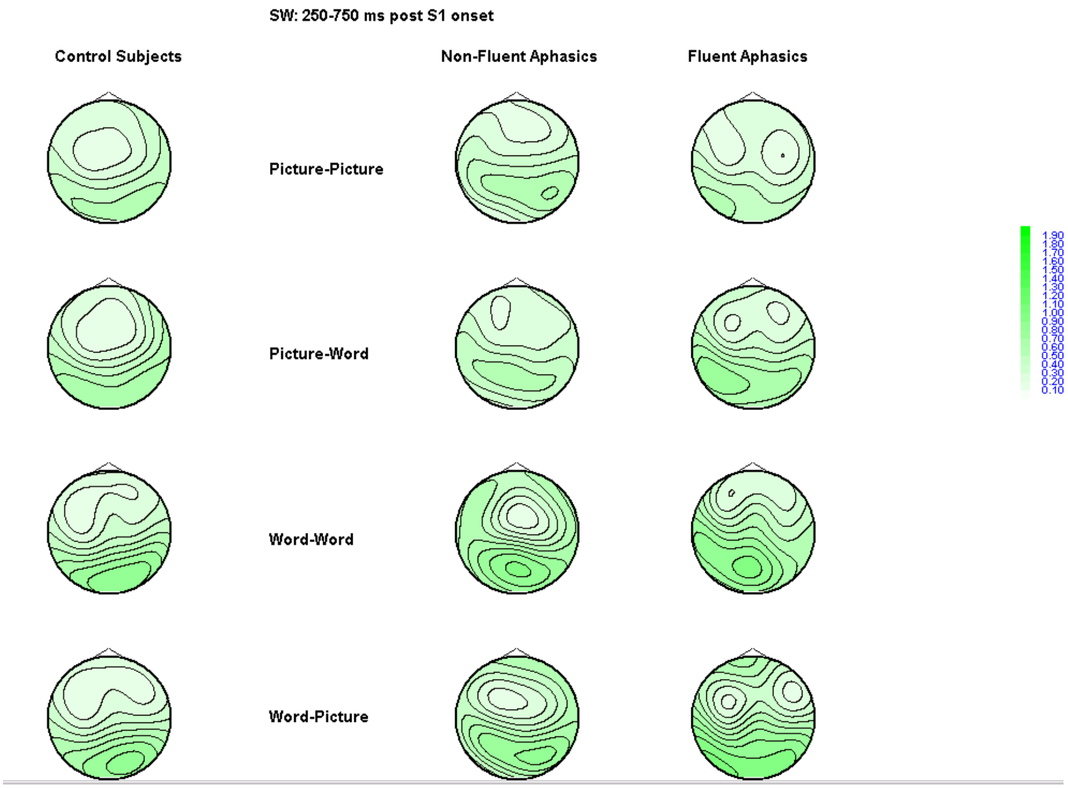
German Picture Name	**German Gender**	**English Translation**	**Token Lemma Frequency**
Maus	feminine	mouse	10
Löwe	masculine	lion	46
Ball	masculine	ball	29
Kirche	feminine	church	183
Bär	masculine	bear	4
Pilz	masculine	mushroom	5
Krone	feminine	crown	29
Birne	feminine	pear	4
Flasche	feminine	bottle	38
Tisch	masculine	table	100
Lampe	feminine	lamp	9
Hund	masculine	dog	61
Arm	masculine	arm	132
Ente	feminine	duck	23
Kerze	feminine	candle	11
Tisch	masculine	table	40
Nagel	masculine	nail	13
Fisch	masculine	fish	35
Katze	feminine	cat	19
Hand	feminine	hand	502
Nase	feminine	nose	36
Hut	masculine	hat	15
Gabel	feminine	fork	5
Schere	feminine	scissors	4
Hose	feminine	trousers	24
Zaun	masculine	fence	15
Mond	masculine	moon	80

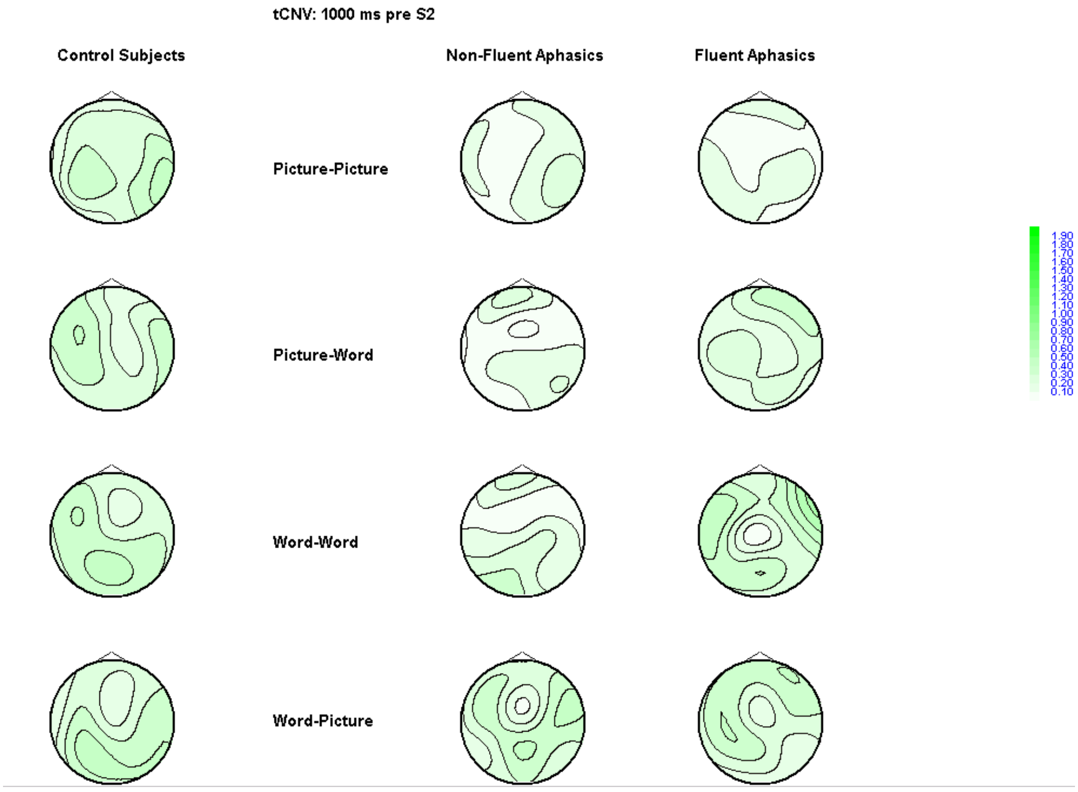
Schwan	masculine	swan	9
Finger	masculine	finger	64
Säge	feminine	saw	3
Fuchs	masculine	fox	8
Frosch	masculine	frog	4
Tasse	feminine	cup	9
Trompete	feminine	trumpet	7
Blume	feminine	flower	35
Mantel	masculine	coat	28
Spinne	feminine	spider	6
Glocke	feminine	bell	188
Uhr	feminine	clock	802
Schuh	masculine	shoe	34
Schirm	masculine	umbrella	6
Kamm	masculine	comb	8
Ziege	feminine	goat	9
Kuh	feminine	cow	43
Löffel	masculine	spoon	7
Leiter	feminine	ladder	63
Schraube	feminine	screw	5
Schlange	feminine	snake	20
Knopf	masculine	button	12
Apfel	masculine	apple	12
Tür	feminine	door	129
Vogel	masculine	bird	35
Schnecke	feminine	snail	0
Topf	masculine	pot	8
Mean			**56.0**

Appendix E: Minimum Norm Maps for All Tasks

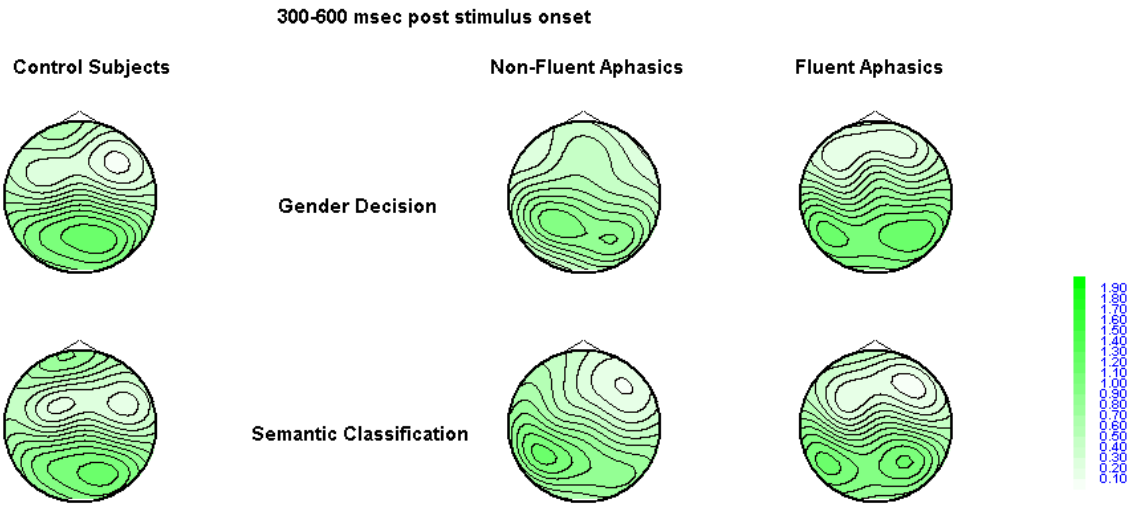
Note: darker colours denote stronger activity; green was chosen to distinguish these maps from blue and red amplitude maps

Feature Comparison Tasks





Gender Decision and Semantic Classification



Word Comprehension and Rhyming