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Electrophysiological Investigations of Internal Compound Structure.
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Morphology and Spoken Word Comprehension: Electrophysiological Investigations of Internal Compound Structure

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der Universität Leipzig
genehmigte
DISSERTATION

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Prof. Dr. Gonia Jarema

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to my parents

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Susan danke ich für Ihre Auf- und Ermunterung, dass Sie mich bei dieser Arbeit begleitet hat und dafür, dass sie mir die wichtigen kleinen Dinge des Lebens zeigt. Von ganzem Herzen

danke ich, nicht zuletzt, meinen Eltern Karin und Udo sowie meinem Bruder Swen. Ohne Zweifeln, ohne Zögern haben sie mich mein Leben lang gefördert und gestützt, als wäre es selbstverständlich. Ohne ihr Vertrauen in mich wäre diese Arbeit nicht zu Stande gekommen.

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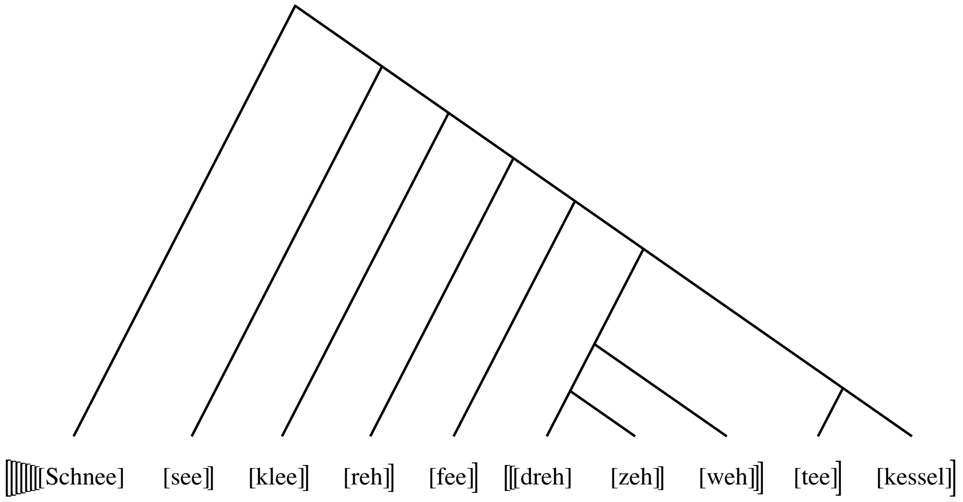

N	N	N	N	N	stem	N	N	N	N
masc	masc	masc	neut	fem	-	masc	neut	masc	masc
/ʃne:/	/ze:/	/kle:/	/ʀe:/	/fe:/	/dʀe:/	/tse:/	/ve:/	/te:/	/kɛsl̩/
(snow)	(lake)	(clover)	(deer)	(fairy)	(turn)	(toe)	(ache)	(tea)	(pot)

Schneeseekleerehfeedrehzehwehteekessel -

A pot for tea that eases the ache of a turn-toe of a fairy who has a deer who likes the clover (growing) by the lake that is covered with snow.

from Franz Fühmann "*Die dampfenden Hälse der*
Pferde im Turm von Babel"

Der Werwolf

Ein Werwolf eines Nachts entwich
von Weib und Kind und sich begab
an eines Dorfschullehrers Grab
und bat ihn: Bitte, beuge mich!

Der Dorfschulmeister stieg hinauf
auf seines Blechschilds Messingknauf
und sprach zum Wolf, der seine Pfoten
geduldig kreuzte vor dem Toten:

”Der Werwolf” – sprach der gute Mann,
”des Weswolfs”, Genitiv sodann,
”dem Wemwolf”, Dativ, wie man’s nennt,
”den Wenwolf”, – ”damit hat’s ein End”.

Dem Werwolf schmeichelten die Fälle,
er rollte seine Augenbälle.
Indessen, bat er, füge doch
zur Einzahl auch die Mehrzahl noch!

Der Dorfschulmeister aber mußte
gestehn, daß er von ihr nichts wußte.
Zwar Wölfe gäb’s in großer Schar,
doch ”Wer” gäb’s nur im Singular.

Der Wolf erhob sich tränenblind –
er hatte ja doch Weib und Kind!!
Doch da er kein Gelehrter eben,
so schied er dankend und ergeben.

Christian Morgenstern

The Banshee (An Approach)

One night, a banshee slunk away
from mate and child, and in the gloom
went to a village teacher's tomb,
requesting him: ”Inflect me, pray.”

The village teacher climbed up straight
upon his grave stone with its plate
and to the apparition said
who meekly knelt before the dead:

”The banshee, in the subject's place;
the banhers, the possessive case.
The banher, next, is what they call
objective case–and that is all.”

The banshee marveled at the cases
and writhed with pleasure, making faces,
but said: ”You did not add, so far,
the plural to the singular!”

The teacher, though, admitted then
that this was not within his ken.
”While bans are frequent”, he advised,
”A she cannot be plurized.”

The banshee, rising clammily,
wailed: ”What about my family?”
Then, being not a learned creature,
said humbly ”Thanks” and left the teacher.

Max Knight (translation)

Preface

The ease and speed with which we understand spoken language is astonishing given that the physical speech signal does not show clear correspondence to the perceived entities (words or sentences). A word uttered by different speakers or by one speaker in different moods may result in seriously changed acoustic signals, yet we perceive the same words. Besides the identification of words, the words need to be integrated into a sentence context within some hundred milliseconds. Pure linguistic models cannot (and do not intend to) account for such performances. Hence, models are needed that take the cognitive structure of the language processing system into consideration.

There is a large number of cognitive models that try to explain how language is processed (see Altmann, 1990; Frauenfelder, & Tyler, 1987; Treisman, Clifton, Meyer, & Wurm, 2003). Cognitive models of language can be distinguished coarsely by the assumed underlying mechanism, and by the directionality of the information flow within. Models that incorporate abstract rules, besides a memory component (lexicon), are called *rule-based* models (Caramazza, Laudanna, & Romani, 1988; see also Baayen, Dijkstra, & Schreuder, 1997). On the other hand, *connectionist* models assume only one underlying mechanism, namely an associative memory mechanism (Rumelhart, McClelland, & the PDP research group, 1986; McClelland, Rumelhart, & the PDP research group, 1986). The former process regular and novel forms by a set of finite rules that operate on a principally expandable list of stored items. The latter process the same forms by analogy to previously acquired (associated) patterns of similarity among items. Another classification distinguishes *serial* from *interactive* models (Fodor, 1990). These models differ in the temporal order in which processing stages are thought to occur. For example, the processing stages underlying word comprehension include e.g. visual, phonetic/phonological, phonological/lexical, and semantic processing (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Ziegler, Besson, Arthur, Nazir, & Carr, 1997). In serial models, information flow is unidirectional, bottom-up going from visual to semantic processing stages (Forster, 1981; Norris, 1994). Interactive models, on the contrary, assume that information from higher processing levels may influence the processing at earlier levels (e.g. semantic processing may influence phoneme detection; Elman, & McClelland, 1984; Taft, 1994).

These classifications are not exhaustive; there are models that fall between the extreme points of classification. For instance, so-called *cascading* models stand between serial and interactive models. In such models, successive stages may overlap in time but the general order of stages is preserved, or, in other words, information may be exchanged between successive stages but cannot skip stages (cf. the earlier version of the cohort model; Marslen-Wilson, & Welsh, 1978). In some models it may be assumed that certain processing stages are only entered after others have failed (Baayen et al., 1997).

In addition to word recognition, sentence structure (syntax) and proposition (semantics) have to be processed. One major question, whether syntactic and semantic processes interact during sentence comprehension, has received an enormous amount of attention and research (Friederici, in press, 1995; Hagoort, Brown, & Osterhout, 1999; Hagoort, Brown, & Groothusen, 1993; O'Seaghdha, 1997; Osterhout, & Holcomb, 1992). Very broadly, a syntactic structure has to be computed and held active while words are accessed from the lexicon as they are perceived. In addition, semantic information has to be stored until semantic relations or a proposition can be computed. The syntactic structure permits the assignment of thematic roles to the serially incoming words and thus, makes the computation of a proposition possible. Moreover, a reanalysis and a repair mechanism is required for syntactically ambiguous sentence structures. Once it turns out that the inadequate structure has been pursued, sentences need to be reanalysed. Similarly, outright violations do not completely deplete utterances of meaning, i.e. some repair mechanism must be assumed to explain such observations.

The thematic role assignment is partially controlled by morphosyntactic agreement relations of different features (e.g. gender, number, case, tense, aspect, and so on). Some languages mark these features on the surface while other languages do less so. German is a morphologically rich language (though not the richest) and as a result morphological marking is very important in German. However, morphologically complex words are not only assembled for marking morphosyntactic features, words themselves may be concatenated to express facts, events, or concepts – so-called compounds. Their structure has to be processed in addition to the normal processes of word recognition, lexical access, and syntactic and semantic (propositional) integration.

Compounding as a lexical process of word formation will be the focus of the present work. Interest in morphological processes and the mental lexicon has grown over the past decade (Libben, & Jarema, 2002). Here I will concentrate on morphosyntactic processes during auditory comprehension and lexical-semantic constituent integration of German compounds. Major questions are whether compounds are decomposed, i.e. whether constituents are extracted separately from the speech signal, whether and when the constituents are integrated semantically in order to yield the compound meaning, and, as will turn out in the course of the investigation, whether linking elements subserve one particular proposed function, namely to indicate plural of the preceding constituent.

After a short introduction into morphological processes (Chapter 1) the method of recording the electroencephalogram (EEG) and calculation of the event-related brain potential (ERP) will be discussed in Chapter 2. Linguistic concepts and empirical evidence related to compounding and aspects of the lexicon are introduced in Chapters 3 and 4, respectively. Empirical findings will be criticised (Chapter 5) before, in Part II, the experiments of this thesis are reported (Chapters 6 through 8). Finally, the findings will be discussed (Chapter 9) and the thesis is closed with a summary and some preliminary perspectives (Chapter 10).

Part I

Linguistic and empirical background

Chapter 1

Introduction

Compounding is a morphological operation (Spencer, 2001) that is present in most languages of the world. It refers to the concatenation of words (free morphemes)[1] in order to denote particular objects. That is, compounding permits to name (not exclusively) new objects, concepts, or facts without the need to invent a genuinely new word. In this sense, compounding is an example for the generative nature of language which makes language a unique human capability (Hockett, 1960; quoted from Harley, 1995). From a finite set of symbols (e.g. letters, words[2]) an infinite set of well-formed symbol chains (e.g. new words, sentences, or compounds) can be formed. If the constituent words of compounds (called constituents throughout this thesis) are combined in the psycholinguistic sense, the constituents must be stored separately in memory. (The human storage with regard to language is known as the mental lexicon.[3]) Although it is well possible that compounds are stored in their entirety novel compounds have to be separated into their constituents because otherwise they cannot be understood. Such a decomposition of nominal[4] compounds is the focus of the present thesis.

In general, the main functions of the lexicon can be described as the storage[5] and the delivery of words to the syntactic system which in turn sorts them according to word order rules and the intended meaning. The search of lexical entries is, of course, also a lexical

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[1] Morphemes are the smallest meaningful language particles. Free morphemes may be used as syntactic words, e.g. "car". Bound morphemes cannot be used, they need another morpheme with which they form a syntactic word. The -s in "cars" is a bound morpheme, it carries the meaning *more than one of x*, where x=car.

[2] The set of words is not finite as it can be extended. The point here is the unlimited possibility to combine words.

[3] The use of an individual term reflects the suggestion that language processing is functionally autonomous (or informationally encapsulated) from other cognitive resources (see Fodor, 1983).

[4] Compounds consisting of nouns only.

[5] It is still undecided whether morphemes or words are stored in the mental lexicon. Here it is assumed that word formation rules operate on morphemes but the present thesis is only concerned with free morphemes. For a discussion of the psycholinguistic pros and cons of different approaches to morphology see Sandra (1994) and Marslen-Wilson (2001).

function. In particular processes of compound formation and the structure of the lexicon with regard to compound words will be investigated. The lexicon structure refers to the way in which words are stored. For example, different types of words (e.g. inflectional classes) may be stored differently. Also, different types of word information, i.e. phonological, grammatical (syntactic), or semantic information, may be stored distinctly. Here, I will argue that lexical entries are underspecified, i.e. lexical storage space is optimised. Lexical entries are underspecified in the sense that lexical entries contain only invariant but not variable morphosyntactic information of the respective words. That is, the morphosyntactic representation of ”Tisch” (table) would contain, for instance, word class (noun), inflectional class (strong), and gender (masculine) but not variable information such as number (singular or plural) or case (nominative, genitive, dative, or accusative).

By contrast, it may be assumed that lexical entries are fully specified (Pustejovsky, 1993) and, thus, reduce processing costs (cf. Sandra, 1994). In this case, all morphosyntactic (and semantic) features of a word would be included in the lexical entry. That is, the syntactically specified word forms (syntactic words), e.g. ”teacher” or ”(he) teaches” would have separate entries. If, on the other hand, it is assumed that the lexicon contains morphemes and not syntactic words, the word forms ”teacher” and ”(he) teaches” would be generated from the morphemes TEACH-, -ER, and -S. Here it is necessary to differentiate between the conception of a base form of a word (called stem or root) and a syntactic word. The stem is the minimal form of a word for which the morphosyntactic features are not specified. Syntactic words are fully specified, e.g. ”teacher” is in the singular form. Syntactic words are used in speech but not stems; stems are abstract entities.

If compounds do not have a lexical entry besides their constituents’ entries, and at least novel compounds cannot have an entry by definition, they must be generated from their constituents. For compound comprehension it follows that the constituents must be accessed and combined, and subsequently the compound must be specified morphosyntactically. It is not sufficient to access and combine the constituents, even if they were already syntactic words, because constituents may carry different morphosyntactic features (”mice$_{plural}$ plague$_{singular}$” or ”weapons$_{plural}$ inspector$_{singular}$”) but compounds are marked unequivocally (”[mice plague]$_{singular}$” or ”[weapons inspector]$_{singular}$”). If compounds are decomposed during comprehension it should be possible to track the access of constituents on the morphosyntactic level by manipulating the agreement of morphosyntactic features with, for instance, preceding determiners.

Since language comprehension is a very fast process a method with a high temporal resolution is necessary for its investigation. During auditory compound comprehension, processes of constituent search, access, and integration have to proceed in about 800 ms for an average two-constituent compound. Subsequently the compound has also to be integrated into a syntactic structure and a semantic proposition. With the electroencephalogram (EEG), and the subsequently calculated event-related potential (ERP) it is possible trace brain activations in the range of milliseconds (Regan, 1989). Thus, it is possible to track the time course of constituent access with high precision. Questions of spatial localisation, i.e. which neural correlates are involved in compound comprehension may be addressed with different methods, e.g. functional magnetic resonance imaging.

The aim of this investigation is to find out whether constituents are accessed from the mental lexicon during auditory comprehension. The morphosyntactic processing of constituent information will be emphasised. In particular, is gender and number information made available for all constituents or only for (syntactically relevant) head constituents? Furthermore, the question of lexical-semantic constituent integration will be addressed. When are constituents integrated in order to derive the meaning of the compound word? The results will be discussed in the light of previous findings on morphological and semantic constituent activation.

Chapter 2

EEG and ERP: Measures of brain activity

2.1 The EEG and the brain

The EEG (electroencephalogram), a non-invasive technique, records mainly the summed activity of the neocortex, the brain's grey matter. It was first described by Canton (1875) in animal research and by Berger (1929) in humans. Brain activity underlies all cognitive functions in general and language functions in particular. Information processing in the brain is done by electrochemical means. Within neurons, the basic unit of the brain, an electrical signal (action potential) is transmitted and induces the release of a chemical (neurotransmitter) at the connection to another neuron (synapse). This neurotransmitter induces at the postsynaptic membrane of the *target* neuron a slow departure from the resting potential which amounts to about -70 mV inside the neuron. The neurotransmitter may either increase the resting potential (hyperpolarisation) in which case it is called an inhibitory postsynaptic potential (IPSP), or may decrease the resting potential (depolarisation). The latter is called excitatory postsynaptic potential (EPSP) and will elicit an action potential if the membrane potential is lowered under a threshold of about -30 mV.

Inhibitory and excitatory PSPs of neurons that are aligned in parallel, cause electric fields and these electrical fields are recorded in the EEG (Barlow, 1993). Voltage changes e.g. at the synapses induce electric currents in the extracellular tissue which are accompanied by an electric and magnetic field. The electric fields caused by action potentials, IPSPs, or EPSPs of single neurons cannot be recorded at the scalp, because they are too small. An electric field large enough to be detectable can only be produced when many, about 10^3-10^4 neurons are active in synchrony (Barlow, 1993; Regan, 1989).

The duration of action potentials (1-2 ms;) is too short to account for the voltage fluctuations at the scalp (Regan, 1989). The IPSPs, and EPSPs, however, are slow enough to produce electric fields of the respective. Each neuron can be viewed as an electric dipole and in order to produce a macroscopic dipole many neurons need to be aligned in parallel. If so, they cause an open electric field which is detectable even at some distance, i.e. at the scalp (see Ch. 1 in Hall, 1992; Regan, 1989). If neurons are aligned incoherently, in a clumsy bulk the resultant field is a closed field which has the distribution of a sphere. Outside the zero potential of this sphere no field is generated and electric activity from such neural substrate cannot be recorded on the scalp.

Neurons in the outer cortical layers (pyramidal cells) are organised in parallel and their activity causes the EEG. The neocortex, the outmost sheet of the brain has a regular architecture in all areas and consists usually of six layers (see Fig. 2.1). Pyramidal cells[1] reside in layer III, IV, V, and their axons which transmit information to other cells, extend into deeper layers and other areas. Conversely to axons, dendrites receive signals from different neurons in other areas. The pyramidal dendrites reach up to layer II and I where axons from other cortical areas and unspecific thalamic areas end and connect to the dendrites. The dendrites are organised in parallel and perpendicular to the brain surface (Amaral, 2000). This orientation allows an electric open field to be generated due to IPSPs and EPSPs and this electric field is recorded in the EEG. The evolution of a scalp potential from an IPSP is schematically depicted in Figure 2.2. Subcortical structures, although connected to the neocortex, are not assumed to exert a relevant influence on the scalp EEG. Subcortical activity may modulate cortical activity but is not directly reflected in the EEG.

For measurement purposes, electrodes are placed at the scalp according to the nomenclature of the American Electroencephalographic Society (1991) which extends the 10–20 system (Jasper, 1958, cf. Fig. 6.1). The EEG is recorded between each of those electrodes and a reference electrode, often placed over the left mastoid (monopolar recording[2]). That is, the EEG reflects the relative potential difference across time between two electrodes but not absolute voltage values. The reference electrode cannot be placed over an inactive region (absolute zero potential) for practical reasons. Therefore, the EEG amplitude and polarity, i.e. scalp distribution, depends on the choice of the position of the reference electrode. As

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[1] The neocortex consists of mainly pyramidal and star cells whereby pyramidal cells account for 80% of all neocortical neurons.

[2] Bipolar recording is another recording possibility whereby the EEG is recorded between several adjacent electrode pairs. The distinction between monopolar and bipolar recordings is conceptually relevant for data interpretation; technically they are equivalent. In most cases of psycholinguistic research bipolar recordings are only used for the recording of the electrooculogram (EOG).

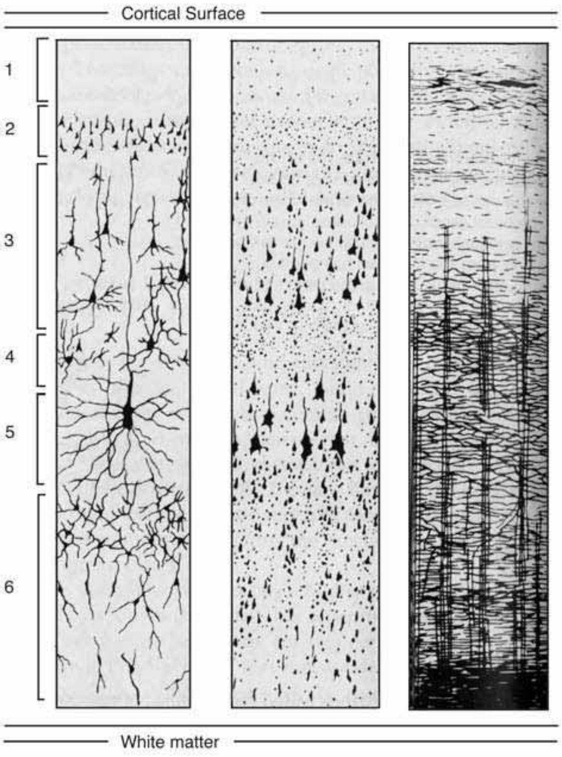

Figure 2.1: A cross-section of the neocortex that shows the distinct layers of cortical neurons as marked by different stains (from left to right: Golgi, Nissl, & Weigert stain). The pyramidal neurons can be seen best in the Golgi and Nissl stain. The Weigert stain shows predominantly the axon distribution. Numbers on the left indicate roughly the cortical layers. (Adopted from Amaral, 2000.)

the ERP (event-related potential) depends, ultimately, on the EEG distribution a standardised reference position is necessary in order to make research findings comparable across studies (for a detailed discussion cf. Nunez, 1981; Regan, 1989). For instance, the left mastoid is used as the reference in experiments that investigate N400 effects; the nose may be used to examine effects over temporal regions. The positions of measurement electrodes are standardised for the same reason.

At present, the continuous EEG is mostly interpreted clinically, or used to distinguish different stages of sleep[3] (Birbaumer, & Schmidt, 1995b), it indicates roughly an individual's state of alertness. Electrode labels code the anatomical region (F: frontal; C: central; T: tem-

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[3] Note that sleep functions are also investigated using ERPs (Campbell, 2002, for a special issue).

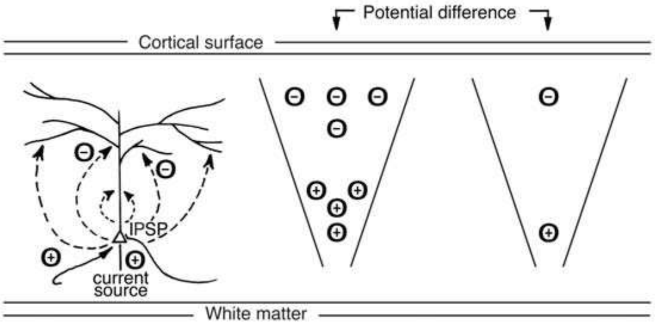

Figure 2.2: An inhibitory postsynaptic potential decreases the resting potential of a neuron. A resulting shift in the extracellular potential entails a current which is accompanied by an electrical field (left section). If such electrical fields are stronger (middle section) or weaker (right section) the difference between these electrical fields may be measured at the scalp. These changes in scalp potential are represented in the EEG. (Adapted from Nunez, 1981.)

poral; P: parietal; O: occipital) and hemisphere over which they are placed (odd numbers: left; even numbers: right; Z: midline).

2.2 Extracting the ERP

The ERP is the average scalp potential across time usually measured at several positions. It reflects specifically the brain's processing of a stimulus type as well as cognitive processes elicited by this type of stimuli. The ERP is characterised by deflections with a given amplitude and latency (see Fig. 2.4); it is comprised in the EEG which also reflects other processes (emotional, attentional, alertness etc.) The remaining EEG activity that is not specific to the stimulus processing, reflects background processes, so-called noise. The EEG amplitude which may amount in healthy, awake persons to $100\,\mu$V (Birbaumer, & Schmidt, 1995a), makes it practically impossible to detect the ERP (the signal) by eye because the ERP amplitude reaches only 10, at most $15\,\mu$V. In order to estimate the ERP the background noise is reduced by averaging the EEG of repetitive presentations of stimuli from one stimulus type, i.e. from one experimental condition (McGillem, & Aunon, 1987). The averaged EEG time epochs are time-locked to the stimulus onset[4]. In doing so, the signal-to-noise ratio is reduced if one assumes that the ERP is constant in amplitudes and latencies across trials, the ERP is independent from the background EEG activity, and that the background EEG varies only stochastically across trials (Rösler, 1982; Vossel, & Zimmer, 1998). The signal-to-noise

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[4] For other purposes the EEG epochs can also be aligned to other points in time e.g. the onset of a (response) movement.

ratio gives the ratio of ERP intensity to EEG intensity, usually measured in μV. That is, the signal-to-noise ratio of a raw EEG will range from $0.1:1$ to $0.15:1$ for large ERPs. The signal-to-noise ratio depends on the number of averaged trials and by averaging more trials, the signal-to-noise ratio is enhanced. The signal-to-noise ratio increases by a factor of $\sqrt{N}$ where N is the number of averaged trials (pp. 47; Regan, 1989, cf. Fig. 2.3).

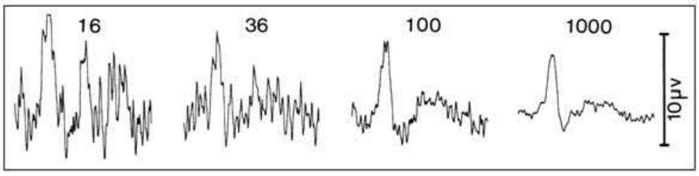

Figure 2.3: The increase of the signal-to-noise ratio by increasing the number of averaged EEG epochs (trials). Depicted are the ERP estimates resulting from averaging 16, 36, 100, and 100 EEG epochs. The ERP to EEG amplitude ration (signal-to-noise) increases by a factor of $\sqrt{N}$ where N is the number of averaged trials. (Adapted from Regan, 1989.)

The resulting ERP usually consists of a pre-stimulus baseline[5] and a time window that usually covers (at least) the time of stimulus processing. The latter time window shows characteristic deflections which are often called components and are labelled according to their polarity (negative or positive) and the latency of the peak amplitude (e.g. N100, P200). Alternatively, negativities and positivities are sometimes labelled according to their order of appearance, i.e. N1 (first negativity) and P2 (second positivity) are equivalent terms with N100 and P200 (cf. Fig. 2.4, although this classification is not completely consistent. Here both notions will be used synonymous.

The classification of ERP components is not undebated (cf. Coles, & Rugg, 1995) but classically they are defined on the basis of their polarity, peak latency, topographic distribution across the scalp, and their sensitivity to experimental manipulations (Donchin, Ritter, & McCallum, 1978). The last point alludes to the general ERP rationale, i.e. an ERP component can only be assumed to reflect a specific cognitive process if it can be modulated by an experimental manipulation. From this rationale it follows that at least two conditions are necessary for the interpretation of ERP results, namely a control and an experimental condition. These conditions must differ only in one variable or cognitive process in order to justify inferences drawn from such comparisons.

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[5] The absolute potential values cannot sensibly be interpreted. Thus, a reference time window, a baseline is required for each stimulus which should reflect the same processes in all conditions, i.e. no condition specific process. It should also be independent of drifts in the electric field across the experimental session. The time window immediately preceding each stimulus fulfils exactly these requirements. That is, the mean value of the baseline window (reference) is subtracted from any sample point of the ERP for standardisation reasons.

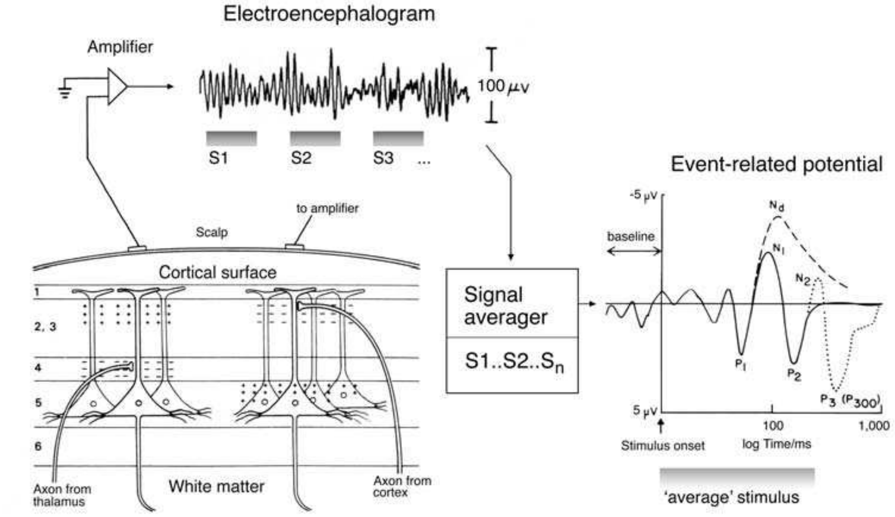

Figure 2.4: A simplified depiction of an event-related potentials. The electrical activity elicited by a stimulus is recorded from the scalp and amplified. The potential changes recorded from different electrodes are known as the EEG. Averaging the EEG epochs that correspond to stimulus induced processes yields the ERP with its typical components. The EEG epochs are usually time-locked to the stimulus onset for averaging. (Adapted from Barlow, 1993.)

A more specific classification of ERP components shall be mentioned briefly. ERP components can be categorised to be exogenous or endogenous (Donchin et al., 1978; Regan, 1989). Exogenous components appear roughly before 100 ms and are determined by physical stimulus properties as e.g. loudness, frequency, colour, contrast etc. Endogenous components occur later and their appearance is determined by psychological factors as e.g. relevance, task, probability (of occurrence), and so on. The distinction between exogenous and endogenous components is not strictly categorical. Components, especially in the time range 100-200 ms post stimulus onset, may be determined by physical stimulus properties and psychological factors.

2.3 Interpreting the ERP

2.3.1 The exogenous components N1 and P2

The presentation of stimuli in the auditory and in the visual modality elicits a phasic negativity with a peak latency of 100 ms (N1) and a phasic positivity with a peak latency around 180-200 ms (P2). These components have usually been investigated with simple acoustic stimuli as e.g. clicks or short tone pulses (Hall, 1992, Ch. 1 & 2).

In studies, mainly concerned with selective attention, both the amplitude and peak latency of either component could be modulated by physical stimulus parameters (Mangun, & Hillyard, 1995; Milner, 1969; Onishi, & Davis, 1968). Changes in the P2 peak latency have been associated with stimulus selection, based on their brightness (but not based on colour or spatial orientation; Harter, & Guido, 1980; Harter, & Salmon, 1972; Previc, & Harter, 1982). Accordingly, it was assumed that the N1/P2 complex reflects the processing of the physical stimulus information (loudness, frequency, brightness, etc.) but not the subjective categorisation or psychological representation of the stimulus. The P2 was also shown to be sensitive to more complex acoustic material, namely pitch contour of German disyllabic words. It was larger for initially unstressed words compared with initially stressed words (Friedrich, Alter, & Kotz, 2001; Friedrich, 2003). However, the P2 was insensitive to the correctness of the pitch contour which suggests that the P2 is determined by physical parameters but not by abstract, psycholinguistic features such as correctness of word accent.

Contrary to the interpretation of the N1/P2 as exogenous components it was shown that N1 and P2 are also sensitive to attentional processes (in the visual and in the auditory domain; Davis, 1964; Gross, Begleiter, Tobin, & Kissin, 1965; Hillyard, Vogel, & Luck, 1999; Näätänen, 1992; Woldorff, Hansen, & Hillyard, 1987) which are clearly cognitive in nature. Others interpret the N1 to reflect the perceived pitch of a more complex sound rather than the spectral content of the stimulus (Pantev, Elbert, Ross, Eulitz, & Terhardt, 1996).

At present, no consensus is reached on the functional interpretation of the N1/P2 yet. For the time being, the function of N1/P2 can be described as the generation of a cortical representation from physical stimulus parameters, e.g. an acoustic-phonetic analysis in speech processing. In this case, it may be affected by physical stimulus properties and by cognitive processes, for example by the action relevance of stimuli in a given situation.

2.3.2 The endogenous components (E)LAN and P600

Syntax related components will be introduced here in short; more detailed evidence with regard to syntactic processing is discussed in Chapter 4.3.

A specific ERP effect of (morpho)syntactic violations during sentence comprehension is the left anterior negativity (LAN), named after its occurrence at left anterior scalp electrodes. The effect is typically found between 300 and 500 ms after the onset of the critical word (for a survey see Friederici, 1999; Hagoort et al., 1999). During sentence processing a hierarchical structure is constructed for thematic role assignment and new words need to be checked whether they fit the so far calculated syntactic structure. A particular word may render a sentence ungrammatical for a mismatch of one or more (morpho)syntactic features (word class, gender, number, verb argument structure, etc.). For example, the sentence *"Peter sagt, dass er der Geld auf den Tisch legte."[6] (*"Peter said, that he put the$_{masc}$ money$_{neut}$ on the table.") is ungrammatical because the determiner and the noun do not agree in gender. The sentence *"Der Karpfen wurde im geangelt." (*"The carp was in the fished.") is ungrammatical because the preposition "im" has to be followed by a noun. "Geangelt", however, is a verb, i.e. the word class does not agree. Such mismatches represent violations of symbolic agreement rules and the former violation elicits a LAN which is taken to index the detection of a morphosyntactic violation (Gunter, Friederici, & Schriefers, 2000; Wedel, & Hahne, 2002). Note that the word class violation in the second example elicits an even earlier left anterior negativity (ELAN) which shows that word class information is processed before other morphosyntactic features (about 130 to 180 ms; Friederici, Pfeifer, & Hahne, 1993; Hahne, 1998; Neville, Nicol, Barss, Forster, & Garrett, 1991).

Another component that is related to (morpho)syntactic violations is the P600, a positivity in the ERP with an average peak latency of 600 ms (also called syntactic positive shift, SPS). Sentences that contain a violation of a syntactic constraint, elicit a more positive ERP at posterior electrodes which is often preceded by a LAN. The positive component is found in a wider time range; it may extend from 500 to, and beyond 1,000 ms post onset of the critical word (Friederici, 1999; Hagoort et al., 1999; McKinnon, & Osterhout, 1996). Given the fact that language rule violations are detected, a possibility is required for a revision and/or repair process; for example, neighbours' talk or mistakes of second language learners may result in misunderstandings but usually the hearer ends up with a (possibly inadequate) sentence. Sentence like ?"The broker hoped to sell the stock was sent to jail." (the critical word is underlined) elicited a LAN followed by a P600 which suggests that after the detection of the phrase structure violation[7] the sentence structure was reanalysed (as indicated by the acceptability judgements; Osterhout, & Holcomb, 1992; Friederici et al., 1993; Hagoort et al., 1993).

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[6] Following a linguistic convention a preceding asterisk indicates that a sentence or a word form is not acceptable

[7] It is assumed that the parser initially attempts a simple active analysis of such sentences. In a simple active analysis the auxiliary word "was" represents a phrase structure violation.

The P600, however, is also elicited by grammatical sentences with an unpreferred syntactic structure (Hagoort et al., 1993; Osterhout, & Holcomb, 1992). In such sentences, as ”The horse raced past the barn fell.”, a preferred syntactic structure (subject verb object; SVO) is only acceptable before the word ”fell” is read. The sentence is also compatible with another, although unpreferred, syntactic structure, namely a main-clause/sub-clause construction ([The horse [(that was) raced past the barn]$_{sub}$ fell.]$_{main}$). In the SVO reading ”horse” is taken to be the subject of the verb ”raced” whereas in the alternative and eventually correct reading ”horse” is the subject of the verb ”fell”. Sentences with an unpreferred syntactic structure do not require a repair but a prevision process. Such revision processes are also reflected in the P600 (Friederici, 1995, 2002; Kaan, & Swaab, 2003).

2.3.3 The endogenous component N400

The N400 is a negative deflection in the ERP with a peak latency of 400 ms and usually a maximal amplitude over centroparietal scalp regions. It is related to semantic processing and was first reported by Kutas and Hillyard (1980c,a). They showed that the N400 is associated with the semantic incongruity of a word within a sentence but not with a physical deviation, e.g. an unexpected word form. Words that were semantically apt but physically deviant (upper case) elicited a positivity with a peak latency of 560 ms but no N400 (Kutas, & Hillyard, 1980b; McCallum, Farmer, & Pocock, 1984). For example, the underlined word in the sentence ”He shaved off his mustache and city.” elicited an N400 whereas the underlined word in the sentence ”I take coffee with cream and SUGAR.” elicits a P560. Moreover, it was also shown that the N400 is not solely elicited by semantically unrelated words but also by semantically unexpected words as in the sentence ”He shaved off his mustache and eyebrows.” (Kutas, & Hillyard, 1980c). The N400 was observed in the auditory, and in the visual modality, but the scalp distribution differs between modalities (Holcomb, & Neville, 1990). In the visual modality the N400 has a centroparietal distribution whereby the maximum of the effect may be shifted to the right hemisphere (Kutas, & Van Petten, 1994). In the auditory modality the N400 is symmetrical and more broadly distributed, and may also be recorded at anterior electrodes (Bentin, Kutas, & Hillyard, 1993, McCallum et al., 1984). Furthermore, its extension in time is larger compared with the visual N400. The reason for this seems to be the extended stimulation duration (Anderson, & Holcomb, 1995) and the fact that some variance is introduced with respect to the point at which a word is recognised in auditory presentation[8] (jitter).

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[8] The *recognition point* is estimated by an experimental procedure called gating (Grosjean, 1980, 1996). In this procedure subjects are presented repetitively with acoustic word fragments that are usually increased by 50 ms and begin with the word

The components introduced here are clearly sensitive to cognitive processes and are not elicited by physical parameters. That is, they are examples of endogenous components. The empirical evidence supporting the functional interpretations will be discussed in more detail in Section 4.4.

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onset. Subjects have to provide the word they think has been presented, for each fragment; additionally, they indicate how confident they are about it. The recognition point corresponds to the fragment length that subjects need to identify the word with certain confidence and without changing their response for longer word fragments (see also Tyler, & Wessels, 1983).

Chapter 3

The linguistic perspective

In this chapter, linguistic theories and concepts are introduced that provides us with the necessary terms and concepts to investigate the abstract nature of language processes. The German gender and number systems are explained as these features will be central in the experimental investigations. The following sections describe lexical entries and the mechanism of compounding in some detail. Chapter 4 will introduce the empirical evidence supporting one or the other conception.

3.1 The German gender system

Gender is a grammatical feature in many languages but not in all (Comrie, 1999; Corbett, 1991). It subdivides the noun word class into two or more categories. Each gender class is determined by the agreement between its member nouns and other words such as determiners, adjective, or pronouns. Different gender systems may assign their gender classes according to semantic and/or formal properties; the latter incl. morphology and phonology.

In German, there is no clear rule for gender assignment. Gender is neither strictly based on biological gender nor is it overtly marked; assignment seems to be largely arbitrary (Comrie, 1999)[1]. Gender assignment is predictable only in derivation; derivational (i.e. bound) morphemes are able to assign gender systematically. For example, -heit and -keit assign feminine gender regularly to the derived word (”Schönheit”$_{fem}$, beauty; ”Fähigkeit”$_{fem}$, capability). Given that monomorphemic nouns carry a particular gender and that gender as-

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[1] There are, however, descriptive probabilities recruiting semantic, morphological, and complex phonological features for the German gender assignment (Köpcke, 1982; Salmons, 1993). As these rules were derived from a large language corpus they describe but cannot explain the gender assignment in the German language. Moreover, with more than 40 probabilistic rules (Köpcke, 1982) they are far more complex than e.g. the phonological gender marking in Spanish or Russian where gender is often simply marked by the word final phoneme.

signment is unpredictable, gender can be assumed to be stored in the lexical entries together with the stem of the respective noun.

There are three gender classes in German (masculine, feminine, and neuter) and a noun's gender is unequivocally indicated by e.g. the form of the definite determiner (”der”$_{masc}$, ”die”$_{fem}$, ”das”$_{neut}$; all ”the” in English). Gender agreement between linguistic elements establishes local and global coherence in sentences or even across sentence boundaries.

3.2 The German number system

Number is a grammatical feature that is present in most languages of the world (Biermann, 1982; Corbett, 2000). It expresses a fact about world entities, a certain amount of denoted objects. It is usually marked on the noun and the noun's marking has to agree with other words (verbs, determiners, pronouns, etc.). That is, number marks formally a semantic aspect; it is classified as a morphosyntactic feature (Corbett, 2000).

German possesses a common number system and distinguishes only between singular and plural. Whereas singular nouns do not carry an affix (they are not marked), it is the plural forms of nouns that are marked by a suffix and sometimes by a vowel change (umlaut). Five suffixes (-er, -e, -n, -∅, and -s) are used for marking the plural form which may be combined with vowel changes (Wegener, 1999). Vowel changes are not conceived as independent plural morphemes, instead they are phonological or morphological variants of the aforementioned plural suffixes (Bartke, 1998; Wegener, 1992).

If the plural form of a noun is idiosyncratic, i.e. cannot be predicted from the singular form it must be stored in the lexicon (e.g. ”Muskel<u>n</u>”, muscles); if it can be generated by rule it is not necessary to store the plural form (e.g. ”Auto<u>s</u>”, cars). The descriptions of the German number system differ remarkably with respect to the underlying regularity (Bartke, 1998; Gawlitzek-Maiwald, 1994; Köpcke, 1987; Wegener, 1994). To mention only some positions, Köpcke (1987) argues that number is largely irregular in German, Wiese (1996) assumes one regular plural suffix (-s), and Wegener (1994, 1999) claims that plural formation is mainly regular. Thus, consensus reaches so far that only idiosyncratic or irregular plural forms are stored in the lexicon but theories diverge on which plural forms can be generated by rules. The number inflection in compounds is discussed in more detail in Sections 3.3.3 and 3.3.5.

3.3 Compounding: A word formation mechanism

Compounding is one of the major means of word formation besides inflection[2] and derivation[3] in German. The precise distinction between inflection and derivation, i.e. the definition of their difference is a problem in linguitic theory and only of peripheral relevance in the present work (see Anderson, 1982). Derivation and compounding may be understood to form lexemes[4] which in turn undergo inflection (just as free morphemes do).[5] Inflection, then, forms syntactic words from lexemes (cf. Anderson, 1982; Linke, Nussbaumer, & Portmann, 1994).

The compound constituents may belong to the same or different word classes (noun, adjective, verb, etc.) and the morphosyntactic features of constituents do not have to agree among constituents (e.g. syntactic gender). How word class and grammatical features of compounds are determined is explained in Section 3.3.3.

The constituents may contribute meaning in different degrees to the meaning of the compound. In so-called endocentric compounds (also called determinative compounds) one constituent determines the category meaning of the compound (*head* constituent) whereas the other constituent(s) modifies the head constituent's meaning. In so-called exocentric (also called possessive or bahuvrîhi compounds, incl. copulative compounds) none of the constituents has primacy in determining the meaning of the resulting compound. Section 3.3.4 will elaborate on this classification.

The number of compound constituents is not limited in principle. Compounding is a recursive mechanism, i.e. complex morphemes that are already the result of lexeme formation may enter again into the process of composition with a further morpheme. In this way, as is common in German, compounds with more than two constituents may be produced. The number of concatenated morphemes is not limited on linguistic grounds, rather a restricted working memory imposes an upper limit on the length of compounds in normal speech (Becker, 1992; Fleischer, & Barz, 1995; Linke et al., 1994).

Compounds are marked by a specific lexical stress pattern that is independent from phrase and sentence stress (Spencer, 1996). Compounds in German are stressed on the initial compound constituent and subsequent constituents are mostly deaccentuated (Kohler,

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[2] Inflection forms syntactic words from lexemes (see footnote 4, p. 19). It is mainly done by means of suffixation.

[3] Derivation forms lexemes from free and bound morphemes. The right most morpheme determines the (morpho)syntactic features of the derived lexeme in German. For example, the adjective ”schön” (beautiful) becomes a noun by adding the suffix -heit, ”Schönheit” (beauty). Derivation is mostly achieved by affixation.

[4] A lexeme is the collection of a number of words (a paradigm) in which some morphosyntactic features are neutralised, e.g. number. The syntactic words ”door” and ”doors” belong to the lexeme DOOR-.

[5] Whether or not inflection can also occur before compounding is not decided yet (cf. Section 3.3.1).

1995; Stötzer, 1989; Wiese, 1996). In phrases the last word (noun) is stressed. For example, in the phrase ”eine blaue BEEre” (a blue BErry; stressed syllables are printed in upper case) the first syllable of the noun is stressed and not the adjective whereas in the compound ”eine BLAUbeere” (a BLUEberry) the initial constituent is stressed. That is, prosodic information (stress) allows a hearer to distinguish between compounds and phrases and, thereby, between alternative sentence structures (Vogel, & Raimy, 2002). Other prosodic factors such as coarticulation, assimilation, or a change of stress pattern, may also influence the pronunciation of compound words and thus, differentiate compounds from single words (Kohler, 1995; Pompino-Marschall, 1995; Wiese, 1996).

3.3.1 The lexicon and lexical entries

In early linguistic conceptions the lexicon was proposed to store all, and only, unpredictable word information, i.e. it was designed as a list of exceptions (Chomsky, 1965; Chomsky, & Halle, 1968). Thus, all regular inflection, derivation, and compounding was done by transformational rules; there was no morphological component included in the grammar besides, for example, the lexicon and phrase structure rules. Over time this basic conception has changed and a more dynamic function has been attributed to the lexicon (Anderson, 1982; Toman, 2001). Word formation rules have been included, i.e. a morphological component of its own (Halle, 1973). This component actively, i.e. dynamically provides via inflection, derivation, and compounding, syntactic words needed for the processing of syntactic and semantic structures, be it in production or comprehension. That is, the lexicon does not only store unpredictable information but it also carries out processes of word formation.

Lexical entries are structured and contain at least idiosyncratic, i.e. unpredictable information of the respective words. According to Saussure’s conceptual split of signs into *signifiant* (sign expression) and *signifié* (sign content) as two sides of the same coin (de Saussure, 1917/1967), a word’s lexical representation consists of an expressible representation (the form) and an abstract representation (the content, see Fig. 3.1). The representation that might be produced or perceived physically, i.e. the word form is the resulting sound or spelling. The abstract representation (which cannot physically be expressed itself) is subdivided and includes semantic, word class, and morphosyntactic information (Linke et al., 1994). Only the expressible representation is exchanged among speakers and may function as an access code to the abstract information of a word (grammatical and semantic information). In short, the lexical entry of a word consists of a phonological form (PF[6]), a grammatical form (GF), and a semantic form (SF). Word class and morphosyntactic information of the word stem are separated and constitute together the GF.

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[6] A grapheme representation would be included here. It is not considered because it is of no relevance to this thesis.

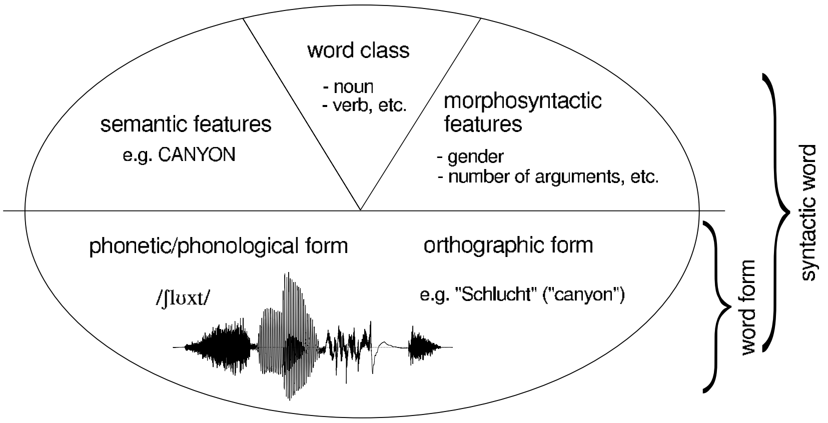

Figure 3.1: A schematic representation of a word. An expression based representation (phonological or orthographic form) is related to an abstract representation (content, including semantic, word class, and morphosyntactic information). The representation that might be produced or perceived is called the word form whereas the complete representation is the syntactic word; adapted from Linke et al. (1994).

The transformation of lexical entries into syntactic words is conceptualised as a lexical process. Some morphosyntactic features are anchored in the lexical representation (word stem) such as gender or word class. Other morphosyntactic features are variable in the lexical representation (e.g., case or number) but are fixed in a syntactic word. That is, the variable features have to be specified at some point. Similarly, novel compounds cannot have a lexical entry but they constitute single words in sentences; they are characterised by a stable word structure (Fleischer, & Barz, 1995). Hence, different lexical entries must be concatenated to yield compounds. Here, such morphological processes are assumed to be lexicon driven.

From the observation that certain inflectional suffixes do not occur between compound constituents but others do it was concluded that the formation of words (compounds) takes place in distinct steps, i.e. the lexicon may be ordered into different strata or levels. The most prominent model of a level-ordered lexicon was put forward by Kiparsky (1982) which divides the lexicon into three levels[7]. Basically, each level is associated with particular morphological (and phonological) processes, and by this the observed order of inflectional suffixes in compound words is explained[8] (Wiese, 1996). On the first level irregular inflec-

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[7] There are other models which assume e.g. two (Giegerich, 1999, for English) or four levels (Halle, & Mohanan, 1985), or argue against the level-ordered conception of the lexicon (Fabb, 1988; Plag, 1996, for a reply).

[8] This would, obviously, be circular reasoning if no independent evidence were found for the postulated level-ordering.

tion is achieved, before on Level 2 compounding and derivation is performed. On the last level, Level 3 regular inflection is done. For instance, -er, -e, -n, and -∅ are assumed to be the irregular German plural affixes (cf. Section 3.2) and hence, may appear between compound constituents. On the contrary, the -s is assumed to be the only regular (or default) German plural affix. Thus, the -s can only appear at the head constituent as a plural morpheme. The formation of syntactic words/compounds proceeds from one level to the next. At each level different morphological and phonological processes can take place and change the word form. Processes associated with a lower level can never follow processes associated with a higher level. According to this order, regular affixes, i.e. Level 3 affixes (in the present terminology), are only applied after compounding and can, therefore, not appear between compound constituents[9].

The level-ordering approach has been criticised because it does not account for all forms. As noted above, Level 1 affixes cannot be applied after Level 3 affixes. However, in the word ”ungrammaticality” the Level 1 suffix -ity must be applied after prefixation by un- (a Level 3 prefix) for selectional restrictions[10]. Also, the succession of two Level 1 affixes is acceptable according to the level-ordering approach. Nevertheless, the word *”personalify” is ungrammatical although both suffixes (-al & -ify) belong to Level 1 (for a detailed discussion see Fabb, 1988; Plag, 1996). That is, this approach cannot explain all morphological phenomena and overgenerates words that are not acceptable. However, the level-ordered lexicon is a prominent example of conceptions of the lexicon that ascribe active word formation rules to the lexicon within the language system. That is, the lexicon is not assumed to contain nothing but unpredictable information.

In principle, the list of lexical entries can be extended, i.e. new word coinages or loan words may be taken up into one's vocabulary. If compounds are used very often they may also get their own lexical entry in order to reduce calculation costs. That is, although constituents already have a lexical entry it may prove to be more efficient to store the whole compound in addition to the constituents. Established compounds or their constituents may also change their meaning over time, or the constituents may be used metaphorically and remain in the language community. As a result some compounds may not be semantically related to the constituent meaning anymore (see Section 3.3.4).

This is usually the goal of linguistic inquiries. Another possibility is to collect empirical data that support such proposals.

[9] According to the bracket erasure principle (Kiparsky, 1982) the word internal, morphological structure is deleted at the end of each lexical level. Therefore, the morpheme boundary is not *visible* to regular inflection, and the -s- cannot be inserted there.

[10] The prefix un- is restricted in its application to adjectives. ”Grammaticality” is a noun and cannot be prefixed by un-. The prefix un- is assigned to Level 3 for independent, phonological reasons (Siegel, 1979).

3.3.2 Productivity of compounding in German

Compounding is a simple mechanisms to describe (new) facts or ideas in an efficient, short way, i.e. instead of uttering a longer syntactic phrase (Fleischer, & Barz, 1995; Meyer, 1993). This efficiency in communication may be a reason for the availability of compounding in most languages.[11] The productivity reflects the degree to which new word combinations occur, so-called novel compounds. Indeed, the construction of nominal compounds is syntactically unconstrained in German and novel compounds are used very often[12] (cf. Becker, 1992; Fleischer, & Barz, 1995; Meyer, 1993; Olsen, 1986). However, not all nominal compounds are acceptable for native speakers, presumably for semantic reasons or the lack of appropriate context, e.g. ?”Talentleim” (talent glue), or ?”Benzinerfolg” (fuel success). Nevertheless, one may always argue that these compounds may be intelligible if a very specific explanation is provided. Meyer (1993, p. 3) notes that the logical operations negation and disjunction are principally excluded for compound interpretation. For instance, a two-constituent compound (AB) cannot be interpreted as *an* A *that is not* B or *something that is either* A *or* B. Furthermore, exclusion seems also not to be a possible interpretation (*something that is neither* A *nor* B).[13] Other compounds may not be acceptable for reasons of word form, e.g. *”Blumvertrieb” (flow[er] sale, acceptable form: ”Blumenvertrieb”[14]). Note that BLUM- is a German morpheme as it appears in the adjective ”blumig” (flowery). Compounding is less productive if constituents are adjectives, and is even more restricted with verbal constituents. Productivity also declines drastically for compounds with more than four constituents. Longer compounds are normally used only in technical or scientific talk (Fleischer, & Barz, 1995).

Novel compounds are mostly text bound, i.e. their intelligibility depends on context information; ”Fleischgebäude” (flesh building) becomes intelligible if the context *muscle systems* is provided (Fleischer, & Barz, 1995; Meyer, 1993). In general, it is characteristic of novel compounds that their interpretation is not fixed in a speakers’ community (Olsen, 1986). This is reflected in the use of novel compounds as a means in poetry (e.g. in metaphors, metonymy, or puns). Novel compounds may, however, become lexicalised over time if the denoted object is of general interest and the compound is accepted by the speakers’ commu-

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[11] Although Wunderlich (1986) assumed that compounding is universal Bach (2002) claimed that there are languages in Pacific Northwest without compounding, for example Wakashan and Eskimo-Aleut.

[12] Müller-Bollhagen (1985) found 22% novel compounds even in cook books in an analysis of nominal compounds (quoted from Fleischer, & Barz, 1995).

[13] The exclusion of negatives was previously noted by Fanselow (1981) quoted from Becker (1992).

[14] ”Blumenvertrieb” does not seem to be unusual at all. However, it is not listed in available databases (Baayen, Piepenbrock, & Gulikers, 1995; Quasthoff, 2002, August 2003).

nity. Due to an increasing use, the compound may enter the vocabulary of a community and, thereby, gain a fixed interpretation.

The restrictions on the productivity of compounding suggest that it is not an arbitrary process by which any two or more free morphemes may be concatenated. The fact that compounding is not arbitrary but still productive suggests that it can be described by some rules. Simple context-free rules would be of the form X → YX, where each letter stands for a word (free morpheme) with a given word class (Di Sciullo, & Williams, 1987; Selkirk, 1982).[15] Acceptable word classes for each position have to be specified and such configurations are language specific. For instance, the only compounding rule producing verbs in English, is V → PV (P-prepositions; e.g. ”outlive”) according to Selkirk (1982) whereas in German there are also VV (”drehbohren”; ”turning-drill”, to drill) or NV compounds (”radfahren”; ”wheel-cycle”, to pedal, ride a bicycle; see also Becker, 1992). Such regularities which may be captured by rules, are discussed in the next sections.

3.3.3 Grammatical relations of constituents

Compounds behave like single words in sentences or phrases. Nevertheless, their constituents carry at least those (morpho)syntactic features that are marked in the lexicon, and these may differ among constituents. As a consequence, one constituent has to have primacy with respect to grammatical features because compounds are not ambiguous with regard to their (morpho)syntactic features. In German, as in English the right most constituent (*head*) determines the compound’s (morpho)syntactic features (Di Sciullo, & Williams, 1987). This was formulated in the Right-hand Head Rule (RHR; Williams, 1981). The features of the head are said to percolate to the composite form (see Fig. 3.2; Selkirk, 1982). For example, ”Hochhaus” (”high house”; multi-storey building) consists of an adjective and a noun but the compound is still a noun, whereas the reversal of constituents (”haushoch”, by a mile) yields an adjective. The compound ”Steinhaus” (stone$_{masc}$ house$_{neut}$) is composed of a masculine and a neuter noun but the compound’s grammatical gender is neuter. That is, the last constituent determines all (morpho)syntactic features of the compound. However, the RHR is not universal; other languages are left headed (e.g. in French[16]), or the head may either be the left or the right most constituent (e.g. in Italian).

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[15] Such rules overgenerate compound words. To account for overgeneralisations additional filter rules are needed. See Selkirk (1982) for an elaborated discussion of such problems.

[16] French is predominantly left headed; there are exceptions to the rule (In ”Le trolleybus” (the trolley bus), clearly the object is a bus and in ”Le marchepied” (the$_{masc}$ step$_{fem}$-ladder$_{masc}$) the compound’s gender is determined by the right constituent.). See also Nicoladis (2002) for an argument that even French noun-preposition-noun constructions are in the process of acquiring compound status.

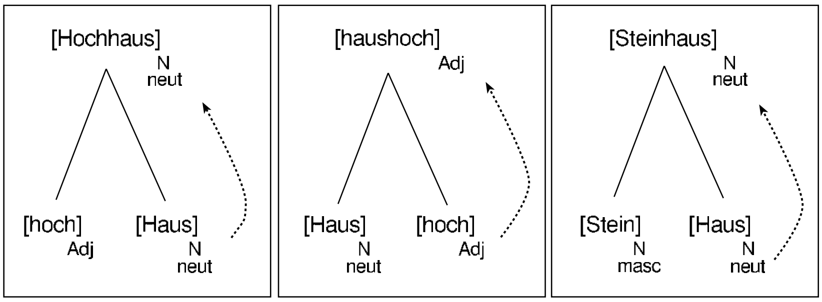

Figure 3.2: Schematic representation of the grammatical relations among German compound constituents. Compound constituents carry word class and morphosyntactic features. The features of the right most constituent percolate to the compound word and determine word class and morphosyntactic features of the compound. (See text for translations)

The concept of a level-ordered lexicon predicts that inflectional morphemes appear not only at the head constituent but also between constituents. Indeed, there are German compounds in which the initial constituent is identical in form with their plural word form, e.g. ”Traub$\underline{\text{en}}_{pl\ form}$ -saft” (grape juice). However, it does not consistently reflect semantic grounds; a snake bite (”Schlang$\underline{\text{en}}_{pl\ form}$ -biss”) is caused by only one snake, neither is such a marking required for number agreement with other sentence elements. In fact, only the head constituent has to agree syntactically with corresponding words (see also Section 3.3.5). In addition, no plural marking appears in some cases where it would be appropriate (”Apfelbaum”, apple tree or ”Fischkutter”, fishing smack). Another point of inconsistency is that the plural reading of ”Schlangen-” becomes possible if the compound is used as a plural (”Schlangenbisse”, snake[s] bites). That is, the interpretation of the initial constituent would not solely be determined by the supposed plural morpheme. This is in clear contrast to the general conception of morphemes as being the complete formal expression of some information be it semantic or (morpho)syntactic.

Another morpheme that appears between constituents (-s-) may function as a case marker for genitive as e.g. in ”Königshof” (king’s court). This principle does not apply systematically, e.g. the -s- cannot indicate genitive in ”Geburtsort” (place of birth) because the initial constituent is grammatically of feminine gender and genitive is not marked with -s on feminine nouns. Moreover, in other compounds there is no -s- between the constituents although their relation is clearly possessive and the initial constituent is masculine, i.e. genitive case is marked with -s (”Räubermantel”, robber cloak).

In conclusion, it can be stated that the right most constituent determines word class and morphosyntactic features of compounds but it remains to be shown whether morphemes between constituents are inflectional morphemes (These morphemes are further discussed under the heading linking elements in the Sections 3.3.5 and 4.2.3).

3.3.4 Semantic relations of constituents

From a semantic point of view, endocentric compounds consist of a head constituent and one or more modifiers. The head, analogous to the grammatical view, determines the semantic category of the compound. A ”computer programme” is a programme and not a sort of computer. The modifier, however, specifies the meaning of the head constituent. In the example, it is a programme that runs on a computer and not a programme on television. The semantic primacy of the head constituent can also be seen from the change in meaning if constituents change their order. A ”Glastür” (glass door) is a kind of door whereas ”Türglas” (door glas) is a kind of material.

The semantic relation among compound constituents is not expressed in the compound (Fleischer, & Barz, 1995; Ortner, & Ortner, 1984; Fanselow, 1981, for a different position). For example, a ”Königsteppich” (”king rug”, royal rug, king’s rug) can mean a rug produced by a king PRODUCT, a rug of highest quality QUALITY, or even a rug in which a king is wrapped (after being murdered; INSTRUMENT). And, more relations are possible. The correct relation has to be selected from a list of basic semantic relations if such a list is available at all, i.e. if it is stored. Linguists have tried to classify the constituent relations of compounds but the results seem not to converge. Fandrych and Thurmair (1994) found four basic relations.[17] Fleischer and Barz (1995) reported 17 compound meanings that are most productive, whereas others classified nominal compounds alone into 20 relation categories and 14 action types which are relevant for interpretation (Ortner, & Ortner, 1984). If there is no such list of basic semantic relations the appropriate relation has to be inferred by the parser as it is clearly expressed in the compound form. Moreover, as Meyer (1993) points out, the huge variety of compound meanings can also be traced to different meanings of the constituents, e.g. a ”Museumsbuch” (museum book) may be a book that is located in a museum (PHYSICAL OBJECT), a book that is written about or published by a museum (PRODUCT), and so on. At present it is still unclear what the fundamental basic relations of compounds are and whether such functions are avaiable to the parser. Here, it must remain speculation whether the flexibility of compound interpretation is the reason for the high productivity of compounding; it makes compounding a very potent mechanism to communicate facts using short(er) expressions.

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[17] The relations are *situation* (”Gartenbrunnen”, a well situated in a garden), *constitution* (”Glasflasche”, a bottle made of glas), *means* (”Nähmaschine”, a machine for sewing), and *instrument* (”Windmühle” a mill that works with wind). Most of these relations have also some subcategories (Fandrych, & Thurmair, 1994).

One relevant factor in compound processing is *semantic transparency*. It can be defined as the semantic relation of each constituent to the whole compound. These relations may be transparent as in ”Holzhammer” (”wood hammer”, mallet) which denotes a hammer made from wood. On the other hand, a compound meaning may not be related to its constituents’ meanings in so-called opaque compounds (Monsell, 1985). Examples are ”Maulwurf” (”mouth chuck”; mole), and ”Lampenfieber” (”lamp fever”; stage-fright). Semantic transparency is important because for opaque compounds the meaning cannot be inferred from the constituents and, therefore, the meaning of opaque compounds must be stored in the lexicon in addition to their constituents. It is also possible that only one constituent is semantically not related to the compound meaning as in ”Flutlicht” (flood light), or in ”Ohrfeige” (”ear fig”; a slap in the face). By enduring use and over time transparent compounds may change their meaning and become opaque. For transparent compounds it may, in principle, be possible to compute the compound meaning from the stored constituents if there is also a list stored of basic semantic compound relations (but see Sandra, 1994).

In exocentric compounds the denoted category is not determined by the head constituent. The referent of the compound is not explicitly mentioned and must be inferred from the context (Fleischer, & Barz, 1995; Ortner, & Ortner, 1984). For example, a ”Rotbart” (red beard) is a person who has a red beard, and a ”Hasenherz” (”rabbit heart”) is a coward but in neither compounds any reference is made to a person. One may say that *some* attributes of each constituent are assigned to the denoted object or person. The concept of exocentric compounds is similar although not identical to the group of opaque compounds. Exocentric compounds refer predominantly to persons, plants, and animals whereas opaque compounds do not show such a preference.

Another category are the copulative compounds (Fleischer, & Barz, 1995) which lack also semantically a hierarchical relation between constituents. In difference to exocentric compounds, copulative compounds may in principle reverse the constituent order without changing the compound meaning. Furthermore, the compound meaning shares a similar amount of meaning of both constituents but the the denoted object does not need to be inferred; it is referred to by both constituents. Examples are: ”Sofabett” (sofa bed), ”Strumpfhose” (”stocking trousers”; tights), and ”Manteljacke” (cloak jacket). Irrespective of whether the semantic hierarchy is missing (exocentric/copulative) or not (endocentric), the right most constituent is syntactically the head of these compounds in any case. The experiments of the present work will use semantically transparent and opaque endocentric compounds.

3.3.5 On the function of linking elements

Compounds sometimes contain graphemes/phonemes[18] between the free morphemes; about 35% of German nominal compounds contain such linking elements according to the Celex database (Baayen et al., 1995). These are: -s-, -n-, -en-, -er-, and -e-.[19] Linking elements cannot be inserted freely in compound words nor can they be used in any combination with a given compound. Although native speakers will generally agree on the *acceptable* compound form, there is also some variance with respect to the choice of linking elements. There are regional differences for some compounds and there are also compound (constituents) that appear with different linking elements. Speakers in some regions might argue that the compound ”Haushaltswaren” (household supply store) is correct with the linking element -s- whereas speakers of other regions might argue, for instance, that it is only correct without a linking element (”Haushaltwaren”). However, regional differences will not be considered in the present thesis. Some words take different linking elements in different compounds (”Kinderbett”, ”children bed”, cot; ”Kindbett”, childbed; ”Kindskopf”, ”child head”, silly person) or sometimes even in the same compound (”Schweinebraten” & ”Schweinsbraten”, both ”pork roast”, roast pork). Other words take the same linking element consistently if they are the first constituent of a compound, e.g. ”Handelsvertrag”, trade agreement; ”Handelsbank”, commercial bank; ”Handelsblockade”, trade blockade. Although there is some variation, there is also a high agreement among speakers concerning the choice of linking elements for most compounds. This suggests that the use of linking elements is governed by some rules.

Such rules may simply describe the functions of linking elements if they subserve any (cf. Becker (1992), who proposes an analogy based selection of linking elements). Fuhrhop (1998, 2000) describes four possible functions, namely a syntactic, a prosodic, a morphological, and a semantic function. According to Fuhrhop linking elements may indicate a genitive relation of constituents, prevent too many stressed syllables in a row, preserve morpheme boundaries, and indicate the semantic hierarchy of constituents.

The appearance of the -s- between constituent suggests a syntactic function; the -s- may indicate a genitive relation between constituents as was said in Section 3.3.3. That is, in ”Erfolgskontrolle” (”success control”, control of success) the -s- may be a remain of the

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[18] Phonemes are the smallest phonological units that may change the meaning of larger units but carry no meaning themselves. For instance, the phonemes /b/ and /d/ are meaningless but change the meaning in ”big” and ”dig”. A grapheme is the associated letter.

[19] Other linking elements such as -es- are unproductive, and -ens- and -o- are rarely used (Fuhrhop, 2000). The forms -o- and -i- appear only in concatenations of loan words and may be already opaque with regard to the status of a linking element, e.g. in ”Elektromotor”, electro motor, ”Nachtigall”, nightingale, or ”Bräutigam”, groom (Fleischer, & Barz, 1995).

case inflection -s for genitive ("Kontrolle des Erfolgs"). However, this function does not apply systematically (see Section 3.3.3) and is, therefore, questionable.

The prosodic function Fuhrhop (Fuhrhop, 1998, 2000) describes, is to avoid the succession of too many stressed syllables. Consider the German compound "Rind.fleisch" ("beef meat", beef; the dots indicate syllable boundaries). It does not contain a linking element but -er- is inserted for the compound "Rin.der.hack.fleisch" ("beef chop meat", minced meat). Fuhrhop states that *schwa* (-e) syllables (".der." in the example) cannot be stressed and all linking elements, except -s-, appear only in schwa syllables. That is, one may assume that linking elements are inserted for prosodic reasons; because they cannot be stressed they avoid too many stressed syllables in a row. The -s- has no syllabic status[20], i.e. -s- can appear in stressed syllables and cannot, therefore, hinder the succession of stressed syllables. Fuhrhop (1998) claims that the /s/ cannot be combined with any syllable initial consonant in standard German[21]; the /s/ remains always at the end of a syllable. Therefore, it remains also with initial constituents in compound words, yielding the correct syllabification for "Hoch.zeits.rausch". Without the /s/ the last consonant of initial constituents may be bound phonologically to the onset of the next syllable. This would result in an incorrect syllabification, e.g. *"Hoch.zei.trausch" (wedding flush). It is unclear whether for the same or for another reason the -s- is not bound to the following syllable if it begins with a vowel ("Ar.beits.es.sen", working dinner). The other linking elements that end in -n and -r do not attach to subsequent syllables due to their high sonority[22] (Pompino-Marschall, 1995; Vennemann, 1988). For these reasons Fuhrhop (1998) suggests a possible morphological function for linking elements: to mark the morpheme boundary by a syllable boundary. She points out that there is no preference for the cooccurrence of morpheme and syllable boundaries in German; otherwise such a function of linking elements were redundant.

The proposed semantic function of linking elements is to indicate the hierarchical order of constituents (Fuhrhop, 1998). If, for example, the compound "Kirchturm" ("church tower", steeple) is changed to "Kirchturmsuhr" (church clock) the linking element -s- shows that "Uhr" is modified by "Kirchturm". In doing so, the alternative interpretation ("Turmuhr" modified by "Kirche") is excluded. That is, linking elements may indicate the se-

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[20] Neither has the -n- syllabic status, but the -n- appears only in schwa syllables (Fuhrhop, 1998).

[21] Although the letter s occurs word initially together with other consonants (e.g. "Stein", stone; "Stock", stick) it is always produced as /ʃ/ (i.e. /ʃtajn/ & /ʃtɔk/). Fuhrhop claimes that there is only one exception, namely "Skat", /skɑ:t/, a card game. It remains unclear for what reason she disregards "Skizze", /skɪtzə/ (sketch) or "Skandal", /skandɑ:l/ (scandal); possibly they are ignored because they are taken to be loan words.

[22] Sonority is a perceptual property that refers to the loudness of a sound (phone) in relation to other sounds (phones) with the same length. It reflects the degree of resonance with which the oral or nasal cavities vibrate (Giegerich, 1992; Mateescu, 2003).

mantic hierarchy among compound constituents. Although this seems plausible, it is not systematically the case. There are numerous three-constituent compounds without a linking element but a clear semantic hierarchy in the sense just reported (”Werkzeug”, tools; but ”Werkzeugkasten”, tool box; in which the -s- would be required according to the semantic function: *”Werkzeugskasten”). Another function of linking elements that touches semantic aspects, is to indicate plural of initial constituents (see below).

Another proposed function of linking elements is the ability to re-open morphologically closed words (Aronoff, & Fuhrhop, 2002). Words are morphologically closed if their derivational suffix cannot be followed by other derivational suffixes that are expected to follow because they fulfil all selectional restrictions. The German closing suffixes, identified by Aronoff and Fuhrhop (2002), are -ling, -keit/, -in, -isch, -igkeit, -ung, -heit/, and -e$_{suffix}$. For instance, the words ”Prüfling” (examinee) and ”Tapferkeit” (bravery) are morphologically closed by the suffixes -ling and -keit. These words cannot be further derived, i.e. *”Prüf-ling-lein” (diminutive of examinee) and *”tapfer-keit-lich” (brave) are ungrammatical. Note that both suffixes -lein and -lich require a noun as the base form. Both ”Prüfling” and ”Tapferkeit” are nouns and fit the selectional restrictions of the suffixes. The closing suffixes are claimed to end the derivational process and to hinder compounding with these morphological forms. Linking elements are suggested to re-opened these closed morphemes so that they can enter a compound word as nonhead constituent (”Prüflingsangst”, examinee’s fear; ”Tapferkeitsmedaille”, bravery medal).

There are some counter examples (”ein-heit-lich”, unitary) which are claimed to be lexicalised and non- productive. Although there may be only a few counter examples, the proposed function presupposes other, grammatical functions of linking elements. In the analysis of Aronoff and Fuhrhop (2002) all cases of linking elements were excluded that bear a plural meaning (see below) or formed a genitive of initial constituents. Hence, the claim of the re-opening function of linking elements implies the approval of other, grammatical functions. However, the proposed genitive and the plural functions are themselves questionable and have not been confirmed yet. Thus, the function of linking elements, to re-open closed morphemes, cannot be taken for granted.

Linking elements are often identical in form with the plural marker of the initial constituents as mentioned in Section 3.3.3. That is, they may function, in principle, as plural morphemes of initial constituents. If so, they mark formally a semantic feature (number). Sometimes, the modifier denotes more than one object (”Liederabend”; ”songs night”; recital) and in such cases the linking element may plausibly reflect this fact. Although the apparent plural function seems plausible for many compounds, it does not occur systematically and, moreover, is not semantically constant but the interpretation may change with the marking of the head constituent (see Section 3.3.3). Furthermore, the proposed plural marking is irrelevant for agreement marking. Hence, the proposed plural function of linking elements is rather questionable.

With regard to the plural interpretation of linking elements it seems important to note that not all German plural morphemes may appear between compound constituents as a possible plural marker (Wegener, 1992; Wiese, 1996). The -s- cannot appear as a linking element if initial constituents' plural is marked with -s (*”Autosverkauf”, car sale). Wegener (1992, 1999) reports on some counter examples (”Chipstüte”, crisp bag; ”Kuckucksinsel”, cuckoo island) but the mechanism is unlikely to be productive since the known examples are very sparse. However, if linking elements do indicate number of initial constituents, the non-appearance of -s- has to be explained. The lack of -s- in compounds as a possible plural morpheme is mostly explained in linguistic theory with the structure of the lexicon. The order of compound formation proceeds, for instance, on three strata (or levels): irregular inflection – compounding – regular inflection. The levels are strictly ordered processing proceeds unidirectionally. According to this order, regular plural morphemes (-s; Wiese, 1996) cannot attach to initial constituents because they are applied after compounding took place. That is, the -s alone cannot appear between constituents (Kiparsky, 1982; Wiese, 1996).

To summarise, there is no agreement on *the* function of linking elements; syntactic, prosodic, morphological, and semantic functions have been suggested. It is well possible that different functions apply to subgroups of linking elements. In this case, these subgroups have to be determined independently of the proposed functions. Up to date there is no linguistic argument favouring one interpretation over another.

3.4 Summary

This chapter introduced the linguistic conceptions of the lexicon and the structure of lexical entries. The lexicon stores at least all idiosyncratic information of words. The lexicon contains free and bound morphemes, i.e. underspecified representations of words (word stems) and derivational and inflectional suffixes. A lexical entry is characterised by the word form and the respective content. The word form is the according sound or spelling and the content is divided into a semantic form (meaning) and a grammatical form. The grammatical form in turn, consists of word class information and morphosyntactic features. Fixed morphosyntactic features are assumed to be stored in the grammatical form whereas variable morphosyntactic features need specification in a given (syntactic) context, hence, they are not stored in the grammatical form. Free morphemes can be combined productively in German, yielding compounds. Compounds are internally structured. The right most constituent determines all (morpho)syntactic features of the compound in German and mostly also the semantic category of the compound. The nonhead constituents modify semantically the meaning of the head constituent. Sometimes compounds contain linking elements between constituents. However, the function of linking elements is not precisely understood yet. Compounding and derivation are usually thought to be lexical processes whereas this is more controversial for inflection. Intralexical connections among lexical entries are not specified, i.e. no effects of semantic associations among morphemes are predictable.

Chapter 4

The empirical stance

The most linguistic conceptions discussed in Chapter 3 suggest that lexicon contains underspecified entries (word stems and bound morphemes). The processes of feature specification and morphological combination are taken to be lexical processes.

This chapter is concerned with empirical research that addressed the question of how such lexical processes can be linked to human language performance. Empirical findings are reported that relate to lexical processes and compound processing.

4.1 The mental lexicon and processes of word formation

Given the large amount of entries to be stored in the mental lexicon[1] and the fact that new words are encountered (and understood) rather often, it is plausible that the structure of the mental lexicon is adapted to permit an efficient storage and retrieval of the entries. One efficient organisation principle is to store semantic representations of semantically related words together and to group also form related entries together. As said earlier, it is undecided yet whether the form representation is word or morpheme based (Sandra, 1994) but morphological structure is suggested to be encoded in the mental lexicon (Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000; Marslen-Wilson, Tyler, Waksler, & Older, 1994; McQueen, & Cutler, 2001; Schriefers, Friederici, & Graetz, 1992), possibly besides whole word/compound representations (Marslen-Wilson, 2001; Schriefers, Zwitserlood, & Roelofs, 1991; Zhou, & Marslen-Wilson, 2000). A mechanism of interlinked entries was proposed by Collins and Loftus (1975) in the spreading activation hypothesis. According to this hypothesis the lexicon is conceived of as a semantic net (see Fig. 4.1). The meaning of

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[1] The English and the German vocabularies contain about 300,000-500,000 words, and high school graduates are estimated to have 60,000 words represented in the mental lexicon (Miller, 1993).

lexical entries is represented by nodes and the strength of the links represents the strength of the semantic association among entries. Nodes can be activated and the activation can spread across links to other entries. The conditions for selection of an entry depend on the conception. For example, an entry may be selected if it reaches a specific activation threshold (e.g. by a matching input signal) or has the highest activation among candidates. In this way a semantic expectation or context may be build up. If one or a couple of words are accessed from the lexicon they may strongly activate other words that are semantically closely associated; words that are less strongly associated would be less activated. Besides effects of facilitation there may also be inhibitory effects among entries. Note that, according to some linguistic theories, such a net is restricted to lexical semantics, i.e. denotations. If so, connotations (and world knowledge) would then be stored in a separate (conceptual) system.

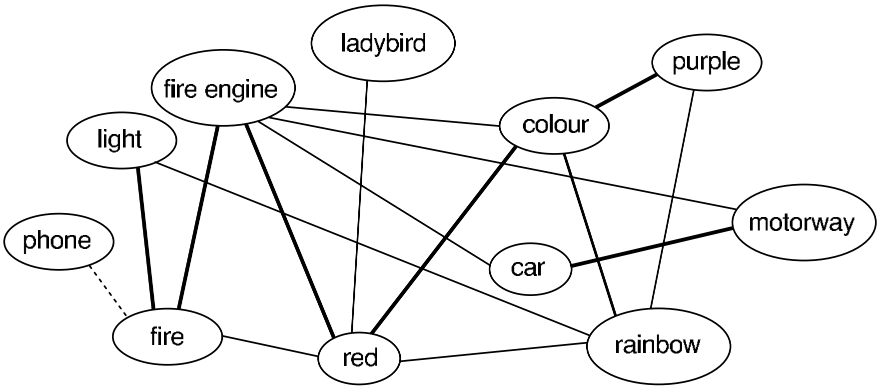

Figure 4.1: The semantic net of lexical entries. The meaning of entries (the semantic form) is represented by nodes and the semantic relation by links among entries. The stronger the semantic association the stronger the link (represented by thicker lines). Activation of a node flows via the links to other semantically related nodes and increases their activation. Note that the meaning of opaque compounds is stored separately in a lexical entry (cf. ”ladybird”). For novel compounds linked or unlinked (dashed line) nodes may have to be combined (cf. ”fire light” & ”fire phone”, respectively).

The hypothesis of interlinked lexical entries leads to testable predictions. Aphasic patients often produce semantically related paraphasias in naming tasks which supports the assumption that the mental lexicon is structured according to semantic relations among the entries (Stachowiak, 1979). In addition, the access of one entry should facilitate the access of other, semantically related entries but not of semantically unrelated entries. Similarly, the identification of repeated letter strings that constitute morphemes, should be facilitated in comparison with the identification of repeated letter strings that do not constitute morphemes. (To control for effects of orthographic overlap the stimuli are usually printed in different fonts.) In fact, such effects are obtained using different methods, for instance, lexical decision tasks or semantic categorisation tasks. In these tasks subjects have to decide whether presented items are words or nonwords, or belong to one or another semantic category, respectively. In another experimental paradigm, repetition priming, the effects of morphological relatedness are assessed. The repetition of parts of a word which coincide with a morpheme, are processed faster compared with repetitions of word parts which are non-morphemic (cf. Andrews, 1986; Frost et al., 2000; Sandra, 1990; Taft, & Forster, 1976; Zwitserlood, 1994). Since the relevant information for such tasks is stored in the lexicon, the entries of the stimuli have to be accessed. Hence, differences in reaction times (RT) may reflect lexical-semantic association strengths.

4.1.1 The independence of word formation processes

Compounding, derivation, and inflection are logically independent processes, according to linguistic conceptions. Compounds can be derived (e.g. ”Maulwurfslos”; moleless), and derivations can enter compounds (e.g. ”Schönheitsklinik”; beauty$_{deriv}$ clinic); both compounds and derivations undergo inflection. Inflection is often conceived of as a syntactic, i.e. not a lexical process (Anderson, 1982). There is, however no definite empirical evidence for either position. As the level-ordering approach is used here as a working model, inflection is assumed to be a lexical process (Kiparsky, 1982; Wiese, 1996).[2]

The psychological reality of independent word formation processes is supported by evidence from brain damaged patients.[3] On the one hand, compounding may be specifically impaired in the face of preserved inflectional morphology of simple and derived nouns (Delazer, & Semenza, 1998; Luzzatti, & De Bleser, 1996). Delazer and Semenza (1998) report on a patient with naming difficulties who was severely impaired in several compound production tasks (confrontation naming, repetition, reading, etc.) but had almost no problems with monomorphemic words. Luzzatti and De Bleser (1996) investigated thoroughly two agrammatic patients who showed a good performance in inflectional tasks with single nouns and derivations (gender and number determination and/or realisation). However, both patients showed an almost complete loss when gender and/or number had to be assigned to compounds. From these results the authors concluded ”that the morpholexical rule system is preserved for inflection as well as derivation but not for compounds” (ibid. p. 59). On the other hand, compound formation knowledge may be retained in aphasic patients (Hittmair-Delazer, Andree, Semenza, Bleser, & Benke, 1994; Mondini, Jarema, Luzzatti, Burani, &

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[2] This issue is not central to the present work; neither can it be decided here.

[3] Unfortunately, the patients’ lesions are hardly described in detail. Mostly only neuropsychological testing is reported.

Semenza, 2002, see also Trumpp, 2003). Hittmair-Delazer et al. (1994) reported on 15 patients with different neuropsychological classifications.[4] These patients had to name pictured objects with an appropriate compound word. Almost all paraphasias and neologisms respected the compound structure and German word formation rules. In addition, if a constituent was named correctly it always kept its position. These findings suggest that the patients, although aphasic, retain knowledge of morphological compound structure and that this knowledge is neurologically distinct from the lexical knowledge of constituents. Mondini et al. (2002) found that an agrammatic and a non-fluent aphasic patient[5] performed superior on inflection within adjective-noun and noun-adjective compounds compared with inflecting the same words in non-compound phrases. In a similar vein, Cholewa and De Bleser (1996) reported dissociations of the morphosyntactic processing of monomorphemic, derivational, and compound words in four aphasic patients.[6] Two of these patients showed selectively impaired access to the syntactic gender of nouns or compounds in article production and/or selection tasks.

The distinction of inflection and derivation was also confirmed by experimental evidence (Miceli, & Caramazza, 1988). An Italian patient[7] showed an inflectional impairment but committed little derivational errors. In spontaneous speech he committed an enormous amount of inflectional errors, i.e. violations of determiner-noun, noun-adjective, and subject-verb agreements. In addition, almost all of his morphological errors in single word repetition tests were inflectional but only very few errors were derivational. Thus, the authors concluded that derivation and inflection are subserved by distinct neurological systems.

In summary, the patient data suggest that processes of word formation, compounding, derivation, and inflection, are independent cognitive functions. The occurrence of inflectional errors in single word repetition (Miceli, & Caramazza, 1988) supports empirically the claim that inflection is also a lexically driven process, unless it is assumed that single word repetition involves syntactic operations.

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[4] These patients were classified as anomic (5), Broca's (4), Wernicke's (2), and transcortical (2) aphasics. Two patients were not classifiable.

[5] Their aphasias resulted from a vascular lesion in the left frontoinsular area and an infarct in the region of the left middle cerebral artery, respectively.

[6] Classified as Broca's aphasics resulting from a left hemispheric infarct and atrophy.

[7] This patient suffered from a hypodense area in the left hemisphere, which involved the temporal lobe in its anterior and middle portions, the claustrum, the internal capsule and probably the insula, as well as the white matter of the parietal lobe.

4.2 The psycholinguistics of compound words

4.2.1 The storage form

Efficient processing of morphologically complex words involves a trade-off between storage and calculation costs (cf. Sandra, 1994). One approach to lexical representation of compounds reduces calculation costs but maximises storage costs. It is represented by the full-listing hypothesis (Butterworth, 1983; Bybee, 1995) which assumes that all compound words have their own lexical entry besides the entries of the respective constituents. Another approach assumes that compounds are not stored in the lexicon; instead compounds are generated each time by combining those lexical entries needed. In comprehension, a mechanism preceding from left-to-right extracts the underlying morphemes (so-called decomposition; Taft, & Forster, 1975, 1976). Either the word stem or the initial syllable is then used as an access code to the entry in the mental lexicon. Such theories assume an extensive morphological analysis (Libben, 1994; Libben, Derwing, & de Almeida, 1999; Taft, 1994), thereby increasing calculation costs and reducing storage costs.

It is unclear how novel compounds are processed in full-listing models (without a morphological analysis) because novel compounds cannot have a lexical entry. A similar point can be made for models assuming a complete morphological analysis; how are semantically opaque compounds processed given that their meaning cannot be generated from the meaning of their constituents?

Andrews (1986) showed that the parser is sensitive to the morphological structure of compound words. In a lexical decision task, she investigated the processing of compounds whereby the whole word frequency was constant but compounds differed with respect to the frequency of their first constituent[8] (Andrews, 1986). On the basis of a full-parsing model (Taft, & Forster, 1976) a facilitation for compounds with a high frequency first constituent was predicted as it serves as an access code. This was, however, not found; compounds with a high frequency first constituent were classified as quickly as the control items (pseudo compounds; e.g. ”Trombone”). Moreover, a low frequency first constituent slowed down the classification decision suggesting that inhibitory processes are responsible for the RT differences between high and low frequency conditions. Andrews (1986) concluded that the parser is sensitive to the morphological structure of complex words although the full-parsing model needs a second processing route.

Dual-route models take an intermediate position between full-listing and full-parsing models. In dual-route models, the storage of compound words depends on their proper-

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[8] Andrews talks about first syllables. However, for all but one item the first constituent was monosyllabic.

ties, e.g. frequency of use or semantic status (Baayen et al., 1997; Caramazza et al., 1988; Isel, Gunter, & Friederici, 2003; Sandra, 1990; Schreuder, Neijt, Van der Weide, & Baayen, 1998; Zwitserlood, 1994). High frequency compounds and semantically opaque compounds (e.g. ”greenhorn”) have their own lexical entries because it is more efficient to store the former instead of calculating them each time anew, and the meaning of the latter cannot be derived from the constituents. Low frequency and semantically transparent compounds (e.g. ”buffalo horn”) are not stored in the lexicon because it affords little effort to generate them as they are not often used, and the meaning can be derived from the constituents (Coolen, van Jaarsveld, & Schreuder, 1991; Gagné, 2002, for novel compounds).

Different storage forms entail different access processes. Compounds that are stored in their full form may simply looked up whereas others that have no full form representation require some computation (cf. Fig. 4.1). Support for different processing routes during compound comprehension comes also from eye movement studies[9]. In a (Finnish) sentence reading study, the frequency of the initial constituent was found to influence the duration of the first and second fixation on the compound word (Hyönä, & Pollatsek, 1998). The fixations were shorter if the constituent had a higher frequency. A higher frequency of the initial constituent reduced also the probability of subsequent fixations which may reflect an easier processing of the respective compound. These effects suggest that the parser is sensitive to the morphological structure and that the frequency of initial constituents affects an early stage of reading. The effects cannot be explained by whole word frequency or constituent length as these were controlled for. The shorter fixation duration suggests that, after decomposition, the initial constituent is found faster in the lexicon due to its higher frequency. In addition, the frequency of the head constituent (the last constituent) was also found to influence reading measures. Here, the effects occurred only at later stages (probability of third fixations and gaze duration; Pollatsek, Hyönä, & Bertram, 2000). Again, frequencies of initial constituents and of the compound were controlled and cannot explain the effects. The authors assumed that comprehension takes place in several stages. First, morpheme boundaries are identified and constituents are accessed. Later on, after all constituents have been accessed, they are integrated, i.e. the meaning of the compound word becomes available. If that is true, the frequency of the compound (whole word frequency) should affect reading measures only late, possibly at the same time as the head constituent is processed. Pollatsek et al. (2000) found an effect of compound frequency but it occurred rather early. The duration of the second fixation on the compound was shorter if the compound had a higher frequency.

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[9] For the processing of visual information the eye does not make continuous movements. Instead periods of fixation alternate with (short) periods of movements, so-called saccades. In eye tracking studies, locations of fixations are recorded both spatially and temporally. That is, information is gained what people look at, when, and how long.

There was already a tendency to shorter fixation durations of first fixations. Given the sequential frequency effects of initial and second constituents plus the early frequency effect of the compound form, it was concluded that compounds are processed via two routes that run in parallel. Hence, these results support a dual-route architecture of the reading system. Whereas these results are based on frequency effects, another factor influencing compound processing, is semantic transparency.

4.2.2 Semantic transparency

Earlier behavioural studies investigated mostly two-constituent compounds in the visual modality. Sandra (1990) and Zwitserlood (1994) showed in repetition and semantic priming experiments that semantically opaque as well as transparent compounds activate the morphemes of both of their constituents. However, opaque compounds did not activate the meaning of either constituent whereas transparent compounds did. This suggests that the parser disposes of two processing routes; a direct route, which accesses lexical entries via a whole word representation, and a decompositional route, which decomposes morphologically complex words into their morphemes and activates the lexical entries of compound constituents. These routes may operate in parallel in a race fashion, or in a cascading[10] mode (cf. Baayen et al., 1997). However, the eye movement studies quoted above suggest that the routes work in parallel (Hyönä, & Pollatsek, 1998; Pollatsek et al., 2000, see also Bertram, & Hyönä, 2003).

Because the priming experiments made use of simultaneous visual presentation it is unclear which constituent is processed first, or whether both are processed at a time. Thus, it is not possible to tie certain effects specifically to the processing of one constituent. Experimental effects related to the first constituent may, in principle, be affected by processing of the head constituent.

The time course of constituent activation may, however, be examined in the visual modality by recording the eye movements during reading. A sentence reading study differentiated two cognitive processes of compound comprehension (Inhoff, Radach, & Heller, 2000). German speaking subjects read sentences containing transparent three-constituent compounds while their eye movements were recorded. The compounds appeared in three different conditions. In a standard condition, compounds were written according to German orthography ("Datenschutzexperte", data protection expert). In a second, the upper case condition each constituent began with a capital letter ("DatenSchutzExperte") and in a third, the spaced con-

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[10] One route is employed only after the failure of another; the principle order of processing stages is preserved but successive processes may overlap partially.

dition constituents were separated by a space ("Daten schutz experte"). The upper case and the spaced conditions are orthographically illegal in German. Results in the upper case and standard condition did not differ from one another. The spaced condition, however, yielded generally shorter first fixation durations than the standard condition which suggests that constituent marking by spaces facilitates constituent recognition. An adverse effect of spacing was observed on the last fixation if three or four fixations were necessary for compound reading. Last fixations (and post target fixations) increased in duration compared with first fixations whereas the opposite was true for the standard condition. In the standard condition last fixation durations declined generally in comparison to first fixations. Inhoff and colleagues (2000) argued that interconstituent spaces help to identify constituents and, thereby, speed up constituent access. By the same token, they note that the head constituent is less distinctive as it cannot be differentiated from the following word. This does not only explain the prolonged fixation duration on the post target word but also the increase in last fixation durations. The first process of constituent recognition is facilitated by inserted spaces but the process of assignment of compound meaning is hindered. The assignment of compound meaning hinges on the identification of the head constituent as the head determines the semantic category of the word (see Section 3.3.4). These data suggest that reading (comprehension of) compounds involves a process of separate constituent recognition followed by the specification of a (conceptually unified) compound meaning (Inhoff et al., 2000, cf. also Juhasz, Starr, Inhoff, & Placke, 2003). Because the head constituent has semantic primacy the initial constituent has to be subordinated to the head constituent. Inhoff, Brihl, and Schwartz (1996) found longer first fixation durations on compounds than on suffixed or monomorphemic words. The three categories were matched for frequency and number of letters and cannot explain the effect. These authors argue that the effect is due to the atypical distribution of meaning-defining information in compounds. In compounds the end section (head) carries the meaning-defining information but in suffixed and in monomorphemic words the beginning is claimed to be most informative (Inhoff et al., 1996). These eye tracking results show that the temporal order of reading processes can be disentangled and support the idea of morphological decomposition. However, the interpretation cannot be extended to all types of compounds because only transparent ones were investigated. In addition, the results must be interpreted carefully because eye movement measures (e.g. fixation duration) are sensitive to several cognitive processes (see Chapter 5).

Recent experiments investigated the processing of two-constituent compounds in the auditory modality, i.e. experimental effects can be linked to particular constituents due to their temporal order (Isel et al., 2003; Wagner, 2003). Wagner (2003, Ch. 6 & 7) presented subjects acoustically with novel compounds that contained an ambiguous word as initial constituent. With a cross-modal priming design she examined the semantic activation of the ambiguous constituent at different points in time. While listening to the compounds subjects performed a lexical decision task to visually presented target words. The target words were semantically related to the dominant or subordinated meaning, or unrelated to the initial constituent. At the acoustic end of initial constituents (still followed by the head constituent) reaction times were faster for related than for unrelated target words. This priming effect suggests that both meanings of the ambiguous word were activated at this point. In addition to behavioural measures, the ERP was recorded. The visual target words elicited an N400 that was modulated in its amplitude by the semantic relation to the ambiguous constituent. At the end of initial constituents but not 150 ms before, both semantically related target groups elicited a significant N400 effect. The results show that both meanings of ambiguous initial constituents were activated and suggest that compounds are semantically decomposed.

Contrary to Wagner, Isel et al. (2003) used low-frequency lexicalised compounds. These were divided into four groups that differed in their semantic status; each constituent was either transparent (T) or opaque (O) yielding the four combinations TT, OT, TO, and OO (cf. Libben, 1994, 1998, for a similar approach in the visual domain). In a series of four experiments, semantic activation of initial constituents was tested in a cross-modal semantic priming paradigm at different positions of the compound, i.e. at the end of initial and last constituents. It turned out that the semantic status of head constituents alone was relevant for the semantic activation of initial constituents. There was only an activation of initial constituents if the head was transparent and only at the offset of the compound. Initial constituents were not semantically activated at their end in any condition.

The authors interpreted their findings in favour of a cascading dual-route model. In this prosody-assisted head-driven (PAHD) model the acoustic input is processed continuously and the output of the acoustic phonetic analysis is mapped onto lexical entries via a direct route. If the prosodic structure of the initial morpheme which is analysed in parallel, indicates a morphologically complex word a decompositional route is called up. Isel et al. (2003) found the duration of the first constituent to be a valid parameter to signal morphological complexity. The decompositional route works in addition to the direct route and extracts the right constituent. Thus, a morphological unit for each constituent can be used as an access code to lexical entries if needed. As soon as one route is found to be appropriate the other route is disregarded. That is, opaque compounds should be accessed via the direct route as they have an own lexical entry and have no semantic relation to the lexical entries of their constituents, whereas transparent compounds do not need to have their own lexical entries (especially if they are of low frequency) and may be processed by integrating the information of two lexical entries activated by the decompositional route. The crucial assumption of the PAHD model is that for each constituent a morphological representation must be accessed in case the meaning of a compound must be analysed by activating the lexical entries of each constituent. Such a mechanism might explain how novel compounds are understood.

4.2.3 Linking elements

Several functions have been proposed for linking elements and some have also been addressed empirically. The selection of linking elements is language specific (Jarema, Libben, Dressler, & Kehayia, 2002). However, Dutch and German are closely related Germanic languages and findings from Dutch appear relevant for the present investigation. It has been argued that the Dutch linking element -en- is a plural morpheme and evokes a plural interpretation of initial constituents (Schreuder et al., 1998). In a number decision experiment Schreuder et al. (1998) found increased decision times for singular compounds that included -en- as a linking element (”boek<u>en</u>kast”, bookcase) compared with singular compounds that included the homophonous but meaningless -e- (”lamp<u>e</u>kap” lamp shade). The authors suggested that a plural semantics was activated due to the linking element which becomes available only after decomposition. In another experiment subjects rated the plurality meaning of initial constituents higher for those compounds that included the -en- compared with -e- (Schreuder et al., 1998). Krott, Krebbers, Schreuder, and Baayen (2002), on the contrary, showed that the choice of Dutch linking elements is co-determined by the form properties of both constituents, i.e. they do not belong to the first constituent as a suffix. The authors suggests that the choice of linking elements is determined by the constituents’ family sizes. The constituent family size is determined by the number of compounds that share the constituent in question and contain the same linking element. The choice of a linking element for novel compounds is determined by the frequency with which each linking element is used by the left and the right constituent, i.e. by the family size of both constituents.

Turning to German, there are two behavioural studies that investigated the influence of linking elements in a visual decomposition (Dressler, Libben, Stark, Pons, & Jarema, 2001) and composition task (Libben, Jarema, Dressler, Stark, & Pons, 2002). In the former, subjects had to name either the first or the second constituent (indicated by an arrow), and in the latter they had to produce a compound from two given words. Response latencies were recorded separately for predefined categories of linking elements. These categories were formed according to presumed grammatical and morphological functions. The response patterns across the experiments are similar with the decomposition task generally resulting in longer RTs (both experiments used the same stimuli) which was interpreted as an effect of difficulty. The categories of linking elements, however, did not yield a clear pattern of RTs. For example, in neither experiment subjects responded differently to -s- linking elements, which were possible (”König$\underline{s}_{gen\ form}$ -hof”) or impossible (”Geburt$\underline{s}_{non\ gen}$ -ort”) as a genitive marker. The authors showed that the RTs, instead of being determined by grammatical categories, are more determined by the consistency with which a linking element is taken by a preceding constituent (Libben et al., 2002) which might be interpreted as a constituent family size effect. Compounds whose initial constituents take always the same linking element were responded to faster than compound whose initial constituents take different linking elements.

This interpretation corresponds with Krott’s (2001, Ch. 6) finding that linking elements are determined by statistical regularities in German, too (cf. Haskell, MacDonald, & Seidenberg, 2003, for the involvement of statistical regularities in English compounds). Krott found, in contrast to Dutch, that the selection of German linking elements is determined by form properties of left but not of right constituents. The features rime, gender, and inflectional class of the left constituent also increased prediction accuracy which suggests that these features are involved in the selection of linking elements. Note that linking elements are suggested to be independent entries in the lexicon (see Fig. 4.2). The selection of linking elements can be described by the activation metaphor. If a linking element is to be chosen for a novel compound the linking elements are activated by existing compounds with the same initial constituent as the novel one. The linking element that is used by the largest constituent family gets the highest activation. In addition, linking elements are also activated (too a less degree) by all existing compounds for which the initial constituent agrees in rhyme, syntactic gender, and inflectional class with the initial constituent of the novel compound (Krott, 2001). This mechanism presupposes that the left-hand constituent is available to the parser, i.e. that decomposition takes place. Furthermore, it suggests that linking elements bear no grammatical function as they are selected by analogy to other compound forms instead of being processed by grammatical rules. The set of German linking elements used by Krott was a subset of the linking elements investigated by Dressler et al. (2001), and Libben et al. (2002). When Krott reanalysed her data, RT patterns turned out to follow the bias of constituent families instead of the prediction by grammatical categories.

The finding of a patient study also suggests that linking elements are not inflectional morphemes (Costard, 2001). In a reading, lexical decision, and a repetition task, the processing of compounds with and without linking elements was investigated (e.g. *”Arbeit$\underline{s}$geber”, employer and *”Arbeitplatz”, workplace). If the linking element were an inflectional mor-

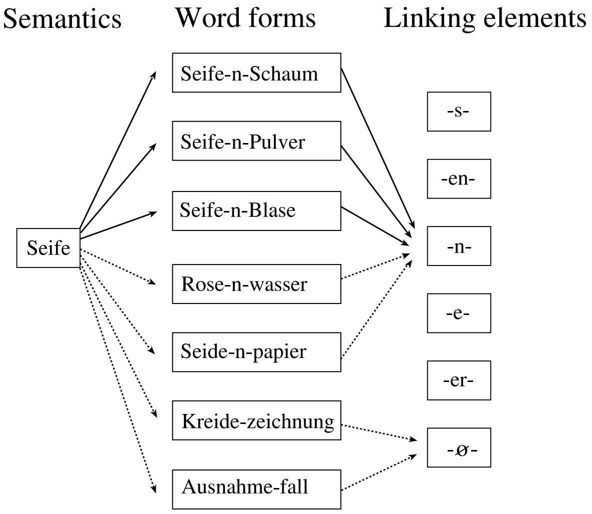

Figure 4.2: The selection of a linking element for a novel compound, e.g. "Seife-?-stift" (soap pen), by existing compound forms (left constituent family) and compounds that share rime, gender, and inflectional class according to Krott (2001). The upper three word forms represent members of the left constituent family and the first constituents of the lower four word forms share the rime (ending in schwa), gender (feminine), and the inflectional class with the target constituent "Seife".

pheme, performance should be worse for compounds with a linking element compared with compound that did not include a linking element. This is expected because the processing of elements of the closed-class[11] (incl. inflectional morphemes) is often impaired in aphasic patients. However, the aphasic patients'[12] accuracy rates were not different for compounds with and without linking elements which suggests that they are not processed as inflectional morphemes (Costard, 2001).

The function of German linking elements was also investigated in a morphological priming study (Jarema et al., 2002). Subjects carried out a lexical decision task on compounds which were primed by different forms of the initial constituent. Reliable priming effects were only found for letter strings that represented syntactic words. It did not matter if they did not include the linking element of the compound word or if they even contained another linking element ("Frau" primed "Frau<u>en</u>heim", women's home, or "Firm<u>a</u>" primed "Firm<u>en</u>sitz", principle office). However, letter strings that are not syntactic words (which

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[11] Word classes that subserve primarily grammatical (syntactic) as opposed to lexical functions, e.g. article, prepositions, conjunctions etc. This class stands in opposition to open-class words; cf. footnote 16, p. 50.

[12] Costard (2001) investigated 23 aphasic patients with a vascular aetiology. Among them were 8 Wernicke's, 9 Broca's, 1 amnestic, 1 global, 1 not classifiable, and 1 residual aphasic patient.

cannot stand alone) do not lead to significant priming although they are present in the compound word form (*"Firm" in "Firmensitz", and *"Supp" in "Suppentopf", stock pot). That is, morphological priming was only achieved by full word forms which suggests that missing or even diverging linking elements are not included in the morphological representation of constituents. In general, Jarema and colleagues concluded that linking elements "have no morphological status beyond that of linking a compound's first constituents to its second constituents" (p. 745; Jarema et al., 2002). Note that Jarema et al.'s but not Krott's interpretation is compatible with the alternative assumption that linking elements are processed by a morphological or phonological rule instead of being lexical entries. Nevertheless, they agree that linking elements carry no grammatical function.

In a similar vein, Gawlitzek-Maiwald (1994) interprets language acquisition data from German in favour of a connecting function of linking elements instead of being a plural marker (see also Haskell et al., 2003). As she points out, the assumption of a level-ordered lexicon and the distinction between regular and irregular plural morphemes (cf. Section 3.3.1) have several implications. For example, if linking elements are plural morphemes one expects that errors in linking elements show the same pattern as errors in plural formation of single nouns during language acquisition. In addition, those plural morphemes that are overgeneralised (treated as regular morphemes by the child) should not be found as linking elements in compounds at the same period of acquisition. However, the observations by Gawlitzek-Maiwald did not conform to these implications. The children (*N*=4) did commit much fewer 'inflectional' errors in compounds than for single nouns. There was also no clear correlation between plural morphemes that were overgeneralised and those omitted as linking elements in compounds. Thus, the results contradict the notion that linking elements are functionally equivalent with plural morphemes.

However, in a number of studies on language acquisition as well as on the processing of number inflection it has been claimed that linking elements are processed as plural morphemes of initial constituents and, therefore, have a grammatical function (except for the -s- which does not appear as a plural marker in compounds; Bartke, 1998; Clahsen, 1999; Clahsen, Marcus, Bartke, & Wiese, 1996; Clahsen, Rothweiler, & Woest, 1992). The argument rests on the distinction of regular vs. irregular plural morphemes (Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995, in analogy to English; Pinker, 1991), and on the observation that those plural morphemes that are overgeneralised by children (i.e. they are regular) are often omitted as linking elements in compounds. This correlation is predicted by linguistic theory, e.g. by the level-ordering account (Kiparsky, 1982) which got soon empirical support and was even claimed to be innate (Gordon, 1985). Gordon stated that if the level-ordered lexicon structure (cf. Section 3.3.1) is innate, children should omit regular plural morphemes as soon as they have acquired the according rule, i.e. show overgeneralisations. In addition, when children stop to overregularise irregular forms (*"mouses"), only *correct* plural forms should be produced in compounds ("mice-infested").[13] Three groups of native English speaking children (aged 3;8, 4;6, & 5;6) were tested in an elicitation experiment (Gordon, 1985). The children had to produce the same word in its singular, plural and a compound form. The children omitted consistently (i.e. across all age groups) the regular plural morpheme (-s) within compounds which confirms the hypothesis because 3 to 5 year olds overgeneralise the regular plural morpheme (-s) according to Gordon. The overgeneralisation of irregular nouns (*"mouses"), however, did not disappear until age 5. These results were basically replicated with German children ranging from 3;1 to 8;11 yrs. (cf. also Bartke, 1998; Clahsen et al., 1996). Although the results generally concur with Gordon's findings it must be stated that regular plural morphemes were not consequently omitted from inside compounds. Moreover in the youngest age group (3 yrs.) only 6 children were included. Taken together, the data are in accordance with the assumption of an innate level-ordered structure of the lexicon but the claim is not completely warranted. First, the level-ordering idea was not supported in a study done in German (Gawlitzek-Maiwald, 1994). Second, as Gordon himself mentioned, it is difficult to adopt the level-ordering idea to Dutch which apparently permits regular plural morphemes between compound constituents ("paardendief", "horses thief"). Third, and more critical, what pattern would be found if younger children were tested? Gordon did not test children below age 3 but children produce the first plural morphemes when they are about 18 months (stage of two-word utterances; Szagun, 1996). Moreover, most of the inflectional morphemes are acquired between 2 and 4 years of age (stage of three and more word utterances; ibid.). Thus, children had about 2 years for learning inflection and compounding before Gordon's data were collected. Therefore, the learning account cannot strictly be discarded in favour of the innateness account.

In summary, no consensus is achieved yet on the particular function of linking elements. Empirically, there are two positions represented. One assumes no grammatical function but argues that linking elements are selected by analogy or phonological rules, whereas the other position holds that linking elements are plural morphemes of initial constituents, except for the -s- which is usually accepted to bear a linking function.

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[13] Singular forms would also be expected ("mouse eater") but not *incorrect* plural forms (*"mouses eater").

4.3 (E)LAN, P600, and morphosyntactic processes

Sections 2.3.2 and 2.3.3 already introduced ERP components related to language processing. Here, relevant findings will be discussed that are involved in morphosyntactic processing and provide the basis for investigating compound comprehension.

The left anterior negativity (LAN; between 300-500 ms) was found in response to a variety of (morpho)syntactic violations, e.g. gender (Deutsch, & Bentin, 2001; Gunter et al., 2000), regularised (i.e. rule based) plurals (Weyerts, Penke, Dohrn, Clahsen, & Münte, 1997), case markings (Coulson, King, & Kutas, 1998), verb inflection (participle constructions; Gunter, Stowe, & Mulder, 1997; Penke, Weyerts, Gross, Zander, Münte, & Clahsen, 1997), word stem formation rules (here it is more posterior Rodriguez-Fornells, Clahsen, Lleo, Zaake, & Münte, 2001), in short phrases that included personal and possessive pronouns (Münte, Heinze, & Mangun, 1993, , but see Schmitt, Lamers, & Münte, 2002), and in subcategorisation errors (Hagoort, & Brown, 2000; Rösler, Pütz, Friederici, & Hahne, 1993). The violation of a more fundamental syntactic feature, word class, elicits an even *e*arlier LAN (ELAN; about 130-180 ms) which suggest that word class information is processed before other, within word class relevant morphosyntactic information (Friederici, Hahne, & Mecklinger, 1996, Friederici et al., 1993; Neville et al., 1991).

An alternative interpretation of the LAN was put forward by Kluender and Kutas (1993; Coulson et al., 1998). These authors investigated the processing of filler-gap constructions[14] in wh-questions. They observed a sustained LAN at the filler and at the gap position which was independent of the grammaticality of the sentence. These negativities were consequently interpreted to reflect working memory processes, namely the storage and the retrieval of items for the filler-gap assignment. However, the LAN reported by Coulson et al. (1998) was observed for ungrammatical words but nevertheless interpreted as a working memory effect.

The difference between the sustained and the more phasic LAN in response to wh-questions and (morpho)syntactic violations, respectively, suggests that the LANs reflect different cognitive functions. The appearance of the sustained LAN at the filler and at the gap position in the Kluender and Kutas study fits the concept of a memory storage and retrieval process. On the other hand, a phasic LAN in response to (morpho)syntactic mismatches is interpreted to reflect the detection of such a mismatch, and this process should be short-lived in itself.

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[14] In filler-gap constructions one sentence constituent is displaced to the beginning of a clause or an utterance in order to draw the hearer's attentions to that element. For example, in the sentence "What$_j$ did you put [t$_j$] on the desk?" "What" is the direct object and the direct object usually follows the verb in English. Here the filler "What" is moved from the gap position t$_j$ to the beginning of the sentence.

It was already mentioned (Section 2.3.2) that the P600 is related to (morpho)syntactic processing, and is elicited by outright syntactic violations as well as by unpreferred syntactic structures (Friederici in press; Hagoort et al., 1993; Kaan, Harris, Gibson, & Holcomb, 2000; McKinnon, & Osterhout, 1996). The question occurred whether the P600 reflects several, different cognitive processes or whether different ERP components can be distinguished that index specifically distinct cognitive processes. Recently, a more frontally distributed P600 was suggested to reflect revision processes and a more posterior positivity was assumed to be associated with the repair of ungrammatical sentences (Coulson et al., 1998; Hagoort et al., 1999). Conversely, it was shown that the frontal P600 is also related to sentence complexity and the posterior P600 is not restricted to repair processes (Friederici, Hahne, & Saddy, 2002, Kaan et al., 2000). Kaan, and Swaab (2003) investigated in one experiment the processing of simple vs. complex sentences, and ambiguous (requiring revision) vs. incorrect (requiring repair) sentences. From their data the authors concluded that the posterior P600 reflects syntactic processing difficulty including revision and repair whereas the frontal P600 is not associated with syntactic revision processes but rather reflects an increase in discourse complexity and/or ambiguity resolution (see also Friederici, in press).

The findings related to (E)LAN, P600, and their time course suggest that processing of linguistic information succeeds in different stages (Friederici, 1995, in press). In a first stage, the syntactic structure is build from the phonological information. Word class information is relevant at this stage and its processing is reflected in the ELAN. In a second stage, semantic information is processed and thematic role assignment takes place. The thematic role assignment depends in parts on morphosyntactic information which is also processed at this stage. The processing of morphosyntactic information is mirrored in the LAN whereas processing of semantic aspects is indicated by N400 effects (see next section). At this stage the processing of morphosyntactic and semantic information is independent of each other (Friederici, 1995; Friederici, Gunter, Hahne, & Mauth, in press). The third stage comprises processes of lexical-semantic mapping onto syntactic structures and in case of a mismatch also processes of revision and repair. P600 effects are reflections of revision and repair as discussed above. These results support serial and cascading models of language comprehension, especially as early effects ((E)LAN) are not influenced by higher cognitive levels, e.g. task demands or probability of occurrence (Hahne, & Friederici, 1999; Gunter, & Friederici, 1999). Moreover, violations of first stage constraints may block processes of later stages, lending support to the idea that information has to proceed through different stages in a certain order (Friederici et al., in press; Hahne, & Friederici, 2002). The early processes are conceptualised as language specific; in fact, they were shown to be independent from a component of deviance detection which is domain general (mismatch negativity; Hahne, Schröger, & Friederici, 2002).

Another approach is to investigate directly lexical processes of decomposition. A recent study investigated how morphologically complex words and nonwords are processed in the visual modality (McKinnon, Allen, & Osterhout, 2003). In this study, subjects were presented with English words (consisting of a prefix + a bound morpheme; ”re-ceive”), nonwords that contained non-productive morphemes (*”in-ceive”), and nonwords that did not contain a morpheme (*”flermuf”) in a lexical decision task. During word reading ERPs were recorded. The nonwords that did not contain a morpheme, elicited a larger N400 compared with existing words. However, nonwords consisting of a prefix and a bound morpheme did not differ from existing words, i.e. resulted in a similar N400. The N400 in response to nonwords that contained an unproductive bound morpheme (*”inceive”), was reduced in comparison to nonwords without a morpheme (*”flermuf”). From this reduction it was inferred that nonwords incorporating an unproductive bound morpheme were decomposed on a morphological level. The authors argue that the N400 is sensitive to the presence of morphemes but does not reflect whether the morphemes combine to existing words (McKinnon et al., 2003). This interpretation suggests that morphological decomposition is ubiquitous.

Although this may be true for unproductive morphemes, it is first not clear what linguistic process is targeted by this investigation since unproductive morphemes are not involved in word formation anymore. Second, the result does not necessarily generalise to other word formation mechanisms because inflection, derivation, and compounding are suggested to be independent of each other (see Section 4.1.1). In contrast, the present thesis does not investigate nonwords but compounds which combine productively free morphemes, and manipulates the agreement of abstract morphosyntactic features (gender, & number). The results will, thus, reflect directly lexical processing of legal language samples. Specifically, the LAN will be used as a valid indicator of the detection of morphosyntactic violations.

4.4 The N400 and semantic processes

The N400, a negativity that occurs about 250-500 ms after stimulus onset, is generally related to semantic processes (Kutas, & Federmeier, 2000). More specifically it was functionally interpreted to reflect the semantic expectancy of a word (or the deviation from the most expected candidate). This is suggested by the finding that the N400 amplitude is larger the less a word is semantically related to the expected sentence ending (Kutas, & Hillyard, 1984). The completion of the sentence ”The pizza was too hot to . . . ” with the word ”cry” elicited the largest N400 whereas the word ”drink” yielded a smaller N400 that was still larger than the N400 in response to the expected ending[15] ”eat”. In a similar vein, the N400 amplitude in response to open-class words[16] decreases across word position in a sentence (Van Petten, & Kutas, 1990, 1991). During the comprehension of a sentence a semantic expectancy is built up which constrains semantically the sentence continuation the longer the sentence is. If the N400 reflects the semantic expectancy of a word this expectancy should be established not only by sentences but also by other context information. Indeed, N400 effects were observed in discourse, sentence, and word list processing (Anderson & Holcomb, 1995; Bentin et al., 1993; van Berkum, Hagoort, & Brown, 1999; Van Petten, 1995).

These findings are also compatible with an interpretation that assumes that the N400 reflects rather controlled semantic integration processes (Brown, & Hagoort, 1993). A word should be easier to integrate the more context is provided. Accordingly, the N400 amplitude is largest in response to words at the beginning of a sentence; and it is larger for unexpected words than for expected words in sentence terminal positions. In order to test the idea that the N400 reflects semantic integration, a late, rather controlled process, Brown and Hagoort (1993) investigated (un)masked priming effects in word pairs. During masked priming the prime word[17] is presented only for a very short time. The prime presentation is preceded and followed by another stimulus (mask) which prevents conscious perception of the prime, i.e. controlled processes. The unmasked priming condition yielded a clear N400 effect whereas in the masked priming condition no N400 effect was obtained. Thus, it was concluded that the N400 reflects the controlled process of semantic integration of a word into a preceding context.

An alternative interpretation is that the N400 reflects the semantic association strength among lexical items (Fischler, Bloom, Childers, Roucos, & Perry, 1983). For example, after reading the sentence fragment ”A sparrow is not a. . . ” the word ”vehicle” might be expected but ”bird” is not expected on semantic grounds. However, the N400 amplitude is not associated with the propositional truth value of a sentence but with the semantic association among words, i.e. the N400 in response to ”vehicle” is larger than to ”bird” in the above example (Fischler et al., 1983). From these data the N400 is suggested to reflect more the semantic as-

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[15] In order to estimate the expectancy of a particular word as a sentence completion the so-called cloze probability is calculated. To this end, a number of subjects is given a list with all experimental sentences which lack the last word. Subjects are asked to fill in the first word that comes to their mind and completes the sentence. The cloze probability of a particular ending equals the proportion of subjects that produced that ending (Taylor, 1953).

[16] The term ”open-class” refers to classes of words that can be extended by new entries, e.g. nouns, verbs, adjectives etc. The members of this class are sometimes called content words because the carry semantic features; function words do not.

[17] The comprehension a word (the prime) activates semantically associated words via spreading activation, thereby facilitating the semantic access of a subsequently presented word (target; cf. Section 4.1).

sociation strength among words rather than the deviation from the *expected* set of candidate words based on the previous context. (See also Federmeier, & Kutas, 1999, who imagine such effects to reflect the human categorisation of world entities instead of perceiving them as a continuum of semantic association strength.)

Pure lexical effects may also be reflected in the N400 component. In the interpretations quoted above the context can in principle affect the N400 because it was presented by necessity with the target words. Lexical effects, i.e. without presentation of context information, may be found in single word processing. For example, the repetition of words was shown to reduce the amplitude of the N400 (Besson, Kutas, & Van Petten, 1992; Doyle, Rugg, & Wells, 1996). Lexical effects are also indicated by frequency[18] effects on the N400; low frequency words usually elicit a larger N400 amplitude than high frequency words (Rugg, 1990; Van Petten, & Kutas, 1990; Van Petten, 1995). In sentences such frequency effects were observed only at early word positions but not at middle, or final positions (Van Petten, & Kutas, 1990). These results suggest, firstly, that lexical effects which are assumed to be automatic, can also influence the N400, and secondly, that the lexical effects can be eliminated by semantic context. Furthermore, a recent study by Deacon and colleagues found significant N400 effects in a masked priming experiment (Deacon, Hewitt, Yang, & Nagata, 2000, see also Kiefer, 2002). Their result contradicts the finding by Brown and Hagoort (1993) who did not find a priming effect in the masked condition. Instead, Deacon et al. (2000) showed that in the absence of conscious perception of words, the N400 can be reduced if the words have been primed semantically. Nonetheless, it is possible that lexical and postlexical processes (e.g. semantic integration) are distinct processes with overlapping ERP correlates and some effort has been made to differentiate such components. A frontally distributed negativity around 300 ms is suggested to be related to lexical processes whereas a more centroposterior negativity (the *classical* N400) may reflect more postlexical processes (Deacon, Mehta, Tinsley, & Nousak, 1995; Dien, Frishkoff, & Tucker, 2000; Nobre, & McCarthy, 1994; Wagner, 2003).

Up to date there is no general agreement on the precise functional interpretation of the N400. In broad terms, whether it reflects an automatic or a controlled process cannot be answered at present. Moreover, it might turn out that the N400 reflects more than one process, i.e. it might not be a unitary component but rather a product of some spatially and temporally overlapping components (Pylkkänen, & Marantz, 2003). So far, processes of lexical access, lexical selection, and semantic integration into a context have been shown to influence the

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[18] Word frequency is determined by the frequency of occurrence of a word in a given language sample (newspaper, television, radio, and so on) in a given time period. The frequency values can be obtained from standard databases (Baayen et al., 1995; Quasthoff, 2002).

N400. The N400 may not only reflect more than one process, it is, moreover, likely that the N400 is not language specific as it was found in a number of other domains. It was found with a similar scalp distribution for the processing of faces (Barrett, & Rugg, 1989), and pictures (Federmeier, & Kutas, 2001; Pratarelli, 1994), arithmetic tasks (Niedeggen, Rösler, & Jost, 1999), and music perception (termed N5; Kölsch, 2000). Besides the discussed relation to language, the N400 was also observed for sign languages (Capek, Corina, Grossi, McBurney, Neville, Newman, & Roeder, 2003; Neville, 1985). These findings suggest that the N400 is related to semantic processes in general not restricted to semantic processes in the language domain.

N400 effects were also found for the processing of other linguistic features which are classified to be morphosyntactic, namely number. Nevertheless, number has also some semantic aspects as it indicates the amount of the denoted object(s). Turning back to the regular/irregular distinction of German plural morphemes (cf. Section 3.2), this distinction is not only supported by behavioural experiments (Clahsen, 1999; Marcus et al., 1995; Sonnenstuhl, & Huth, 2002) but also in ERP studies. Associated with the proposed classification of regular (rule-based) and irregular (storage-based) word formation, distinct ERP responses have been observed (Clahsen, 1999; Lück, Hahne, & Clahsen, 2001; Münte, Say, Clahsen, Schiltz, & Kutas, 1999; Penke et al., 1997; Weyerts et al., 1997; Wolf, submitted.). The classification of German plural morphemes into regular (-s) and irregular forms (-er, -e, -n, or -∅;) was investigated using ERPs, and the processing of incorrectly pluralized regular nouns (e.g. *"Karusell<u>en</u>"; correct "Karusell<u>s</u>", merry-go-round) was found to elicit N400 effects (Lück et al., 2001; Weyerts et al., 1997; Wolf, submitted.). It is generally argued that an effort was made to find these nouns in the lexicon as the word form was not decomposed due to the (incorrect) irregular plural suffix. On the other hand, incorrectly pluralized irregular nouns (*"Muskel<u>s</u>"; correct "Muskel<u>n</u>", muscles) elicited a LAN, which is associated with the detection of morphosyntactic mismatches (Friederici, 1999). For these nouns the number feature of the suffix (indicating plural) does not agree in number with the word stem (which is in its singular form after decomposition).

These findings support the notion of rule-based processing of regular nouns and full-form storage of irregular nouns. Note, however, that this simple regular/irregular distinction is not unchallenged (Hahn, & Nakisa, 2000; Sereno, Zwitserlood, & Jongman, 1999). In two behavioural studies word form frequency effects were not found for a subgroup of irregular nouns, namely feminine nouns ending in -e (schwa) which take the plural suffix -en (Penke, & Krause, 2002; Sonnenstuhl, & Huth, 2002). The plural forms of these nouns are fully predictive and might also be processed according to a grammatical rule.

4.4.1 The N400 and compound comprehension

N400 effects were also scrutinised during auditory compound comprehension (Pratarelli, 1995; Wagner, 2003). Wagner (2003) used the N400 in response to a visually presented target word in order to assess the semantic activation of an acoustically presented initial compound constituent (prime). If the semantic form (SF) of the prime is activated, it should activate all semantically related entries too.[19] If the subsequently presented target word is semantically related to the prime it should be easier to access the SF of the target word. This reduced effort in accessing the SF_{target} is associated with a smaller N400 amplitude in response to the target word. In these experiments, initial constituents of the novel compounds were ambiguous, i.e. they had two unrelated meanings (Wagner, 2003). Target words that were related to either of the meanings elicited a smaller N400 in comparison to semantically unrelated targets (see Section 4.2.2). Thus, the results suggest that initial constituents of novel compounds activate their meaning online, i.e. compounds are decomposed semantically.

Pratarelli (1995) also found ERP correlates of a semantic mismatch of compound constituents and a preceding picture but no behavioural effects were obtained. In this cross-modal priming experiment the primes were pictures, and targets were acoustically presented compounds. Unfortunately, stimuli are neither provided nor described in the paper; assumably they are transparent and lexicalised.[20] In a first experiment a benchmark was establish in which the ERPs were recorded in response to two-constituent compounds. In these compounds either both (e.g. ”dog bone”) or none of the constituents (e.g. ”mailbox”) were semantically related to the preceding picture (e.g. of a dog bone). In a second experiment the same procedure was employed but in this case either both (e.g. ”dog bone”) or only one constituent (e.g. ”wishbone”) was related to the picture. The violation of the semantic relation of the head constituent resulted in a later N400 effect compared with a violation of the initial constituent. If the semantic relation of the initial constituent was violated the N400 effect was observed earlier. The delay of the effects equalled approximately the length of the initial constituents. Their main result is reproduced for reasons of clarity in Fig. 4.3. These plots represent difference wave forms and the solid line (benchmark) shows the N400 effect for completely unrelated compounds, i.e. the difference between completely unrelated compounds and completely related compounds after priming with a picture. The dashed lines show the difference ERPs of Pratarelli’s second experiment. For these difference waves, the ERPs of completely related compounds are subtracted from the ERPs of compounds in which only one constituent is related to the picture.

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[19] A possible mechanism is the spreading activation account introduced in Section 4.1.

[20] The given examples suggest that the stimuli are lexicalised although some seem to be of higher frequency (”notebook”,

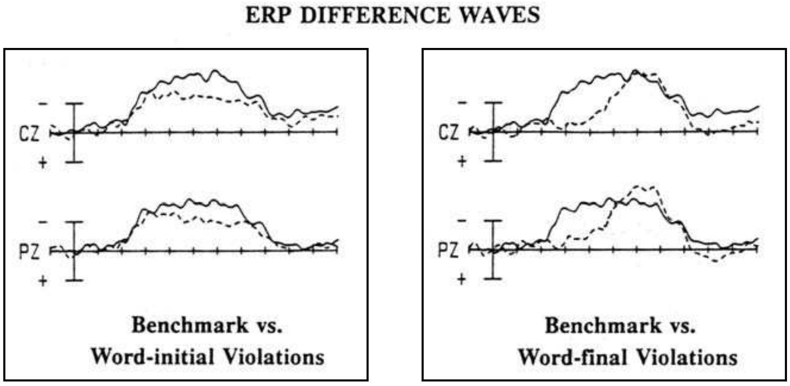

Figure 4.3: Difference waves of the benchmark condition (N400 effect if both compound constituents are semantically unrelated; solid line) and of the experimental conditions in which either the first (left) or the second (right) constituent is unrelated to a picture prime (dashed line). Adapted reproduction from Pratarelli (p. 243; 1995).

The left panel shows the difference ERP at two electrodes for compound initial violations and the N400 effects appear at the same time for the benchmark condition and the one-constituent violation condition. The right panel shows the difference ERPs for head constituent violations. Here, the N400 effect appears later but declines at the same time as the benchmark condition. Thus, it was concluded that each constituent is separately activated with regard to its SF. This result is taken to support semantic decomposition of lexicalised compounds (but see Chapter 5).

Taken together, the N400 can be used to estimate the lexical-semantic processing of compounds and to evaluate the detection of number violations (of irregular nouns). In contrast to gender violations, irregular plural violations elicit an N400 although number is a morphosyntactic feature. Moreover, the N400 may serve as a measure for lexical-semantic integration of compound constituents if it is sensitive to integration effort of lexical processes such as compounding.

4.5 Models of spoken word recognition

Models of spoken word recognition, such as Cohort (Marslen-Wilson, & Welsh, 1978; Marslen-Wilson, 1987), TRACE (Elman, & McClelland, 1984; McClelland, & Elman, 1986),

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”freeway”, ”cowboy”) than others (”dog bone” and ”ski boat” both are neither listed in Celex (Baayen et al., 1995) nor in <http://www.dictionary.com>; August 2003).

Shortlist (Norris, 1994) or the Race model (Cutler, & Norris, 1979; Norris, McQueen, & Cutler, 2000, for a more elaborated version), usually divide the recognition process into an access function, a selection, and an integration function. In order to access a number of potential word candidates from the lexicon during perception, a prelexical function converts the acoustic signal into a phonetic and/or phonological representation. These prelexical representations activate lexical entries according to the degree to which they match the entries. Entries that do not match the sequence of phonemes at some point are excluded and, thus, the number of candidate words is reduced. In a next functional step the best-matching lexical entry is selected and may then be integrated into a higher semantic and/or syntactic representation. At present it remains undecided whether prelexical representations should be characterised in terms of phonemes or phonetic features, and whether they include prosodic information. For a detailed review see Jusczyk and Luce (2002).

None of these models is concerned with the processing of compound words. Moreover, with regard to questions of decomposition they would all make the same predictions. All onset embedded words are predicted to be activated, at least at the form level. That is, the prelexical representations for nonhead constituents should be activated in any case. Whether such a form decomposition extends to the morphological and semantic level is not clear. As this thesis is concerned with compound comprehension the results cannot support one spoken word recognition model over the other.

4.6 Summary

This chapter reported on behavioural and electrophysiological evidence that relates to the comprehension of compounds. Furthermore, ERP components relevant to (morpho)syntactic and semantic processes were discussed. The mental lexicon is organised according to semantic and morphological associations among entries which explains semantic and morphological facilitation in behavioural tasks. Low frequency compounds (transparent & opaque) are suggested to be decomposed morphologically during comprehension. However, the meaning of opaque compounds is not accessed via their constituents, which shows that they have an extra semantic entry. Although all low frequency compounds are decomposed morphologically only for transparent ones the compound meaning seems to be calculated from the constituent meanings. Eye tracking and cross modal priming studies suggest that compounds are processed via two routes that run in parallel. The function of linking elements could not be clarified yet; one position suggests that they are plural morphemes of initial constituents whereas the alternative proposals holds that they bear a non-grammatical (phonological and/or morphological) function. Patient data suggest that word formation processes are independent of each other. Furthermore, compounding and derivation are proposed to be lexicon driven processes. This may possibly hold for inflectional marking too. The ERP component LAN is found to be a reliable indicator of the detection of morphosyntactic violations, in particular syntactic gender. The N400 is sensitive to semantic integration processes but is also sensitive to plural violations assigned by irregular plural morphemes.

Chapter 5

Critique: Some limitations of existing studies

5.1 Critique

Relevant findings and theories with regard to compound processing were described in the previous chapters. Although they provide insights into several aspects of processing, they can only be generalised to a limited extent. Most studies that investigated morphological decomposition of compounds were done in the visual modality. Although some showed that decomposition is induced by compounds (Andrews, 1986) and does not appear regularly (de Almeida, & Libben, 2002), most studies suggest that morphological decomposition occurs regularly for all compounds (transparent & opaque; McKinnon et al., 2003; Sandra, 1990; Zwitserlood, 1994). McKinnon et al.'s (2003) data even suggest an extensive morphological decomposition of written language material which would be necessary for an extensive morphological analysis. These authors reported a similar N400 for nonwords that contained unproductive bound morphemes, compared to legal words that contained the same morphemes. Nonwords that contained no morphemes elicited a larger N400. It was concluded that even unproductive morphemes of nonwords were extracted in visual presentation. Leaving aside issues of a small number of subjects (*N*=12) and uncontrolled word frequencies, their result may also be interpreted as morphological decomposition as a back-up processing strategy if a (non)word cannot be found in the lexicon (e.g. *"exceive"). That is, the results in response to orthograpically illegal material does not necessarily reveal something about undisturbed language processing.

Studies on morphological decomposition that were done in the visual modality, do not permit any conclusion with regard to the time course of morphosyntactic constituent activation (Andrews, 1986; Jarema, Busson, Nikolova, Tsapkini, & Libben, 1999; Libben et al., 1999; Sandra, 1990; Zwitserlood, 1994). Due to the simultaneous presentation of constituents it is not clear *when* a constituent is accessed during the time course of comprehension. Subjects may attend to the whole word first if it is presented at once on the screen. As the present thesis is concerned with the compound comprehension in the auditory domain, those studies done in the visual domain, do not provide strong evidence for morphosyntactic decomposition during acoustic presentation.

Another method, eye tracking, is sensitive to temporal differences of reading processes. In two sentence reading studies, eye movements in response to Finnish compounds suggested two processes that run in parallel; while the compound is decomposed the whole compound is also looked up in the lexicon (Hyönä, & Pollatsek, 1998; Pollatsek et al., 2000). An initial constituent of higher frequency decreased first fixation durations whereas a higher frequency of head constituents affected only subsequent reading stages, namely the probability of third fixations. This temporal sequence of effects suggests successive processing of constituents during reading which speaks for online decomposition. However, since the compound frequency (whole word form) speeded up reading measures rather early (second fixation duration, and first fixation durations tend also to be faster) it was concluded that a direct route works in parallel. A critical point is that these studies compared different item groups. Clearly, the frequency of a given item cannot be manipulated. Although a number of lexical parameters were controlled for (e.g. frequencies of constituents or the compound, and semantic transparency) some uncontrolled item differences may be responsible (in parts) for the results obtained. This issue can only be avoided by within-item comparisons.

In a similar study, first fixation durations on compounds were reduced if the constituents were separated by spaces (Inhoff et al., 2000). In contrast, third and fourth fixation durations on the same compounds were increased due to the spaced notation. These results were interpreted to suggest an early process of constituent access and a late process of constituent integration, the construction of a unified (compound) concept (Inhoff et al., 2000). That is, Inhoff et al. suggest two distinct processes for compound reading, similar to Pollatsek et al. (2000) which have a clear temporal order. Accordingly, it follows that initial constituents are processed differently than single nouns. The complete semantic processing of a word must be postponed if it is identified as part of a compound because the meaning-defining information is carried by the head constituent (see Section 3.3.4). In line with this reasoning Inhoff et al. observed prolonged first fixation durations to compounds compared with non-compounds (Inhoff et al., 1996). Thus, these results also suggest that compound words are identified very early and that constituents are accessed separately. Only at a later stage the compound meaning is constructed from the constituents.

A major issue for eye tracking studies concerns the variable interpretation of eye movement measures. For example, the fixation duration of the first fixation on a compound is related to the access of a constituent. The fixation duration of later fixations on the same word (second or following) may be interpreted to reflect different cognitive processes, e.g. the semantic construction of the compound word (Hyönä, & Pollatsek, 1998; Inhoff et al., 2000). In addition, fixation duration is sensitive to the decision process whether or not a fixated word is part of a compound (Inhoff et al., 1996). That is, one and the same measure may reflect different cognitive processes and the investigator has to decide what it reflects in each case. Moreover, semantic and morphological processes associated with constituent access cannot be dissociated, i.e. a faster *morphological* search cannot be distinguished from a faster *semantic* search for a constituent. The reading measure does not distinguish such cognitive processes. Eye tracking studies, lexical decision and priming experiments all suggest that compounds are decomposed morphologically. Nevertheless, none of these studies predicts conclusively that this is the case in the auditory modality.

Earlier studies concerned with semantic decomposition of compounds were done in the visual and in the auditory modality but findings are more diverse. In the visual modality, compound processing was often investigated using priming and the lexical decision task. Such studies found semantic decomposition for transparent but not for opaque compounds (Sandra, 1990; Zwitserlood, 1994). In the auditory modality, no semantic activation of initial constituents was found by Isel et al. (2003) at the end of initial constituents using behavioural measures. Isel et al. suggested that semantic access of initial constituents is postponed until the head is identified. Wagner (2003), on the contrary, reported semantic activation effects of initial constituents at the constituent end. These effects were found in behavioural and ERP measures which indicate semantic decomposition. Isel et al. (2003) used existing low frequency transparent and opaque compounds whereas Wagner (2003) used novel compounds in which the first constituent was a semantically ambiguous noun. That is, semantic decomposition seems not to be obligatory but may instead be induced by other factors as semantic status (transparent vs. opaque), frequency (novelty), ambiguity, or prosody. It was suggested that novel compounds provoke decomposition (de Almeida, & Libben, 2002) which might explain why Wagner found decomposition effects but Isel et al. did not. However, Wagner's stimuli contained also an ambiguous initial constituents which may induce decomposition due to the phonological form (PF) matching onto two lexical entries (Klein, & Murphy, 2001). Thus, it cannot be concluded from these studies whether novelty per se induces semantic decomposition and whether only novelty can induce semantic decomposition.

Pratarelli (1995) did also a cross-modal priming experiment in which a pictures primed constituents of acoustically presented two-constituent compounds. He reported separate, reduced N400 effects for compound constituents if only one constituent was primed (cf. Fig. 4.3 & Section 4.4). As the effects of the one-constituent violation conditions were shifted by approximately the length of the initial constituent, it was concluded that each constituent was activated separately on the semantic level. However this study has to be criticised for two reasons. First, the task may have induced a decomposition strategy. If subjects were presented with a picture of a dog bone and heard afterwards the word ”wishbone” they had to judge them as unrelated because one of the constituents did not fit the picture. That is, subjects may have emphasised to check each constituent against the picture. If so, the effect would simply reflect that semantic decomposition can be induced by a task. Second, there is a confound of semantic relatedness and constituent repetition. The main argument of Pratarelli (1995) is summarised in Fig. 4.3 in which difference ERPs are compared. The solid line reflects the N400 effect of completely unrelated compounds (benchmark condition) and is less important here. The problem with the experimental conditions (dashed lines) is that the unmanipulated constituent was repeated during the experiment but the manipulated constituent was not repeated, and repetitions are known to reduce the N400 (Besson et al., 1992; Doyle et al., 1996). For example, the picture of a dog bone primed once the word ”wishbone” and once the word ”dog bone”. As a result, the repetition of the unmanipulated constituent (”bone”) may have reduced the respective N400 effect (cf. word-initial violations; left panel in Fig. 4.3). In analogy, the repetition of the initial constituent (”dog bone” vs. ”dog house”; both primed by a picture of a dog bone) may have resulted in a reduced N400 effect for the initial constituents (cf. word-final violations; right panel in Fig. 4.3). Hence, it is unclear whether the results are due to the repetition of constituents or the semantic decomposition of compounds which should be shown by that experiment. This argument does not completely rule out Praterelli’s interpretation. All I want to claim here, is that there is a potential confound in this comparison and the argument made from it seems to be rather weak.

In sum, from the studies on semantic decomposition during acoustic presentation it cannot be concluded whether decomposition occurs regularly, is induced by novelty, ambiguity, or by the task demands. Studies done in the visual modality suggest that only transparent compounds are semantically decomposed but, again, it cannot be generalised easily to the auditory domain.

There are only few studies that investigated the function of linking elements empirically. Those studies that looked at effects on comprehension did not use online methods. Schreuder et al. (1998) used judgement tasks (number decision and rating) and argues for a plural function of linking elements. In a qualitative assessment (native speakers wrote down the best matching linking elements for given constituent pairs), Krott (2001) found that the choice of linking elements is determined by form properties of the left hand constituent. Clearly Krott's interpretation stands in contrast to the function proposed by Schreuder et al.

Language acquisition studies are also inconclusive. Whereas Gordon (1985) and Clahsen et al. (1996) claim that linking elements are functionally plural morphemes. These acquisition studies used offline paradigms and the omittance of regular plural morphemes in compounds is usually interpreted in terms of a level-ordered lexicon (see Gawlitzek-Maiwald, 1994, for some counter evidence from German). But, they do not mean necessarily that linking elements are functionally plural morphemes. In principle, it is possible that linking elements overlap (largely) in form, i.e. phonologically with plural morphemes but subserve one or more other functions. Note that children begin to use inflectional morphemes at about 18 months of age (Szagun, 1996) but were tested at age 3. Thus, they had plenty of time to learn some compounding and (possibly distinct) inflectional rules. In this case, linking elements and plural morphemes were two sets of morphemes that have nothing to do with each other functionally. This possibility has major consequences. The distinction of regular und irregular plural morphemes rests in parts on the appearance of particular linking elements within compounds (see Section 3.3.1). If linking elements and plural morphemes are functionally distinct the restriction of linking elements in compounds does not support (nor does it contradict) the differentiation of regular and irregular inflectional morphemes. That is, besides the numerous functions put forward by linguistic theory (Fuhrhop, 1998, 2000; Wiese, 1996) there is no clear indication of what function(s) linking elements have in psycholinguistic terms.

5.2 Hypotheses and predictions

The major question is whether compounds are morphosyntactically decomposed, and whether and when effects of lexical-semantic constituent integration can be found. In accordance with the PAHD model (cf. Section 4.2.2; Isel et al., 2003) it is assumed that the parser employs a decomposition route in addition to the direct route if a compound is encountered. That is, while the mental lexicon is searched for an entry that matches the whole compound form, the compound is also decomposed into its constituents. These constituent representations can be integrated to arrive at the compound meaning if no whole compound entry is available. As a starting point novel compounds will be investigated because these are decomposed by necessity. In a next step, the morphosyntactic decomposition of low frequency compounds will be investigated as it is assumed that these have no lexical entries. Moreover, it will be examined whether semantic status (transparent vs. opaque) has an impact on the decomposition of low frequency compounds. Opaque compounds must have lexical entries because their meaning cannot be computed from the constituents; hence, decomposition does not help to comprehend them. However, if the semantic status cannot be determined early on, opaque compounds may be decomposed morphosyntactically. If transparent compounds do not have a lexical entry their constituents must be integrated semantically to yield the compound meaning. Such a lexical-semantic integration would entail a larger lexical integration effort compared to opaque compounds.

On the contrary, one may argue that compounds are not decomposed, i.e. that initial constituent compounds are not online accessed semantically due to prosodic cues that indicate morphological complexity (Isel et al., 2003, but see Pratarelli, 1995; Wagner, 2003). Accordingly, a morphosyntactic representation of initial constituents may also not be activated if it is assumed that morphosyntactic information is stored together with the semantic representation.[1] If so, no effects of morphosyntactic decomposition are to be expected but effects of lexical-semantic integration should still occur. At least after the head constituent is identified, the constituents must be accessed somehow and be integrated if the compound does not have a lexical entry.

More specifically, the agreement of the morphosyntactic features gender and number will be manipulated between compound constituents and a preceding determiner. The agreement manipulation of initial and head constituents will be independent of one another. If compounds are indeed morphosyntactically decomposed, i.e. if a morphological representation of initial constituents is extracted, the morphosyntactic features gender and number should be available. If gender and number are available as part of the morphological representation they can disagree with a preceding determiner. For gender violations of initial and head constituents a LAN is predicted for each constituent if morphosyntactic decomposition takes place (Gunter et al., 2000). The number agreement of initial constituents will be manipulated by linking elements and these can only be identical in form with irregular plural morphemes. For comparability head constituents will also be irregular nouns and, therefore, number incongruent constituents are predicted to elicit an N400 effect (Weyerts et al., 1997). The respective violations of the head constituents will serve as a control condition for initial constituents. The head constituents are grammatically relevant, and show what effects are to be expected for initial constituents. For effects of lexical-semantic integration it is expected

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[1] For instance, in analogy to the lexicon structure proposed by Levelt and co-workers in the domain of language production (Levelt, 1989, but see Levelt, Roelofs, & Meyer, 1999).

that low frequency transparent compounds elicit a larger N400 compared with opaque compounds. Such an effect should occur after the initial constituent because the semantic status of the compound cannot be determined by the initial constituent alone. In compounds with more (e.g. three) constituents an effect of lexical-semantic integration is expected to begin during the second or only during the head constituent.

If, on the contrary, it is assumed that prosodic cues prevent an online decomposition, none of the predicted morphosyntactic effects should be observed. Nevertheless, effects of lexical-semantic integration effort are still expected for compounds that have no lexical entry.

Part II

Experiments and interpretations

Chapter 6

The case of novel compounds

The first experiment was set out to investigate whether gender information of nonhead constituents in novel compounds is available to the parser during comprehension in the auditory domain.

6.1 Experiment 1

6.1.1 Introduction

According to the composition principle the meaning of a novel compound is determined by the meaning of the compound constituents and their relationship to one another. Novel compounds have no lexical entry but their constituents must have one. Any lexical entry consists of a phonological (PF), grammatical (GF), and a semantic form (SF). For comprehension, the acoustic/phonetic structure of a word is converted into the PF, which activates the GF and SF either interactively (Jackendoff, 1997; McClelland et al., 1986) or separately (Bierwisch, 1997; Friederici, 2002). Syntactic gender which is in the focus of this experiment, is contained in the GF of a noun. As novel compounds must inevitably be decomposed into separate constituents, gender information of each constituent can in principle be in conflict with a gender marked determiner in German, although the gender information of nonhead constituents is not relevant for agreement. Gender incongruities of nonhead constituents are frequent in German (but hardly ever noticed by native speakers) and should be detected in ERP measures if the compound is processed incrementally, i.e. if each constituent is accessed individually (cf. Pratarelli, 1995; Wagner, 2003).

On the contrary, one might assumed that SFs and GFs are closely linked, i.e. stored on one level in analogy to the lexicon structure proposed by Levelt (1989, but see Levelt, et al., 1999). In this case it may be predicted that the GFs of initial constituents are not accessed because the GFs and the SFs should be accessed together and the access of the SFs was found to be postponed until the identification of the head constituent (Isel et al., 2003). Hence, the access of the GFs should equally be delayed. Psycholinguistic theories representing the full-listing hypothesis and their connectionist implementation (Butterworth, 1983; Bybee, 1995; McClelland et al., 1986; Elman, 1993) would predict the parser to wait for the head constituent as no decompositional processing strategy is available within that framework.

The question of whether novel compounds are decomposed morphosyntactically is addressed by this experiment. In order to examine the activation of compound constituents the gender agreement is manipulated between compound constituents, and a preceding determiner. If the morphosyntactic representation (GF) of each constituent is indeed accessed, its gender information should entail a left anterior negativity (LAN), if incongruent. A LAN in response to the head constituent (which determines the gender of the respective phrase) indicates a successful manipulation. The important question is whether a LAN in response to the first constituent (which is not relevant syntactically) can be observed, and thereby indicates separate activation of each constituent.

The specificity of the LAN for the detection of a gender mismatch is not unchallenged. Hagoort and Brown (1999) reported only a P600 effect in response to gender violations in sentence-medial, and an N400 and P600 effect in sentence-final positions, and hence, it may be suggested that the LAN is not specific to gender violations. Note, however, that a LAN in sentence-medial positions is clearly visible in Hagoort and Brown's data with an extent of approximately 100 ms (Fig. 3, p. 722). The authors, however, chose a 200 ms time window and report that the effect does not reach significance between 300 and 500 ms. Gender violations in sentence terminal positions elicited an N400 followed by a P600, and although the terminal words were not semantically anomalous the authors argue that the ”sentence-final position can impact the overall morphology of the ERP waveform” (p. 725, Hagoort, & Brown, 1999) due to sentence wrap-up, decision, and response requirements. This may also have obscured a LAN. Here, the LAN is assumed to be specifically related to the detection of gender (and other morphosyntactic) violations because it was repeatedly reported for gender violations (Deutsch, & Bentin, 2001; Gunter et al., 2000; Wedel, & Hahne, 2002) and it is unclear whether the descriptively seen LAN (in the Hagoort and Brown study) missed significance for an ill-fitted analysis.

6.1.2 Materials and methods

Subjects. A total of 30 (15 male) right-handed (lateralisation coefficient 93; Oldfield, 1971) German native speakers (mean age 24;5 yrs.; range 18-30 yrs.) were paid for their participation. They had normal or corrected to normal visual acuity and normal hearing.

Materials. German compounds were constructed that consisted of three constituents, for presentation together with a determiner. As a result either only the first constituent (Agreement-Violation condition, AV), only the third (VA), both (AA), or neither of these two agreed (VV) with the determiner in gender (see Tab. 6.1). The second constituent agreed always in gender with the determiner; it was inserted in order to separate the first and third constituent from one another in time. None of the constituents was repeated within a given position of the compounds. Compounds were all novel and constituents did not differ in frequency among conditions. For each condition, 40 compound targets were constructed (160 in total) using masculine and neuter nouns only (see Appendix C.1). Feminine nouns were inserted in filler items (80) which were structurally identical to the targets. Hence, the three genders were equally distributed across the experiment. Twenty-four distracter items were included; 12 single words and 12 two-constituent compounds.

Table 6.1: *Examples of stimuli used in Experiment 1. The four conditions are determined by the agreement (*A*) or violation (*V*) of the first (*C1*) and the head (*C3*) constituent. The second constituent (*C2*) agreed always in gender with the determiner. Note that* C3 *alone determines the compound gender and thus, the correctness of the assigned determiner.*

condition	**determiner**	**C1**		**C2**		**C3**
AA	der	Lärm	–	schutz	–	wall
	the$_{masc}$	noise$_{masc}$	–	protection$_{masc}$	–	dam$_{masc}$
AV	*der	Strand	–	grill	–	fest
	*the$_{masc}$	beach$_{masc}$	–	barbecue$_{masc}$	–	party$_{neut}$
VA	das	Schmutz	–	wasser	–	becken
	the$_{neut}$	dirt$_{masc}$	–	water$_{neut}$	–	basin$_{neut}$
VV	*das	Fuß	–	gelenk	–	bruch
	*the$_{neut}$	foot$_{masc}$	–	joint$_{neut}$	–	fracture$_{masc}$

All stimuli were spoken by a female professional speaker and, thus, samples of naturally spoken words. In order to avoid systematic influences during the recording session the speaker had to produce all items in a randomised order. Each item was read following a phonologically legal pseudo determiner in order to eliminate any systematic prosodic cues with respect to the grammaticality of the upcoming compound, and to avoid changes in fundamental frequency contour of the compound as a result of speech production without a preceding word. Definite determiners were recorded separately but in the same recording session and assigned to the compound sound files. All items contained a 60 ms pause between the determiner and the compound to make the presentation sound naturally. Recordings were digitised online with 44,700 Hz. The acoustic signal of each compound was visually inspected and acoustically tested in order to determine the onset of the head constituent. The sound files were digitally processed and adapted for loudness using a commercial sound editor (Johnston, 2000). As a result stimuli were completely natural speech samples.

Procedure. The experiment was carried out in a dimly lit, sound-attenuated, and electrically shielded room. Subjects were seated in front of a colour computer screen (distance 100 cm) and instructed to respond as quickly as possible when prompted. Instructions were given not to blink while the fixation cross was visible. A training block of 14 trials was given. Compounds were presented in three blocks with short pauses among them.

Each trial consisted of 600 ms blank screen, 500 ms fixation cross presentation only, and the fixation cross remained on the screen throughout the trial. The acoustic presentation of a determiner was followed by a compound; these were separated by a 60 ms pause. After the acoustic presentation subjects were visually cued to give a grammaticality judgement within two seconds. In 20% of the trials an additional subsequent semantic judgement was required within another five seconds (randomly distributed across the trials). These tasks made sure that subjects always attended to all compound constituents as they are relevant for the semantic task but subjects could not predict for which items this would happen. Following the responses feedback was given. The order of presentation was pseudorandom with no more than two successive presentations of any experimental condition. The whole session lasted 30 min.

Behavioural measures for the semantic task, however, are not reliable because this task was presented after a grammaticality judgement was given. They do not only reflect another task of comparing semantically the target compound to a further word. They also reflect the reading of the visually presented word. In addition, the semantic relation among compounds and comparison words were not empirically established (throughout the thesis) but rather agreed upon by at least two native speakers. The purpose of the task was to make sure that subjects paid closely attention to all compound constituents as they are relevant for the semantic judgement.

In a short debriefing session after the experiment subjects were asked in a questionnaire how difficult the grammaticality and semantic task was on a 4–point scale (1–easy, 4–difficult). They had also the opportunity to give comments on the experiment and ask questions.

EEG recordings. Fifty-six Ag/AgCl electrodes (Electrode Cap International) were placed at sites suggested by the American Electroencephalographic Society (1991, nomenclature applies to all experiments) and used for recording the EEG. The continuously recorded EEG was amplified (PORTI-32/MREFA) high-pass filtered (DC-70 Hz) and digitised online at

250 Hz. In order to control for eye movements bipolar horizontal and vertical electrooculograms (EOG) were recorded. Electrode impedance was kept below $5\,k\Omega$ and the left mastoid was used as reference. The electrodes used are given in Fig. 6.1 (left panel). The EEG recording followed the guidelines for ERP studies (Picton, Bentin, Berg, Donchin, Hillyard, Johnson, Miller, Ritter, Ruchkin, Rugg, & Taylor, 2000).

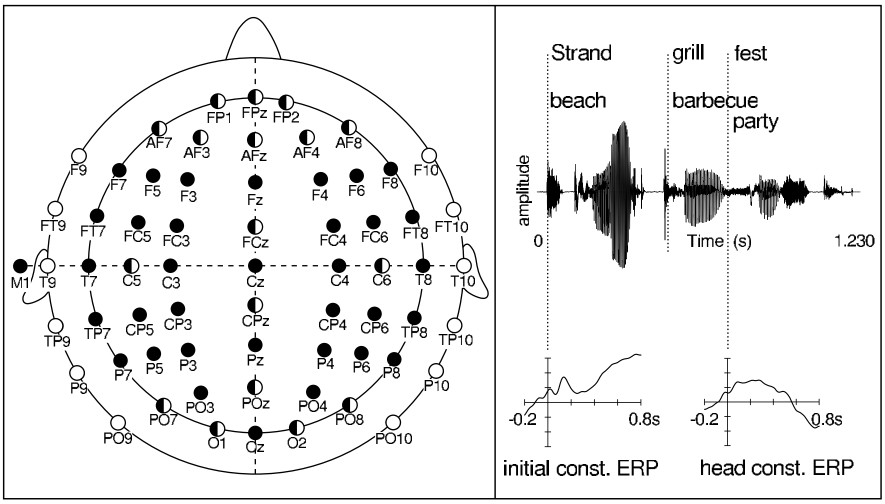

Figure 6.1: Electrode positions for EEG recordings (extended 10-20 system) as suggested by the American Electroencephalographic Society (1991; left panel). A schematic view of the head from above. Odd numbers label left hemispheric electrodes. M1 (left mastoid) is the reference in all experiments of this thesis. Electrodes represented by non-empty circles were used in all experiments except for Experiment 2a in which the EEG was recorded from electrodes represented by full circles. The ERP was calculated time-locked to the onset of the respective constituent as depicted schematically in the right panel.

Data analysis. Automatic rejection was used to exclude all epochs in which eye movements or blinks occurred (EOG $\pm 50\mu V$). Incorrectly answered trials were also excluded from the analyses. Thus, 76% of the trials entered the averaging process. For each electrode, average ERPs were calculated across subjects for each compound constituent separately (cf. Fig. 6.1, right panel). The ERP waveforms were quantified by mean amplitude measures in relation to a 200 ms preconstituent baseline. Time windows for the analyses were determined by visual inspection of the typical time range specified in the literature. Repeated measure ANOVAs were performed on the mean amplitude values and all factors were within subject factors unless specified otherwise. The Greenhouse-Geisser (1959) correction was applied if any factor had more than two levels; in these cases the *epsilon* and the corrected p values are reported. For comparisons of topographical differences the data were normalised according to McCarthy and Wood (1985). All ERPs were filtered (10 Hz low pass) for presentation purpose only.

Each regions of interest (ROI) contained six electrodes (cf. Fig. 6.1, left panel; anterior left (AL): AF7, AF3, F5, F3, FC5, FC3; anterior right (AR): AF4, AF8, F4, F6, FC4, FC6; posterior left (PL): CP5, CP3, P5, P3, PO7, PO3; posterior right (PR): CP4, CP6, P4, P6, PO4, PO8).

6.1.3 Results

Behavioural data. High accuracy rates for the grammaticality (95%) and the semantic judgements tasks (95%) indicate that all items were easy to understand and to assess. Both tasks were judged to be easy on a 4–point scale in the debriefing session (GRA[1] 1.4; SEM[2] 1.7; cf. Tab. A.2, Appendix A.1).

ERP data: head constituent. The ERPs time-locked to the onset of the head constituents (see Fig. 6.1, right panel) show a slow negative deflection which last about 400 to 600 ms. No early components (N1/P2) are seen. The negativity is larger for incongruent head constituents and the effect is mostly visible at frontal electrodes and a little stronger over the left hemisphere.

The mean ERP amplitudes were calculated in the time window 350-450 ms after the onset of the head constituent (Fig. 6.2). The ANOVA with the factors *AP* (2: anterior-posterior), *LR* (2: left-right), and *gender agreement* of head constituents (2), and *gender agreement* of initial constituents (2) yielded a significant 3–way interaction of *gender agreement* of head constituents, *AP* and *LR* ($F(1,29)=5.28$; $p<.05$). *Gender agreement* of head constituents did not interact with the *gender agreement* of first constituents ($F(1,29)=1.63$; ns). That is, the *gender agreement* effect of head constituents was independent of initial constituents and showed an inhomogeneous scalp distribution in which the left-anterior ROI seems to show the largest LAN effect. Hence, separate ANOVAs were performed on the ROIs but no significant *gender agreement* effect was found in any single ROI. These analyses, therefore, seem to indicate that no LAN is present for the head constituents. This is highly implausible since there is solid evidence that gender violations do elicit a LAN (Deutsch, & Bentin, 2001; Gunter et al., 2000; Wedel, & Hahne, 2002). It is, however, possible that the non-significant main effect of *gender agreement* is due to the merging of several electrodes into ROIs. Therefore, a further analysis was carried out incorporating the electrodes of the

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[1] Grammaticality judgement task

[2] Semantic judgement task

left-anterior ROI. Thus, this ANOVA contained the factors *electrode* (6) and *gender agreement* (2). The interaction of *gender agreement* and *electrode* was significant ($F(5,145)=2.26$; $p=.039$; $\varepsilon=0.45$). Based on this 2–way interaction the electrodes were tested separately for an *gender agreement* effect. The electrodes F3 and FC3 reached significance ($F(1,29)=7.08$; $p<.05$; $F(1,29)=4,12$; p=.05) whereas the effect was not significant at the other electrodes (all $F(1,29)<2$; ns).

First constituent. The ERPs for initial constituents show an increasing negativity with an N1/P2 complex. Gender incongruent constituents elicit a larger negativity at frontal electrodes. The effect seems to be stronger over the left hemisphere.

Again, an ANOVA with two factors *AP* (2), *LR* (2), and *gender agreement* of initial constituents (2) was performed (cf. Fig. 6.3). The 3–way interaction was significant ($F(1,29)=4.58$; $p<.05$) in the time window 300-400 ms which is comparable to the analysis of the head constituent. Separate analyses of the ROIs showed that the gender agreement effect is located at the left frontal area (AL: $F(1,29)=4.16$; $p=.05$) although there is a weak tendency at the right frontal area (AR: $F(1,29)=3.11$; $p=.09$); the effect is not significant at posterior areas.

Semantic post–hoc analyses. Although the experiment was set out to explore morphosyntactic processes, it was also possible to explore lexical-semantic integration processes during compound comprehension. The compounds were divided according to how easily the meaning of their constituents may be integrated into the compound meaning. Three native German speakers decided for each compound whether it refers clearly to one concept (*easy compounds*[3]), or suggests several plausible concepts on which no agreement was found (*difficult compounds*[4]). As a consequence, 89 compounds were classified as easily combinable and 71 as difficult to combine. Responses were faster for easy (391 ms) than for difficult compounds (438 ms; $t(29)=4.94$; $p<.001$) for the grammaticality judgement as well as for the semantic judgement (easy 1,190 ms; difficult 1,263 ms; $t(29)=2.54$; $p<.05$). Accuracy was higher for easy (96%) than for difficult compounds (94%) in the grammaticality task ($t(29)=3.39$; $p<.01$) but not in the semantic task ($t(29)=1.66$; ns). On the contrary, no significant difference in length of easy (1,364 ms) and difficult (1,408 ms) compounds was found ($t(158)=1.48$; ns).

The ERPs across the whole compound show a large slow negative shift that lasts about as long as the compound (average compound length 1,386 ms; for detailed constituent lengths see Tab. A.1, Appendix A.1). The negativity is larger for difficult compounds during the last constituents and the scalp distribution of the effect has a centroparietal maximum (see

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[3] For example, ”Kaffeeanbaufeld” (coffee cultivation field) or ”Ballettkurslehrer” (ballet course teacher).

[4] For example, ”Talentplakatleim” (talent poster glue) or ”Gerüstlagerwald” (scaffold store wood).

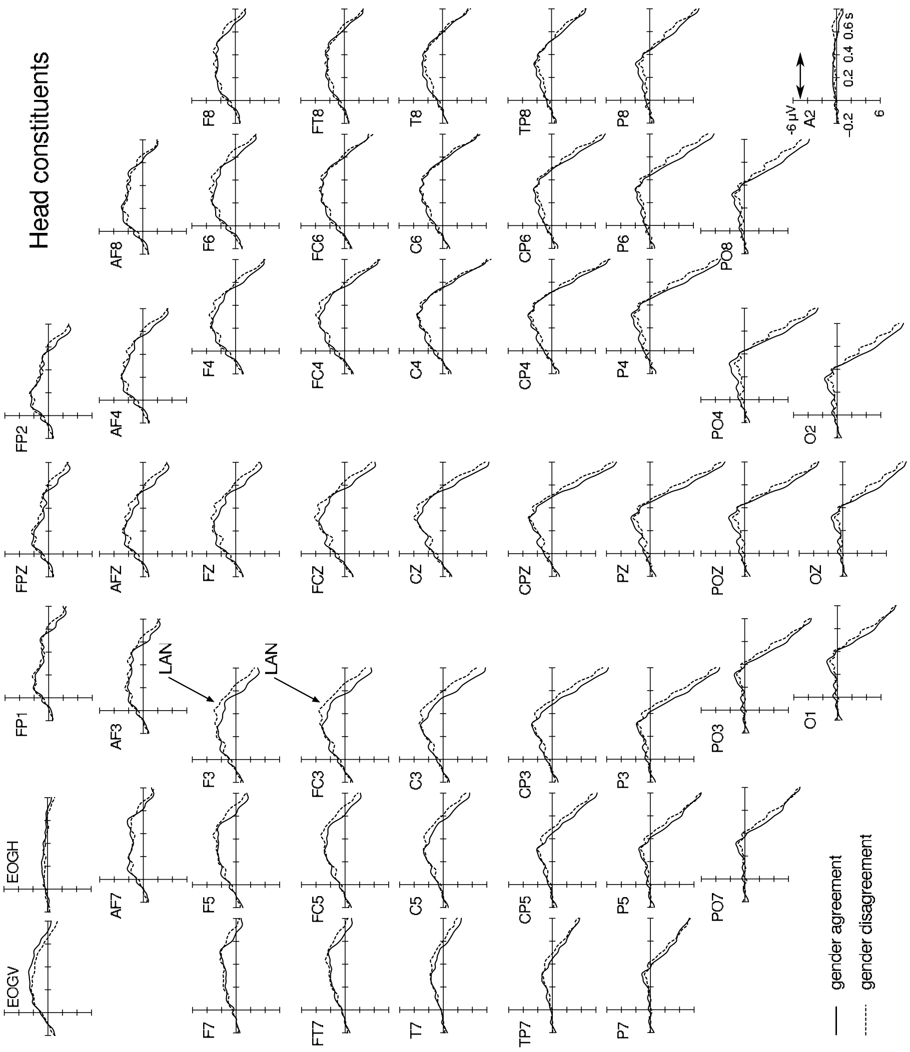

Figure 6.2: The ERP plots for gender congruent (solid line) and gender incongruent (dashed line) head constituents of novel compounds. Gender incongruent head constituents elicit a larger negativity at left anterior electrodes (350-450 ms). The average constituent length is indicated by the arrow in the diagram A2; for the exact lengths of constituents see Tab. A.1, Appendix A.1. Constituent onset is at 0 ms, and negative is plotted upwards as in all subsequent Figures.

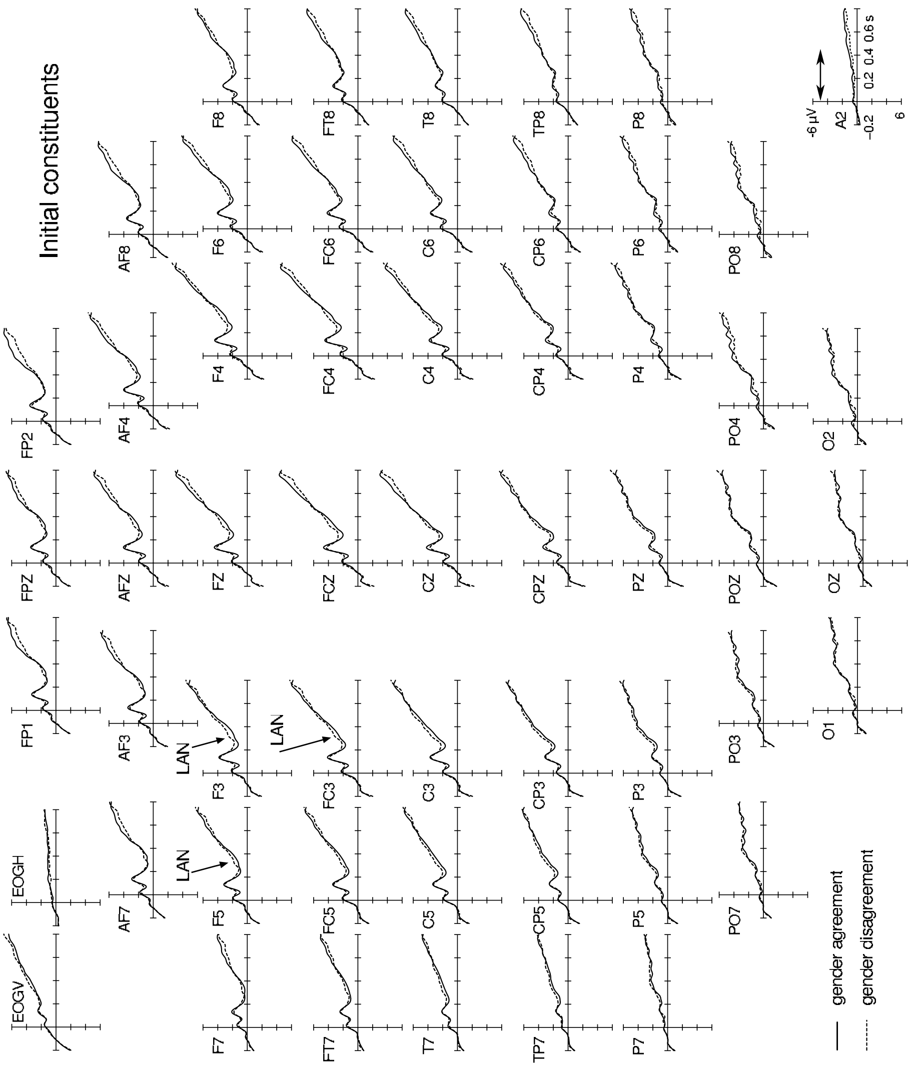

Figure 6.3: The ERP plots for gender congruent (solid line) and gender incongruent (dashed line) initial constituents of novel compounds. Gender incongruent initial constituents elicit a larger negativity at left anterior electrodes between 300 and 400 ms.

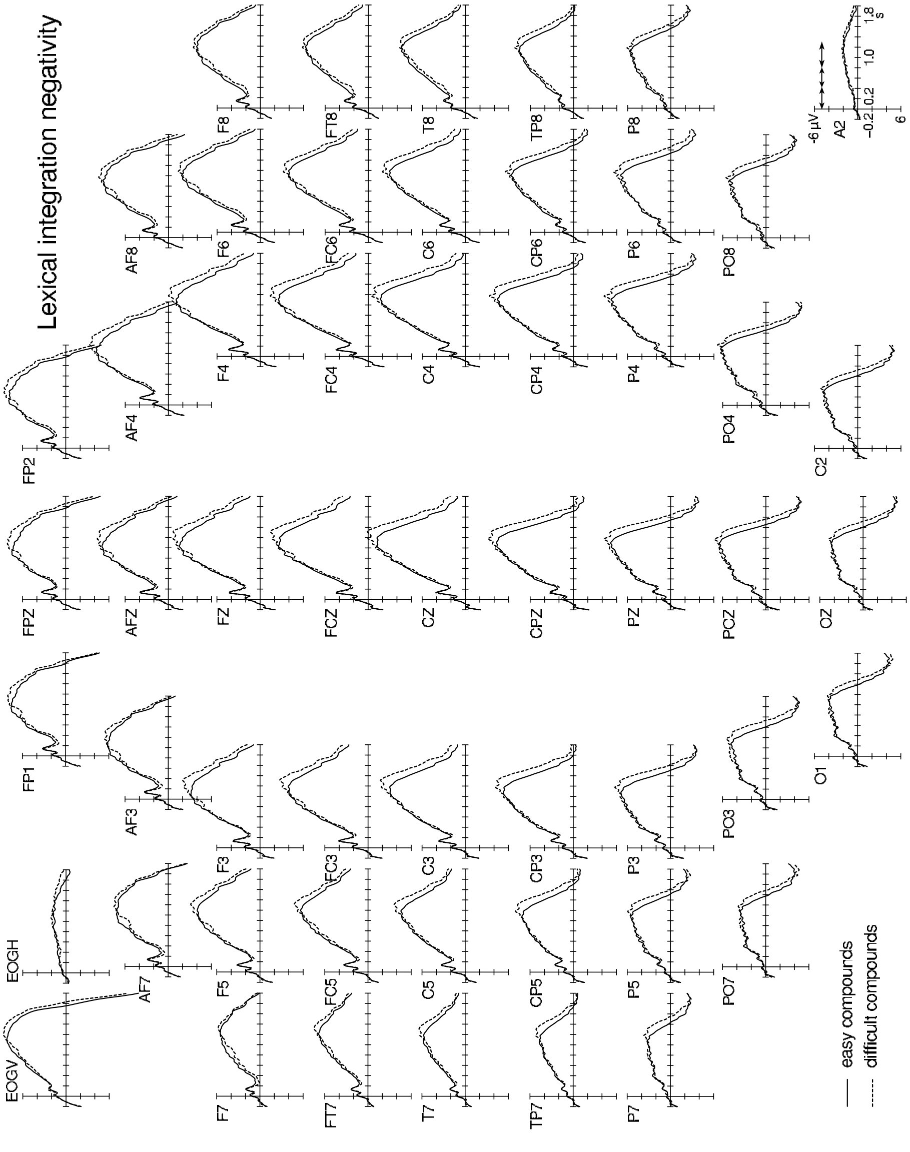

Figure 6.4: The ERPs for difficult (dashed line) and easy compounds (solid line) irrespective of gender agreement. Difficult compounds elicit a larger negativity (lexical integration negativity, LIN) beginning during the head constituent (1,200-1,600 ms). Average constituent lengths are indicated in the diagram A2.

Fig. 6.5). Both the modulation as well as its scalp distribution suggest that the negative shift reflects the integration of meaning of the constituents. An ANOVA was performed with the factors *AP* (2), *LR* (2), and *difficulty* (2) in the time window 1,200-1,600 ms after compound onset. The 3–way interaction did not reach significance (*F*(1,29)=1.22; ns) but the 2–way interaction of *AP* and *difficulty* was significant (*F* (1,29)=10.24; *p*<.01). In a next step the left and right ROIs were collapsed separately for the anterior and the posterior region. The main effect of *difficulty* was significant in both, the anterior and the posterior ROI with a larger negativity for difficult compounds (A: *F*(1,29)=17.99; *p*<.001; P: *F*(1,29)=37.83; *p*<.001).

If the primary ANOVA for the gender violation of the head constituents was repeated and *difficulty* (with 2 levels) was included as a factor, no interaction was obtained for *gender agreement* of the head constituent and *difficulty* (*F* (1,29)=0.17; ns).

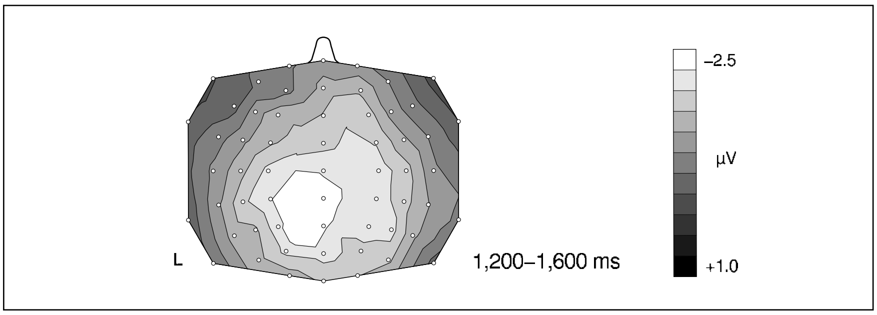

Figure 6.5: The scalp distribution of the lexical-semantic integration effect. The map shows the voltage difference between the ERPs of difficult and easy compounds. Difficult compounds elicit a larger negativity over centroparietal electrodes. The front is at the top of the figure and left is on the left side as in all subsequent maps.

Taken together, the gender manipulation of the head and the initial constituent of novel compounds elicit a LAN for both constituents which were independent of each other. Although the LAN for the head constituent was weaker, a LAN was clearly present for initial constituents. A slow negative shift was observed across the compounds that was sensitive to the lexical-semantic integration difficulty but did not influence the LAN of the head constituent.

6.1.4 Discussion

The behavioural result show that subjects performed well in both tasks. Accuracy was high and subjects did not report on any problems with the experimental task; both tasks were judged to be fairly easy. Grammaticality judgements were timed from the offset of the compound. Thus, ERPs may be affected after the compound offset by visual stimulation, decision processes, or motor responses. Subsequent experiments will introduce a short delay between the compound offset and response query.

Gender incongruent head constituents which are grammatically relevant for agreement, elicited a negativity that was significant between 350 and 450 ms. From the spatial and temporal distribution (see Fig. 6.2) it is concluded that the effect is a LAN reflecting the detection of a gender mismatch. Until now this has only been shown for non-compound words within sentence processing (Deutsch, & Bentin, 2001; Gunter et al., 2000; Wedel, & Hahne, 2002). Contrary to previous findings no P600 was observed. This may be due to the minimal phrase context used in Experiment 1 and the particular instruction. The P600 reflects rather controlled processes of re-analysis and repair (Friederici, 2002; Hagoort et al., 1993; Kaan, & Swaab, 2003; Osterhout, & Holcomb, 1992) and such controlled processes may not have occurred for the present stimuli because subjects were not instructed to repair errors. In addition, these minimal phrases are perfectly understandable even if they contain a gender mismatch (definite determiners do not carry semantic features[5]). The LAN for head constituents was independent of the gender agreement of initial constituents. This suggests that syntactic gender of each constituent is processed separately. Such a process may be triggered by the perceived onset of a constituent (more precisely a free morpheme).

Gender incongruent initial constituents elicited a negativity at anterior-left electrodes between 300 and 400 ms, therefore, the negativity is interpreted as a LAN. The effect suggests that the grammatical form (GF) of initial constituents is accessed during comprehension. Basically, there are two alternatives as to how parsing of novel compounds may proceed. On the one hand, activation of the grammatical form (GF) may be postponed until the head constituent is identified. On the other, the GF of each constituent may be accessed separately but independently of semantic processing. As gender is represented in the GF and gender incongruity of the first constituent elicits a LAN, the data clearly support the decompositional approach for novel compound comprehension, i.e. separate activation of constituents at the morphosyntactic level. The LAN for initial constituents was not followed by a P600 which may be explained by the fact that such a gender incongruity does not violate the determiner-compound phrase and, hence, does not require a repair process.

Post-hoc analyses suggest that the slow negative shift across the compound reflects the construction of meaning from the three constituents. The meaning of novel compounds must

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[5] It is acknowledged that nouns that denote biologically male or female referents, are also grammatically masculine or feminine, respectively, with only few exceptions. However, all other nouns incl. inanimate and abstract nouns require unambiguously *one* particular definite determiner. This strongly suggests that semantic features of biological gender are not carried by the determiners.

be constructed by composition of their constituent semantics (considering also their relationship) because for novel compounds no semantic representation exists yet. The semantic integration crucially depends on the availability of the head constituent because the head determines the semantic category of the compound. If the slow negative shift is related to the semantic integration of constituents it should last about as long as the compound or at least until the head constituent is processed. The negative shift was indeed found to return to baseline approximately at the acoustic offset of the compound. In order to test whether the slow shift is sensitive to the difficulty of compound interpretation the compounds were divided into easy and difficult compounds. The division is supported by the behavioural data. The amplitude of the slow negative shift was larger for difficult as compared to easy compounds. The scalp distribution of the effect has its maximum over centroparietal electrodes (see Fig. 6.5) which resembles that of the N400 (Kutas, & Federmeier, 2000; Kutas, & Van Petten, 1994), an ERP component that is correlated with semantic processing. It is, therefore, suggested that the slow negative shift reflects the lexical-semantic integration of constituents. In this thesis it will be called lexical integration negativity or LIN.

A possible confound of sex and grammatical gender should be mentioned as ”ballet-course-teacher” denotes a male referent and is grammatically masculine. Nine percent of the target items were indeed masculine and denoted male referents. However, a generic reading is possible for these items (the ballet course teacher *in general*) which includes male and female teachers. Moreover, biological gender is a semantic feature and semantic information is processed independently from gender information (Gunter et al., 2000). In addition, Osterhout, Bersick, and McLaughlin (1997) showed in a sentence comprehension study that biologically and stereotypically based gender violations elicit a P600 but no LAN. Therefore, it is argued that the principle confound did not affect the findings, especially as 91% of the items were not confounded.

In summary, gender incongruities elicited LANs for both the initial and the head constituent which were independent of one another. The results show that during comprehension of novel compounds each constituent is activated separately on the morphosyntactic level. Furthermore, a slow negative shift (lexical integration negativity) across the compound was found which is interpreted to reflect the integration of the individually accessed SFs of the constituents but it does not affect the morphosyntactic processing of gender.

Chapter 7

The case of transparent and opaque compounds

The results of Experiment 1 provoke further questions. Is a grammatical form (GF) also accessed for nonhead constituents of compounds that are supposed to have semantically their own lexical entry, i.e. opaque compounds? Can independent support be found for the interpretation of the lexical integration negativity (LIN)? These questions were addressed in the next two experiments.

7.1 Experiment 2a

7.1.1 Introduction

Experiment 1 showed that novel compounds are decomposed into their constituents by necessity for understanding. For existing compounds the processing situation is different because they might have their own lexical entry as suggested by the full-listing hypothesis (Butterworth, 1983; Bybee, 1995). This would make decomposition less likely as a processing strategy. If any compound were indeed stored in its full form morphosyntactic decomposition is not necessary and no LAN should be observed for gender incongruent nonhead constituents. However, it is reasonable to assume that low frequency transparent compounds are not stored but instead are processed via a decomposition route (Andrews, 1986; Isel et al., 2003; Libben, 1994; Sandra, 1990; Taft, & Forster, 1976; Zwitserlood, 1994). In this case, a GF of nonhead constituents should be accessed and elicit a LAN in incongruent in gender.

Another question concerns the semantic status of compounds. Previous research showed that the semantic forms (SFs) of transparent and opaque compounds are not processed equally. In the visual domain Sandra (1990) and Zwitserlood (1994) showed that transparent but not opaque compounds activate the SFs of their constituents in a semantic priming paradigm. The morphological representations of constituents, on the contrary, were found to be activated for both compound types as measured by repetition priming. These results suggest that a GF is accessed for transparent as well as for opaque compounds. Hence, gender incongruent initial constituents should elicit a LAN irrespective of the compound's semantic status. On the other hand, Isel and colleagues (2003) found that the SFs of initial constituents are not activated at all for compounds with an opaque head in the auditory modality. For compounds with a transparent head the SF of initial constituents was only activated at the end of the compound. This suggests that access to the SF of initial constituents is postponed until the head is identified. If, for some reason, GFs of existing compounds are processed in parallel to SFs in auditory presentation no LAN would be expected for gender incongruent nonhead constituents at all. For example, GFs of nonhead constituents may be omitted because they are syntactically irrelevant in German. A third alternative predicts that transparent but not opaque compounds are decomposed morphosyntactically. Opaque compounds are suggested to have their own lexical entry because their meaning cannot be combined from the constituents. Transparent compounds of the same low frequency are not supposed to have a lexical entry and should, therefore, be processed by decomposition. According to this alternative, nonhead constituents of transparent but not of opaque compounds may elicit a LAN during auditory comprehension.

The semantic processing of compounds does not have to parallel the morphosyntactic processing. Sentence processing studies (Gunter et al., 2000) and Experiment 1 suggest that syntactic gender is processed independently from semantic information. Even if transparent and opaque compounds are processed equally on the morphosyntactic level they may be processed differently on the semantic level. Transparent compounds may be computed from the semantics of the constituents. If so, these compounds require lexical-semantic integration that is not required for opaque compounds as the meaning of opaque compounds is not related to the semantics of their constituents. If the LIN reflects lexical-semantic integration it should be larger for transparent compared with opaque compounds.

In Experiment 2a, subjects will be presented with semantically transparent and opaque two-constituent compounds and the gender agreement will be manipulated in the same way as in Experiment 1. In doing so, the access of gender information can be assessed for each constituent and also whether it differs for transparent and opaque compounds.

Given that morphological decomposition was found for transparent and opaque compounds (Sandra, 1990; Zwitserlood, 1994), combined with the results of Experiment 1, it is predicted that all compounds are decomposed morphosyntactically. That is, each gender mismatch should elicit a LAN and the gender processing of head constituents should be independent from gender violations of initial constituents. Based on the finding that gender is processed independently of semantic information (Exp. 1; Gunter et al., 2000) the LANs are also expected to be independent of the compound's semantic status. In addition, compounds are expected to elicit a LIN. If the LIN reflects lexical-semantic integration it should be larger in amplitude for transparent compounds with a maximum of the effect at centroparietal electrodes.

7.1.2 Materials and methods

Subjects. Twenty-three (12 male) right handed (lateralisation coefficient 95) volunteers participated (mean age 24;6; range 19-31 yrs.). Subjects were German native speakers and had normal or corrected to normal visual and auditory acuity and were paid for their participation.

Materials. Eighty two-constituent compounds were collected that were semantically of transparent-transparent (TT) status and another 80 compounds that were semantically of opaque-opaque (OO) status. The latter cannot be constructed as they emerge historically in a language corpus and, thus, the gender combination of their constituents cannot be manipulated. However, the gender distribution across compounds was fairly matched (34% feminine, 38% masculine, and 28% neuter). Both types of stimuli were matched with respect to frequency (TT 17.75; OO 16.89; Quasthoff, 2002)[1] and number of syllables (both 3.2). None of the constituents was in its plural form and no constituent was repeated within a given compound position. A total of 120 transparent three-constituent compounds and 280 single words (one free morpheme at most) were added as fillers. Gender distribution across the experiment was acceptable (37% feminine, 40% masculine, and 23% neuter). Determiner assignment was equivalent to Experiment 1. Twenty-five per cent of the items (for each group of OO and TT) were assigned a definite determiner that agreed in gender with both constituents yielding the AA condition. Another 25% were assigned a definite determiner that did not agree in gender with the first constituent but with the second constituent (VA). In the same way 25% of the items were assigned to the AV and 25% to the VV conditions.

Two lists were constructed whereby the two constituent compounds were assigned a different determiner in the second list. If an item belonged to condition AV in the first list it

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[1] This data base contains about the same amount of entries as the *Celex* database (Baayen et al., 1995). However, the frequency count was terminated 2000 and is, thus, more up-to-date. The frequency values are logarithmic and indicate how often a word occurs in relation to the definite determiner ”der” (the$_{masc}$). A frequency of, for instance, 12 for a word X means that the determiner ”der” appears 2^{12} times more often than X. That is, higher frequency values indicate rarer appearance.

belonged to the condition VA in the second list. Items in condition AA appeared in condition VV on the second list, and vice versa. The recording procedure was identical to Experiment 1.

Procedure. The general procedure was the same as in Experiment 1. Each trial started with a 200 ms blank screen followed by a fixation cross presentation for 800 ms before auditory stimulation began. The fixation cross remained on the screen throughout the auditory presentation of the determiner and the noun. After the acoustic offset no stimulation took place for 200 ms, then a task cue was given either ”Grammatikalität” (grammaticality) or ”Interpretation” (interpretation) in the upper part of the screen. In the interpretation task subjects had to compare semantically the target word to a probe word that was presented on the lower part of the screen together with the task cue. In the grammaticality task the same location was captured by a string of hash marks. Feedback was provided by visual stimuli. The session lasted approximately 60 min consisting of three blocks. The experiment was followed by a debriefing session.

Half of all items were presented with a gender congruent determiner and the other half with a gender incongruent determiner (with regard to the head constituent as only this constituent is relevant for the grammaticality decision). In the semantic task which was applied equally to the gender congruent and incongruent trials, half of the items were semantically similar to the visually presented probe word. The order of presentation was pseudorandom with no more than two successive presentations of any experimental condition. Since the two lists were randomly assign to different subjects each item was presented in two conditions across all subjects. Subjects had 16 training trials that were not used in the experiment.

EEG-Recordings. The EEG was recorded from 34 Ag/AgCl electrodes. The technical parameters were identical to Experiment 1. The electrodes used are indicated in Fig. 6.1.

Data analysis. The ERP calculation was identical to Experiment 1. Contaminated EEG epochs were automatically rejected (EOG rejection $\pm 40 \mu V$; EEG rejection $\pm 25 \mu V$), and double checked by visual inspection. Approximately 11% of the trials were excluded due to rejection criteria, movement artefacts, or incorrect responses. Four ROIs were constructed in order to test spatial distribution differences of effects (AL: F7, F5, F3, FT7, FC5, FC3; AR: F4, F6, F8, FC4, FC6, FT8; PL: TP7, CP5, CP3, P7, P5, P3; PR: CP4, CP6, TP8, P4, P6, P8).

7.1.3 Results

Behavioural data. Subjects reported no problems with the task and performed well as indicated by the high accuracy rates in both tasks (GRA 96%; SEM 91%[2]). Both tasks were judged to be easy on the 4–point scale in the debriefing session (GRA 1.5; SEM 2.1).

ERP data: head constituent. The mean ERP amplitude was calculated for each condition and each ROI in the time window 400-500 ms time-locked to the onset of the head constituent (Fig. 7.1). An ANOVA was performed with the factors *ROI* (4: AL, AR, PL, PR), *gender agreement* of head constituents (2), *gender agreement* of initial constituents (2), and *semantic status* (2). No interaction of *gender agreement* of head constituents with *semantic status*, or *gender agreement* of *initial* constituents was found ($F(1,22)=0.00$; $F(1,22)=0.79$; both ns, respectively). The 2–way interaction of *gender agreement* of head constituents and *ROI* was significant ($F(3,66)=6.58$; $p<.01$; $\varepsilon=0.72$). In order to determine the scalp distribution of the *gender agreement* effect each ROI was tested separately. The main effect of *gender agreement* of head constituents was only significant in the left-anterior ROI ($F(1,22)=10.98$; $p<.01$). None of the other ROIs showed a significant effect of *gender agreement* (AR: $F(1,22)=0.26$; PL: $F(1,22)=2.15$; PR: $F(1,22)=0.66$; all ns).

First constituent. Again, an ANOVA with the factors *ROI* (4), *gender agreement* of initial constituents (2), and *semantic status* (2) was performed in the time window 400-500 ms after compound onset (Fig. 7.2). The interaction of *gender agreement* and *semantic status* did not reach significance ($F(1,22)=0.78$; ns). However, the 2–way interaction of *ROI* and *gender agreement* was significant ($F(3,66)=4.17$; $p<.05$; $\varepsilon=0.75$), and subsequently the effect of *gender agreement* was tested separately for each ROI. Only the left-anterior ROI showed a significant main effect of *gender agreement* ($F(1,22)=4.35$; $p<.05$) whereas the other ROIs were nonsignificant (AR: $F(1,22)=0.25$; PL: $F(1,22)=0.04$; PR: $F(1,22)=0.25$; all ns).

Semantic status. The effects of semantic status were evaluated by an ANOVA with the factors *ROI* (4), *semantic status* (2), *gender agreement* of first (2), and *gender agreement* head constituents (2). From Figure 7.3 it appears that there are two effects of *semantic status*, namely between 500 and 700 ms with a more negative ERP for opaque compounds and a negativity for transparent compounds between 950 and 1,150 ms. In neither of the two time windows did *semantic status* interact significantly with the gender agreement of either constituent or both (all $F(1,22)<2.14$; all ns). The 2–way interaction of *ROI* and *semantic status* was significant between 500 and 700 ms ($F(3,66)=3.32$; $p<.05$; $\varepsilon=0.65$) and

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[2] The difference between grammaticality and semantic judgements ($t(22)=3.69$; $p<.01$) may arise from the assignment of probe words to the experimental items. The semantic relation between each item and the probe was not controlled but cannot affect the ERPs because subjects never knew which task would be required in the present trial during presentation.

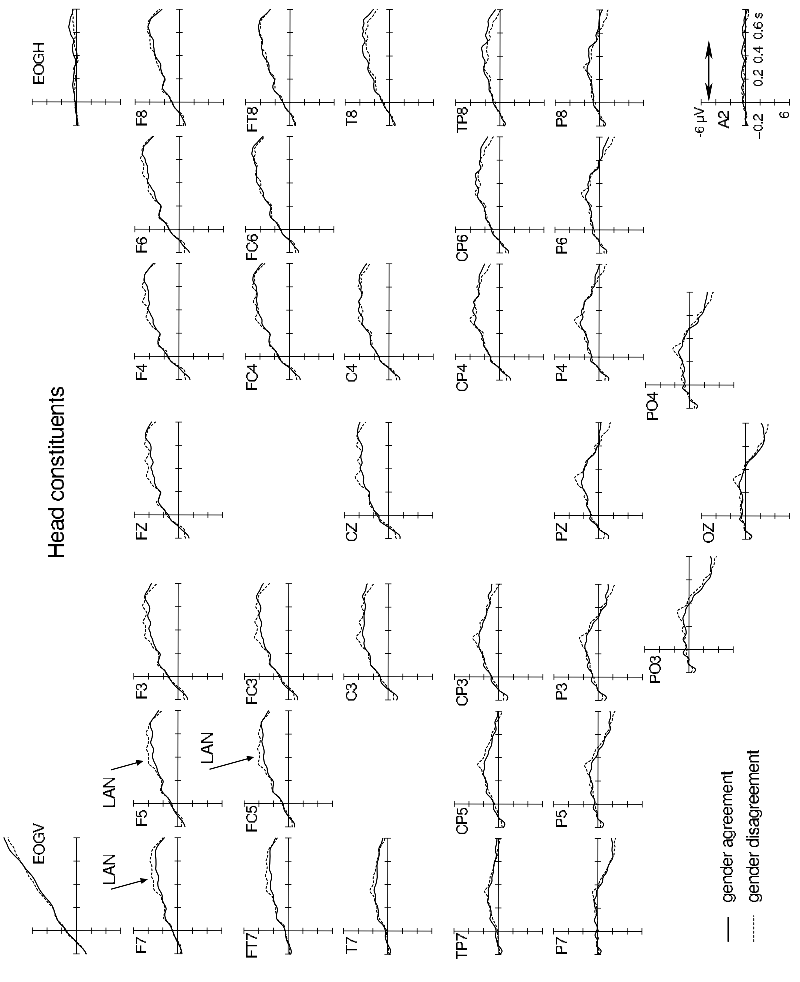

Figure 7.1: The ERPs for gender congruent (solid line) and gender incongruent (dashed line) head constituents of low frequency compounds. Gender incongruent head constituents elicit a larger negativity at left-anterior electrodes (400-500 ms) that was independent of semantic status. ERPs are collapsed across semantic status.

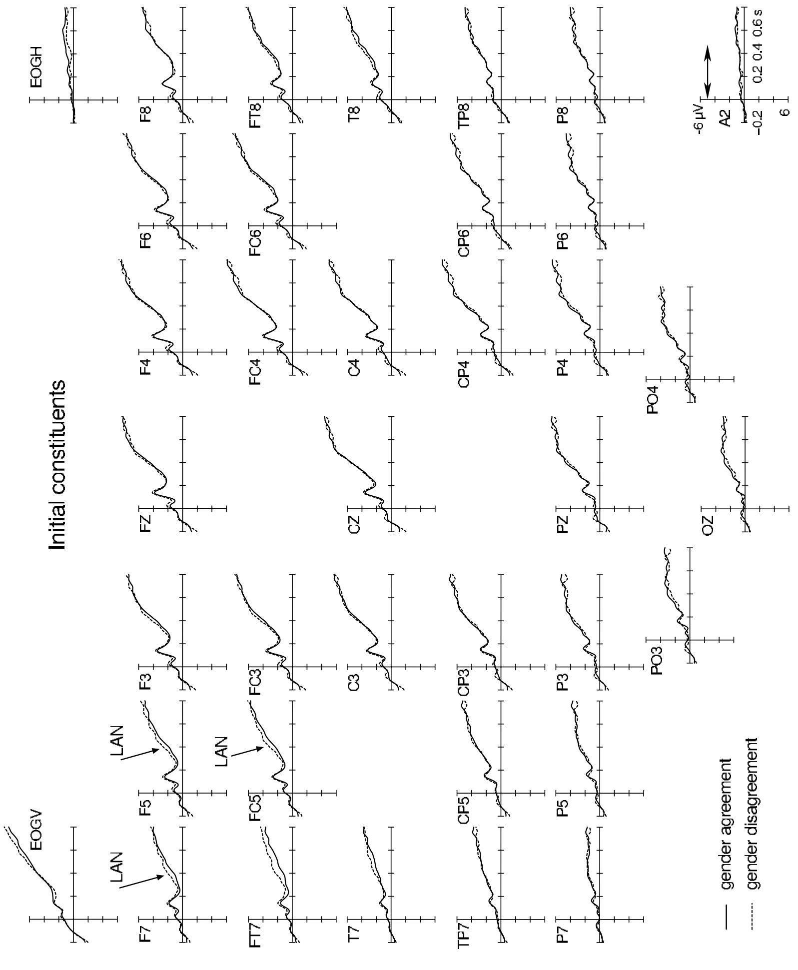

Figure 7.2: The ERPs for gender congruent (solid line) and gender incongruent (dashed line) initial constituents of low frequency compounds. Gender incongruent initial constituents elicit a larger negativity at left-anterior electrodes (400-500 ms) that was independent of semantic status. ERPs are collapsed across semantic status.

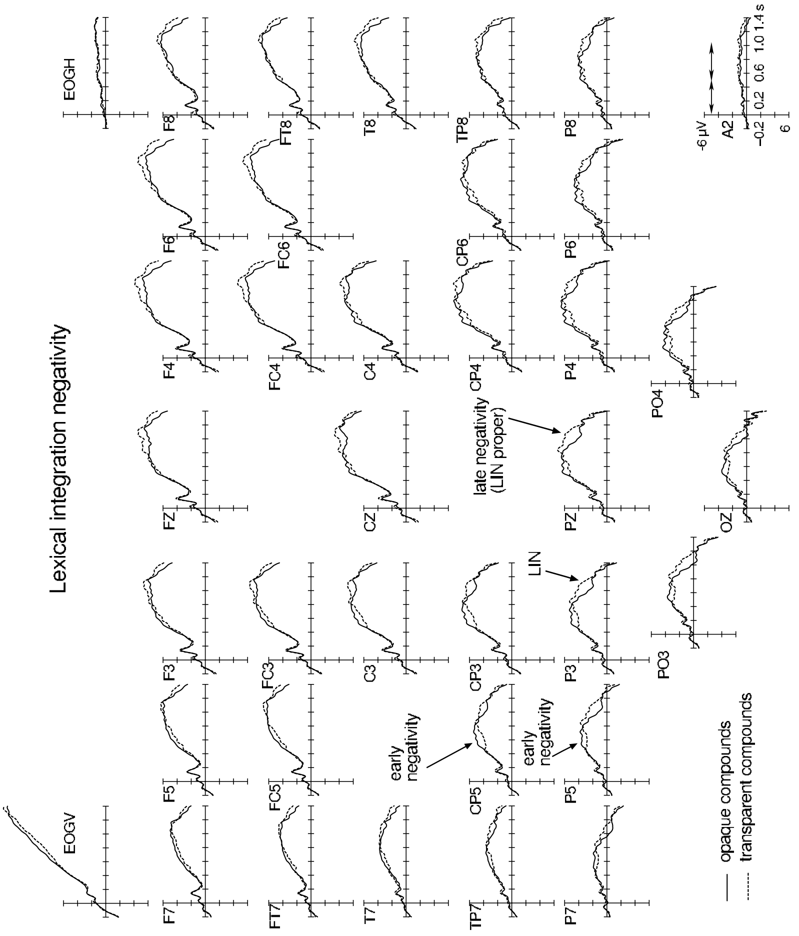

Figure 7.3: The lexical integration negativity for opaque (solid line) and transparent compounds (dashed line). Two effects are observed, opaque compounds elicit a larger negativity between 500 and 700 ms, and transparent compounds elicit a larger negativity between 950 and 1150 ms. The latter modulation is the LIN proper. ERPs are collapsed across gender agreement as the effects of gender and semantic status are independent of one another.

also between 950 and 1,150 ms (*F*(3,66)=3.54; *p*<.05; ε=0.68). Subsequently each ROI was tested separately for a main effect of *semantic status*; this was done for both time windows. There was a main effect of *semantic status* between 500 and 700 ms in the left-anterior ROI (*F*(1,22)=6.15; *p*<.05), in the left-posterior ROI (*F*(1,22)=8.26; *p*<.01), and in the right-posterior ROI (*F*(1,22)=4.68; *p*<.05). The right-anterior ROI did not reach significance (*F*(1,22)=0.23; ns). The main effect of *semantic status* was also significant between 950 and 1,150 ms in all ROIs except for the left-anterior (AL: *F*(1,22)=1.17; ns; AR: *F*(1,22)=6.36; *p*<.05; PL: *F*(1,22)=12.26; *p*<.01; PR: *F*(1,22)=5.31; *p*<.05).

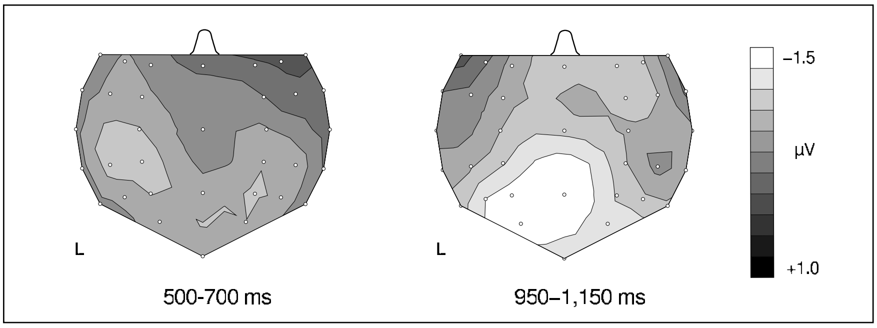

Figure 7.4: The scalp distribution of the effects of semantic status. In the time window 500-700 ms opaque compounds elicit a more negative ERP with a broad distribution and a maximum over left temporal areas (left panel; opaque-transparent). Transparent compounds elicit a larger negativity between 950 and 1,150 ms with a centroparietal maximum (right panel; transparent-opaque).

The difference map (Fig. 7.4) suggests that the late negativity for transparent compounds (950-1,150 ms) has a similar scalp distribution as the LIN effect in Experiment 1. The earlier effect for opaque compounds (500-700 ms), however, shows a broad distribution, sparing only the right-anterior ROI, and the effect seems to be stronger over left-temporal areas. The earlier effect for opaque compounds may be an artefact of the different peak latencies of the LIN for opaque and transparent compounds (see Fig. 7.3). To test this possibility the scalp distributions of the LINs for opaque and transparent compounds were compared. The scalp distributions are highly similar which also suggests a similar underlying process (see Fig. 7.5). The peak latency were determined for opaque and transparent compounds at the electrode CZ. The amplitude values at the peak latencies (1,160 ms for opaque & 1,124 ms for transparent) were tested in an ANOVA with the factors *ROI* (4), and *peak latency* (2). The interaction of *ROI* and *peak latency* was not significant (*F*(3,66)=0.39; ns) indicating that the same neural generator(s) may account for the observed ERPs.

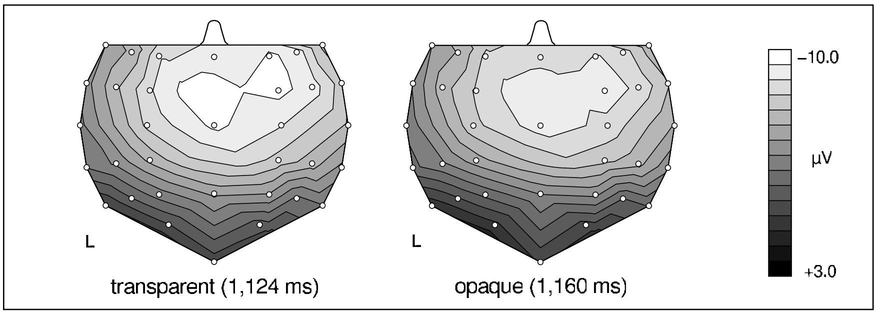

Figure 7.5: The scalp distribution of the LIN for transparent and opaque compounds. The LIN has a frontocentral maximum and the scalp distribution does not differ between transparent and opaque compounds.

In summary, the gender manipulation of the head and of the initial constituent of low frequency compounds elicit a LAN for each constituent which were independent of each other. The LANs were also independent of semantic status, i.e. they were equal for transparent and opaque compounds. The compounds elicited also a LIN that was sensitive to the semantic status but not to the gender manipulations. Semantic status elicited two effects, a negativity for opaque compounds that preceded a second negativity for transparent compounds.

7.1.4 Discussion

Both tasks were rated to be fairly easy by the subjects. High accuracy rates also suggest that both tasks were easy and show that subjects responded reliably.

Gender incongruities of head constituents of low frequency compounds elicit a LAN, i.e. Experiment 1 was replicated. The comparison of agreement and violation conditions was a within item comparison across subjects. Hence, the LAN cannot be explained by differences between item groups. The LAN was also independent of the semantic status which suggests that gender is processed equally for transparent and opaque compounds. This is in accordance with previous findings that semantic processing is independent of gender processing (Exp. 1; Gunter et al., 2000). Furthermore, the LAN was observed relative to the onset of the head constituent which suggests that at least the morphosyntactic information gender is accessed each time a (noun) constituent is perceived.

The LAN for first constituents clearly shows that gender information is processed during the comprehension of compounds and indicates, therefore, that each constituent is activated separately at the morphosyntactic level. Gender of nonhead constituents is accessed regardless of their semantic status. The decomposition effect represents strong evidence against the full-listing hypothesis (Butterworth, 1983) with respect to morphosyntactic processing. The data suggest that compounds do not have a morphosyntactic representation of their own, even not opaque ones. The morphosyntactic representation of the constituents, however, is retrieved and may serve as an access code to the SFs of the constituents.

The experimental manipulation of gender agreement was not confounded with other morphosyntactic or semantic features. Neither could a possible confound with biological gender produce these results. As in Experiment 1 the LANs were not followed by a P600 as reported by Gunter et al. (2000), and Hagoort and Brown (1999). Again, subjects were not required to correct gender violations, hence no re-analysis and repair was necessary. Hence, it is concluded that the LANs reflect the detection of a gender incongruity.

It remains unclear why the gender information of initial constituents is processed at all given that it is never relevant in German. This is surprising since prosodic information, namely the duration of first constituents discloses the constituent as part of a compound (Isel et al., 2003). Hence, the effects suggest that the processing of gender information is rather automatic and/or that gender in an essential part of lexical (noun) entries.

Experiment 2a investigated also differences between opaque and transparent compounds in lexical-semantic integration. The integration of constituents in order to yield the compound meaning is necessary for low frequency transparent compounds but not for opaque compounds. The electrophysiological data show differences in ERP amplitude between opaque and transparent compounds in two time windows; an earlier negativity for opaque and a later negativity for transparent compounds. Both effects occur during the presentation of the head constituent.

The earlier negativity for opaque compounds (500-700 ms) is suggested to be a epiphenomenon of a latency difference between the ERPs. That is, one has to assume that the same cognitive process underlies the LIN but has a different peak latency for transparent compounds compared with opaque ones. The scalp distributions of the LINs for transparent and opaque compounds are highly similar and were not statistically different from each other. The slow rise of the ERP is suggestive of a lexical search process, i.e. the ongoing matching of phonemes to lexical entries. The maximum of the LIN is located at frontocentral electrodes which supports this interpretation as lexical effects such as search processes have been related to more frontally distributed components (Deacon et al., 1995; Dien et al., 2000; Nobre, & McCarthy, 1994; Wagner, 2003). Moreover, the negativity for opaque compounds has no clear focus but is widely distributed across the scalp. This may also be a hint that the earlier effect results from a different peak latency of the LINs.

Transparent compounds elicited subsequently a larger negativity than opaque compounds and the distribution of the effect is similar to an N400 effect and to the scalp distribution of the LIN found in Experiment 1. The meaning of low frequency transparent compounds is constructed from the SFs of the constituents. That is, compared with opaque compounds an additional lexical-semantic integration is necessary. Based on the modulation and the scalp distribution of the effect, it is concluded that the later negativity reflects the lexical-semantic integration of transparent compounds (LIN proper).

Taken together, Experiment 2a shows that low frequency compounds (transparent as well as opaque) are morphosyntactically decomposed during auditory comprehension. Each gender incongruent constituent elicited a LAN and the effects of both constituents were independent of one another. The compounds elicited also a LIN; it was sensitive to the semantic status of the compounds and the LIN modulation did not interact with the morphosyntactic processing. An earlier negativity for opaque compounds is suggested to be an epiphenomenon of the different peak latencies of the LIN. A subsequent negativity for transparent compounds reflects the lexical-semantic integration of transparent constituents which is not necessary for opaque compounds.

After all, it might be objected that the effects of morphosyntactic decomposition are induced solely by the context or experimental set-up, i.e. by the presence of novel compounds. This possibility was checked in a control experiment.

7.2 Experiment 2b

7.2.1 Introduction

Although compounding is very productive and compounds are often used in German one may object that novel compounds are not found in every conversation or newspaper article. That is, the ecological validity of Experiments 1 and 2a may not be of relevant magnitude; the results may solely be due to the (unusual) amount of novel compounds. A decompositional processing strategy might have been induced by the large amount of novel compounds (almost all in Experiment 1; about 1/4 in Experiment 2a). Similarly, it was claimed that compounds are not decomposed regularly (de Almeida, & Libben, 2002). These authors showed with different behavioural measures that the visual degrading (replacing one letter by a hash mark) affects 3-letter words more adversely than 5-letter words. If compounds are processed by accessing the constituents the differential effect should still be found if the 3- and 5-letter words are compound constituents. However, when testing this prediction, there was no differential effect for these words as compound constituents. Hence it was concluded that morphological decomposition does not occur regularly.

If morphosyntactic decomposition is induced solely by novel compounds, decomposition should not take place if no novel compounds are excluded. In this case, gender incongruity of nonhead constituent should not elicit a LAN or any other ERP effect. On the contrary, morphosyntactic decomposition may be a regular process of (compound) comprehension. That is, compounds are regularly decomposed and a LAN is still expected for gender incongruent nonhead constituents.

In order to test whether morphosyntactic decomposition takes place regularly, Experiment 2a is basically replicated without presenting novel compounds. Compounds that are lowest in frequency were also excluded. It is predicted that gender incongruent nonhead constituents elicit a LAN; such an effect would indicate that morphosyntactic decomposition occurs regularly. If the effects of morphosyntactic decomposition (Exps. 1 and 2a) are induced solely by the experimental set up (inclusion of novel compounds), then no effect should be found for gender incongruent nonhead constituents. The semantic status is expected to show the same effects as in Experiment 2a, i.e. an earlier negativity for opaque and a later negativity for transparent compounds.

7.2.2 Materials and methods

Subjects. Sixty-three (31 male) right handed volunteers participated in this study. They were 24;2 yrs. of age (range 19-31) and right handed (lateralisation coefficient 91). Subjects were German native speakers and had normal or corrected to normal visual and auditory acuity and were paid for their participation.

Materials. The material construction was identical to Experiment 2a. Since the morphosyntactic effects of initial constituents are in focus, the manipulation of the head constituent is not relevant for the data analysis and, thus, makes it possible to reduce the number of target items. Semantic status can also be evaluated because it is processed independently of morphosyntactic processing. Thirty-six transparent (TT) and opaque (OO) compounds consisting of two constituents were collected from the stimuli of Experiment 2a. As said before, the gender distribution of OO compounds cannot be manipulated. The selection of TT compounds made sure that the gender distribution within compounds was acceptable (30% feminine, 42% masculine, and 28% neuter). A total of 72 single words were added as fillers. Across the experiment each gender type was equally distributed (33% feminine, 34% masculine, and 33% neuter). The frequencies of TT and OO compounds were matched (TT 17.08; OO 16.41; Quasthoff, 2002,).

Two lists were constructed whereby the second list was the mirror image of the first with respect to the experimental conditions. Note that the gender agreement of the head constituent was manipulated in the same way as in Experiment 2a but cannot be analysed due to the reduced number of stimuli.

Procedure. The experimental procedure was similar to Experiment 2a. In contrast to Experiment 2a, two experimental sessions were recorded that were separated by at least one week. Each subject heard each of the respective lists only once, whereby the order of lists was randomised. That is, the gender manipulation can be evaluated within items for each subject.

EEG-Recordings. The EEG recording was identical to Experiment 1.

Data analysis. Data analyses were done in the same way as in Experiment 2a using the same ROIs. Approximately 13% of the trials were excluded due to rejection criteria, movement artefacts, or incorrect responses.

7.2.3 Results

Due to the reduced number of stimuli a high proportion of subjects had to be excluded as a result of eye movements, blinks, and other motion artefacts. The remaining 40 subjects (17 male) were 23;9 yrs. of age (range 19-30) and right handed (lateralisation coefficient 90).

Behavioural data. Subjects judged both tasks to be easy in the debriefing session (GRA 1.35; SEM 2.15). They performed well as indicated by a high accuracy rate in the grammaticality tasks (GRA 91%) and an acceptable accuracy rate in the semantic task (SEM 83%; $t(39)=5.9$; $p<.001$). The decreased accuracy in the semantic task is due to the judgement of opaque compounds. These were rated much worse (75%) than were the transparent compounds (91%; $t(39)=9.09$; $p<.001$).

ERP data: morphosyntax. In order to evaluate the effect of gender mismatch of the initial constituent an ANOVA was performed with the factors *AP* (2), *LR* (2), *gender agreement* (2), and *semantic status* (2). A main effect of *gender agreement* was found between 400 and 500 ms post onset of the compound that was marginally significant ($F(1,39)=3.17$; $p=.08$). However, there was no interaction with either *AP*, *LR*, or both (all $F(1,39)<2.5$; all ns). Furthermore, *gender agreement* did not interact with the *semantic status* ($F(1,39)=1.33$; ns).

Although the *gender agreement* effect is weak it suggests that the gender manipulation did affect the processing of nonhead constituents. Unfortunately, it could not be localised in a ROI analysis. The absence of an interaction of *gender agreement* and ROI indicates that the *gender agreement* effect is equally distributed across the scalp. This is very unlikely given that gender violations were reported to yield a left-anterior negativity (Deutsch, & Bentin, 2001; Gunter et al., 2000; Wedel, & Hahne, 2002) and also Experiments 1 and 2a showed that the *gender agreement* effect is restricted to left-anterior electrodes. The nonsignificant interaction of *gender agreement* with the ROI factors may be due to the small size of the *gender agreement* effect; the merging of electrodes may possibly have reduced the main effect of *gender agreement*. In addition, midline electrodes are spared from the ROI analyses because they could not be allocated to the present ROI classification. Therefore, separate ANOVAs were performed for single electrodes in the same time window in order to find out whether the main effect is weak in general, i.e. at all or most electrodes. This would confirm the interpretation that the *gender agreement* effect is distributed equally across the scalp. Only eight electrodes showed a significant main effect of *gender agreement*, seven of which are spatially adjacent to each other over the left hemisphere (see Fig. 7.6). The effect seems to be restricted to left hemisphere electrodes although it is not restricted to frontal electrodes. The significant electrodes are F7, FT7, FC5, T7, C5, TP7, CP5, and CZ (all $F(1,39)>4.1$; all $p<.05$). For the complete results see Tab. B.1; Appendix B.1.

Semantic status. There was only one effect of *semantic status*, extending from 600 to 1200 ms with a more negative ERP for transparent compounds (see Fig. 7.8). The effect of semantic status was evaluated by an ANOVA with the factors *AP* (2), *LR* (2), and *semantic status* (2). There was a main effect of *semantic status* between 600 and 1200 ms ($F(1,39)=34.45$; $p<.0001$) and an interaction of *LR* and *semantic status* ($F(1,39)=12.29$; $p<.01$). To follow up this interaction an ANOVA for *semantic status* was performed for each hemisphere. Significant effects of *semantic status* obtained for the left ($F(1,39)=24.22$; $p<.0001$) and the right hemisphere ($F(1,39)=40.2$; $p<.0001$). Although the effect is reliable over both hemispheres, the maximum of the effect seem to be over centroparietal electrodes (cf. Fig. 7.7).

The earlier negativity for opaque compounds, as it was found in Experiment 2a, could not be replicated here. *Semantic status* did not yield a significant main effect in the time window 500-700 ms ($F(1,39)=0.46$; ns) which is the equivalent time window of the effect in Experiment 2a.

Taken together, gender violations of nonhead constituents elicited a larger negativity for gender incongruent constituents. Although this negativity did not interact with the ROI factors it affected selectively electrodes over the left hemisphere. Semantic status elicited a LIN that was more negative for transparent compounds compared with opaque ones with a centroparietal maximum of the effect.

7.2.4 Discussion

Subjects' performance showed a high accuracy in the grammaticality task and also an acceptable performance in the semantic judgement task. The decreased performance in the

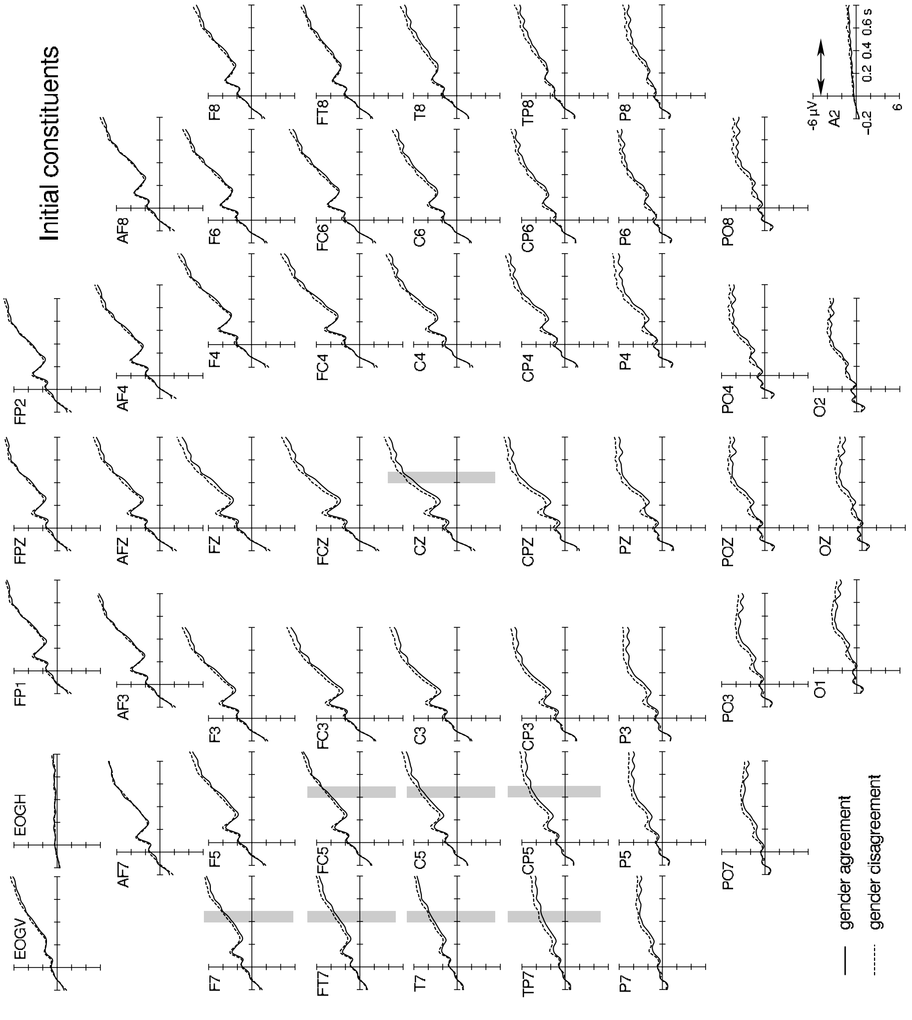

Figure 7.6: ERPs for gender congruent (solid line) and gender incongruent (dashed line) initial constituents of low frequency compounds. Gender incongruent initial constituents elicit a larger negativity at left temporal electrodes (400-500 ms) that was independent of semantic status. The significant electrodes are marked in grey. ERPs are collapsed across semantic status.

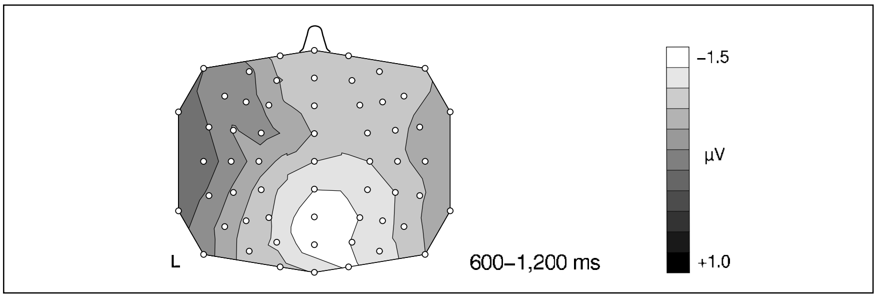

Figure 7.7: The scalp distribution of the lexical integration negativity effect. Only one effect was observed in Experiment 2b. Transparent compounds elicit a larger negativity between 600 and 1,200 ms with a centroparietal maximum.

semantic task is due to the opaque compound condition. The reason for this drop in performance cannot be determined (see footnote 2, p. 85) but it is possible that subjects were not sure whether a literal reading[3] or the *normal*, opaque meaning was intended. Overall, subjects performed well and comparably to the first two experiments except for the semantic judgements of opaque compounds. However, performance was clearly above chance level even in the latter condition.

The results of Experiment 2b show that the morphosyntactic decomposition of compounds is not solely induced by the presence of novel compounds. Conversely, an effect of gender violation of the nonhead constituent was found which was independent of the semantic status. This effect shows that gender of nonhead constituents is available, even if neither novel, nor compounds of very low frequency are included in the experimental session. The effect of gender incongruity was weak and could not be localised statistically in a ROI analysis. This might have been due to the small size of the effect and the exclusion of midline electrodes. However, if all electrodes were tested separately eight electrodes over the left temporal region showed a strong effect including three of the midline electrodes.[4] Seven of these electrodes were spatially adjacent which might be seen as an indication for a rather focal effect. More generally, although no novel compounds were presented in the experimental session the gender manipulation affected the ERP. Hence, it seems not to be justified that morphological decomposition is a pure induced effect. Nevertheless, it should be stressed here that the gender was weak and was not restricted to the left-anterior ROI.

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[3] Opaque compounds can in principle be read as if they were semantically transparent. For example, ”foxgloves” can be interpreted as the gloves of a fox instead of being a plant. This is sometimes used in humour.

[4] A significant effect at eight electrodes out of 56 would not be expected on a chance basis.

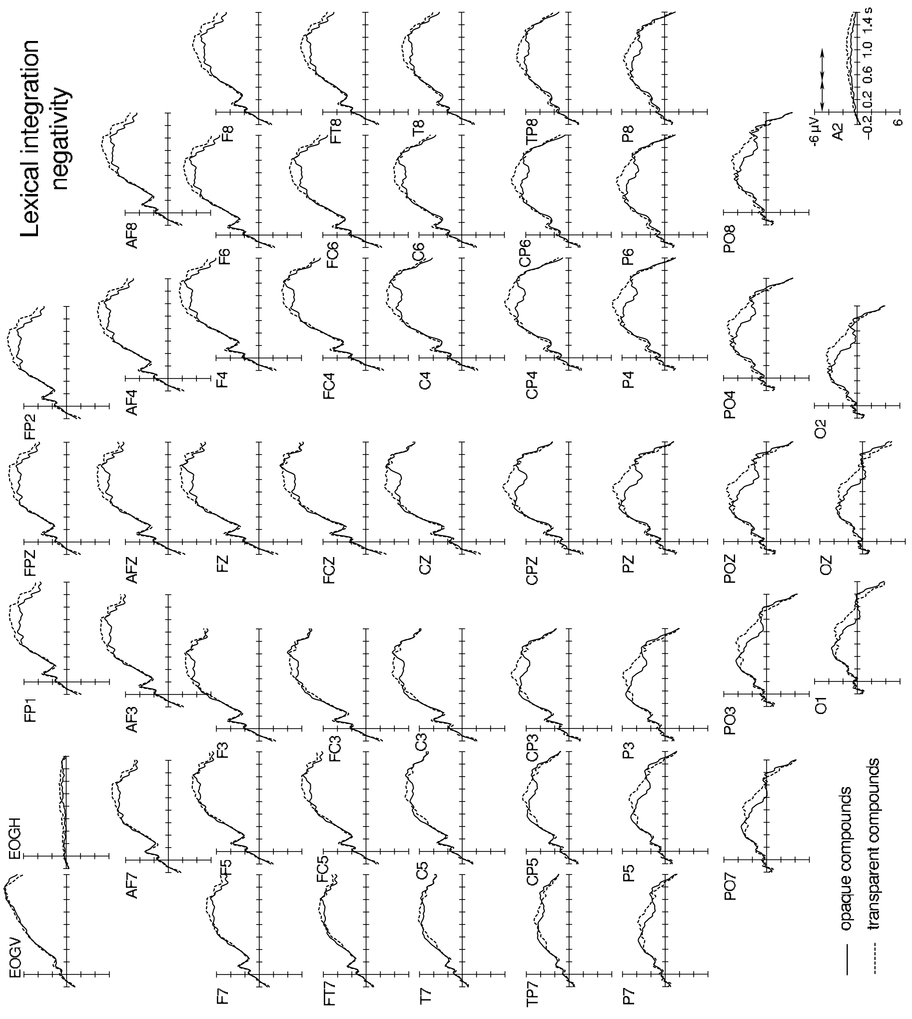

Figure 7.8: The ERPs for transparent (dashed line) and opaque compounds (solid line) irrespective of gender agreement. Transparent compounds elicit a larger lexical integration negativity beginning during the head constituent and lasting beyond it (600-1,200 ms).

Several facts may be responsible for the slightly different topography of the effect compared with the previous two experiments. First, the reduced number of stimuli may have made the ERP more noisy compared to the other experiments. This may affect the statistical analysis and reduce its power. Second, the rather high drop out rate may have resulted in a selected subject group (e.g. relatively more subjects who performed well on the task or made fewer eye blinks during critical periods). In this case, the appearance of the effect at left temporal electrodes instead of left-anterior electrodes would simply reflect interindividual differences but not differences in the cognitive processes. A third possibility is that there is some variability in the distribution of effects related to morphosyntactic violations. For example, a left temporal negativity was found in response to morphologically marked tense and negation violations (between an auxiliary, and either a time adverbial or a negative polarity item; Hagiwara, Nakajima, Nakagome, Takazawa, Kanno, Ito, & Koshida, sub.). The effects were found between 300-400 ms and 200-300 ms, respectively, and were discussed as variants of the LAN. In another study a negativity over left central instead of frontal electrodes was found in response to a grammaticality manipulation of the subject-verb agreement (Kaan, 2002). It was expected that morphologically marked number violations elicit a LAN but the negativity between 300 and 500 ms had a central rather than a frontal distribution. Here, it cannot be decided which is the reason for the slightly more posterior distribution of the gender violation effect. It seems likely that a combination of variability in the *normal* topography of the LAN and a selection bias for well-performing subjects account for the left temporal distribution of the effect.

Experiment 2b replicated partially the effects of semantic status found in Experiment 2a. Compounds elicited a LIN that returned to baseline approximately after the compound offset. It was larger in amplitude and broadly distributed with a centroparietal maximum for transparent compounds in comparison to opaque ones. This negativity extends from 600 to 1,200 ms post compound onset and reflects the additional integration of constituents that is necessary for transparent compounds but not for opaque ones. The earlier negativity for opaque compounds was not replicated. It remains unclear why this earlier effect was not seen in the present experiment (see also Section 9.2).

In summary, Experiment 2b was set out to determine whether morphological decomposition of compounds is induced by the experimental set up, i.e. whether it is a strategic effect. Gender violations of nonhead constituents resulted in a more negative ERP compared with gender congruent constituents. The effect was weak and could not be localised in a ROI analysis. However, since the ERP is affected by the manipulation it cannot be claimed that gender is not processed. That is, gender of nonhead constituents was accessed even if no novel compounds were present. The LIN was found to be more negative for transparent compounds with a centroparietal maximum of the effect but no preceding negativity for opaque compounds was observed.

Chapter 8

Number: The function of linking elements?

The experiments described in the previous chapters suggest that for each compound constituent a morphosyntactic representation is accessed during auditory comprehension. One may ask whether these morphosyntactic representations are also specified for other morphosyntactic features such as case or number. Many initial constituents of German compounds are identical with their singular or their plural form. The identity of plural forms is often accomplished by linking elements. These linking elements are often claimed to be plural morphemes of the preceding constituent (Clahsen, 1999; Fuhrhop, 1998, 2000; Wegener, 1992; Wiese, 1996). As the previous experiments established that compounds are decomposed morphosyntactically, it is now possible to test one proposed function of linking elements, namely to mark number of initial constituents.

8.1 Experiment 3a

8.1.1 Introduction

Experiment 3a investigates whether initial compound constituents are specified for number during auditory comprehension. The question whether linking elements are plural morphemes or bear another function is not clarified yet. There are experiments which suggest that linking elements are plural morphemes (Schreuder et al., 1998). Others suggest that linking elements simply connect constituents (Jarema et al., 2002). A third position claims that the choice of linking elements is determined by form properties of the constituents (Dressler et al., 2001; Krott, 2001; Libben et al., 2002, cf. Section 4.2.3).

Assume that linking elements are processed as plural morphemes. In this case, number of initial constituents is specified in their grammatical form (GF) either as singular or plural. The previous experiments show, additionally that a GF is accessed for each constituent. Hence, the presence or absence of a linking element may establish a number (dis)agreement with a preceding determiner. The proposed function of linking elements, to indicate number of initial constituents (Clahsen, 1999; Schreuder et al., 1998; Wiese, 1996), can be tested by manipulating the number agreement of each constituent. Recall that only the last constituent of a compound is syntactically relevant. Therefore, the manipulation of the head constituents serves as a control condition; it shows what effect is expected for initial constituents if linking elements represent number.

The linking element -s- as a plural morpheme cannot appear inside German compounds. The -s is classified as the regular or default plural morpheme and only irregular plural morphemes can occur between constituents (-er, -e, -n, and -∅; see Sections 3.3.1). Therefore, only compounds are used that do not form their plural with -s in order to make the number manipulation equivalent for the head and the initial constituent. ERP studies have shown that the incorrect use of irregular plural morphmes elicits an N400 effect (for plural; Weyerts et al., 1997). Hence, number incongruent initial as well as head constituents are expected to elicit a larger N400 than number congruent ones. Alternatively, linking elements may not have the grammatical function to indicate plurality of initial constituents (Gawlitzek-Maiwald, 1994; Jarema et al., 2002; Krott, 2001; Libben et al., 2002). The manipulation of number agreement is, then, only a change in form but does not affect the morphosyntactic number agreement; linking elements are not used to specify number. In this case, the GFs that are accessed for congruent and incongruent constituents, would not differ in their number feature. Hence, the number manipulation would not elicit an ERP effect because congruent and incongruent conditions do not differ functionally.

In Experiment 3a, subjects are presented acoustically with number marked indefinite determiners (numerals)[1] followed by two constituent compound words. These compounds differed with regard to the form (singular vs. plural) of each constituent. The compounds were combined with a determiner in order to manipulate the number agreement of each constituent. For example, "Berg$_{sg}$-kristalle$_{pl}$" (rock crystals) was combined with either "ein"

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[1] Numerals are a controversially discussed word class. Semantically they denote numbers and quantifiable masses and measures. Some classify numerals like "ein" (one) and "zwei" (two), and indefinite articles like "ein" (a/an) which is homophonous with the numeral in German, as indefinite determiners (Bußmann, 1990; Don, Kerstens, & Ruys, 1996-99). The important point for the present work is that the numerals or indefinite determiners are unambiguously marked for number and need to agree in number with the corresponding noun/compound. In this sense their syntactic function is equivalent with definite determiners as used in the previous three experiments. This thesis is not meant to support one classification over another. The term "indefinite determiner" is used for reasons of simplicity.

(a(n)/one) or with ”zwei” (two). By using the determiner ”ein”, the first constituent agreed with the determiner in this example, whereas the second constituent did not. If the compound is presented with the determiner ”zwei” the opposite is true. For the compound ”Ohr$\underline{\text{en}}_{pl}$-zeuge$_{sg}$” (ear[s] witness) the agreement conditions are the other way around (cf. Tab. 8.1).

Given that transparent compounds activate at least their constituent morphemes (Exp. 1, 2a, & 2b; Sandra, 1990; Zwitserlood, 1994) and that linking elements are indeed processed as plural morphemes (Clahsen, 1999; Wiese, 1996) the same effect is predicted for number incongruent head constituents and initial constituents, namely an N400 effect. However, linking elements may not function as plural morphemes (Gawlitzek-Maiwald, 1994; Jarema et al., 2002; Libben et al., 2002) which means that linking elements are not sufficient to establish a number incongruity between determiner and constituent. In the latter case an N400 effect is predicted for number incongruent head constituents but no effect for number incongruent initial ones.

8.1.2 Materials and methods

Subjects. In this experiment 24 (13 male) right handed (lateralisation coefficient 93) volunteers participated with a mean age of 24 yrs. (range 21-30). Subjects had normal or corrected to normal visual and auditory acuity and were paid for their participation.

Materials. Eighty-eight low frequency two-constituent compounds were collected that were semantically transparent. They were chosen so that it was possible to assign the compounds to four conditions with regard to number agreement of each constituent (agreement-agreement AA, agreement-violation AV, VA, VV; see Tab. 8.1).

Twenty-five percent of the items were composed of two singular noun forms (”Abendkleid”, evening dress). Another 25% were composed of a singular and a plural form (”Feldwege”, field paths). In a third group, a plural noun form was followed by a singular form (”Motorengeräusch”, ”engine[s] sound”, i.e. sound of engine(s)). The last 25% of the items consisted of two plural noun forms (”Liederabende”, ”song[s] nights”, recitals). That is, the compounds in the two latter groups contained a linking element that was identical to the plural marker of the first constituent if it stood alone (see Tab. 8.1). All constituents take an overt plural marking suffix if they are used as a single word, and none constituent is classified as a mass noun. The constituents do not undergo vowel changes (umlaut) and only such constituents were selected for which the linking element was not confounded with their singular genitive case. All constituents were of masculine or neuter gender and all stimuli were correct German words. No constituent was repeated in a given compound position.

Each half of the four stimulus groups was assigned either a singular (”ein”, a/one) or a plural (”zwei”, two) numeral. Hence, the numeral might agree in number either with both constituents (AA), only with the first (AV), only with the second (AV), or with neither of the two compound constituents (VV). The AA and the VV conditions were each created from half of the singular-singular group and half of the plural-plural group, depending on numeral constituent agreement. In a similar vein, the AV and VA conditions were constructed from half of the singular-plural group and half of the plural-singular group. Since the numerals used always agree in gender with masculine and neuter nouns, number was not confounded with gender. All experimental conditions were matched to one another with regard to number of syllables (AA 4.3; AV 4.3; VA 4.1; VV 4) and frequency of word form (AA 18.5; AV 19; VA 18.7; VV 18.4; Quasthoff, 2002). A total of 88 transparent three-constituent compounds and 176 single words were added as fillers. Two lists were constructed whereby the second list was the mirror image of the first with respect to the experimental conditions. The evaluation of the number manipulation is a within item comparison. Stimulus recording was identical to Experiment 1.

Table 8.1: *Examples of stimuli used in Experiment 3a. The four conditions are determined by the agreement (*A*) or violation (*V*) of the initial (*C1*) and the head (*C2*) constituent. Note that* C2 *alone determines the compound’s number and thus, the correctness of the assigned determiner. Linking elements are underlined.*

condition	**determiner**	**C1**		**C2**
AA	ein$_{sg}$	Tier$_{sg}$	–	versuch$_{sg}$
	an/one	animal	–	experiment
	zwei$_{pl}$	Lied$\underline{\text{er}}_{pl}$	–	abende$_{pl}$
	two	songs	–	nights
AV	*ein$_{sg}$	Feld$_{sg}$	–	wege$_{pl}$
	*a/one	field	–	paths
	*zwei$_{pl}$	Ohr$\underline{\text{en}}_{pl}$	–	zeuge$_{sg}$
	*two	ears	–	witness
VA	zwei$_{pl}$	Feld$_{sg}$	–	wege$_{pl}$
	two	field	–	paths
	ein$_{sg}$	Ohr$\underline{\text{en}}_{pl}$	–	zeuge$_{sg}$
	an/one	ears	–	witness
VV	*zwei$_{pl}$	Tier$_{sg}$	–	versuch$_{sg}$
	*two	animal	–	experiment
	*ein$_{sg}$	Lied$\underline{\text{er}}_{pl}$	–	abende$_{pl}$
	*a/one	songs	–	nights

Procedure. The experimental procedure was equivalent to Experiments 2a and 2b except for the presentation duration of the prestimulus fixation cross. The fixation cross was presented for 1,400 ms. Subjects had to judge the number agreement between determiner and (compound) word or the semantic similarity to a probe word. The tasks are equivalent to the Experiments 2a and 2b with the difference that not the gender but the number agreement had to be evaluated. The randomisation and task assignment to stimuli were identical to Experiments 2a and 2b. Subjects had a training of 29 trials that were not used in the experiment. Two experimental sessions were recorded that were separated by at least one week. List assignment was identical to Experiment 2a. One session lasted about 40 min including three pauses.

EEG-Recordings. The EEG Recording was identical to Experiment 1.

Data analysis. Due to the two recording sessions the analyses are within subject comparisons. The same ROIs were used for data analysis as in Experiment 2a. Approximately 17% of the trials were excluded due to rejection criteria, movement artefacts, or incorrect responses.

8.1.3 Results

Behavioural data. During the debriefing session subjects were asked how long they had already lived in the local area in order to find out whether they are used to specific dialects. All subjects had lived at least one and half a year in the local area. This suggests that they are well acquainted with standard German regarding linking elements.

Subjects reported no problems with the task and performed well as indicated by the high accuracy rates in both tasks (GRA 95%; SEM 95%). Both tasks were judged to be easy on the 4–point scale in the debriefing session (GRA 1.35; SEM 1.94).

ERP data: head constituent. The mean amplitude was calculated for all conditions for the time window 300-500 ms time-locked to the onset of the head constituent. Number incongruent trials elicited a more negative ERP than number congruent trials (see Fig. 8.1). An ANOVA was performed with the factors *ROI* (4: AL, AR, PL, PR), *number agreement* (2) of the first constituent (C1), and *number agreement* (2) of the head constituent (C2). The 3–way interaction *ROI*×*C1*×*C2* was significant ($F(3,69)=3.61$; $p<.05$; $\varepsilon=0.68$). Neither the main effect of *C1* nor any other interaction including *C1* or *C2* reached significance. Subsequent ANOVAs were performed separately for each ROI with the factors *C1* and *C2*. There was a main effect of *C2* in the left-anterior ROI ($F(1,23)=4.45$; $p<.05$). The main effect of *C2* was also significant in both posterior ROIs (PL: $F(1,23)=6.79$; $p<.05$; PR:

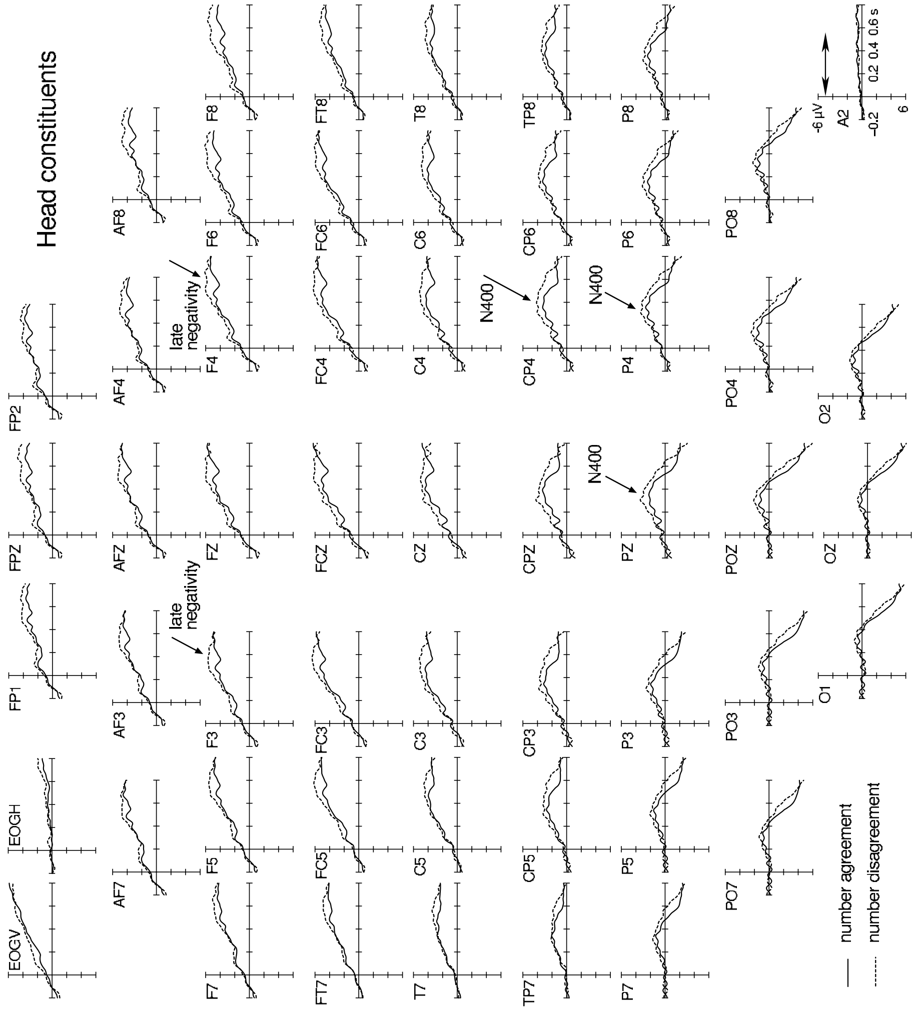

Figure 8.1: ERPs for number congruent (solid line) and incongruent head constituents (dashed line) of low frequency transparent compounds. The number incongruent head constituents elicit an N400 effect (300-500 ms) followed by a later negativity (500-700 ms).

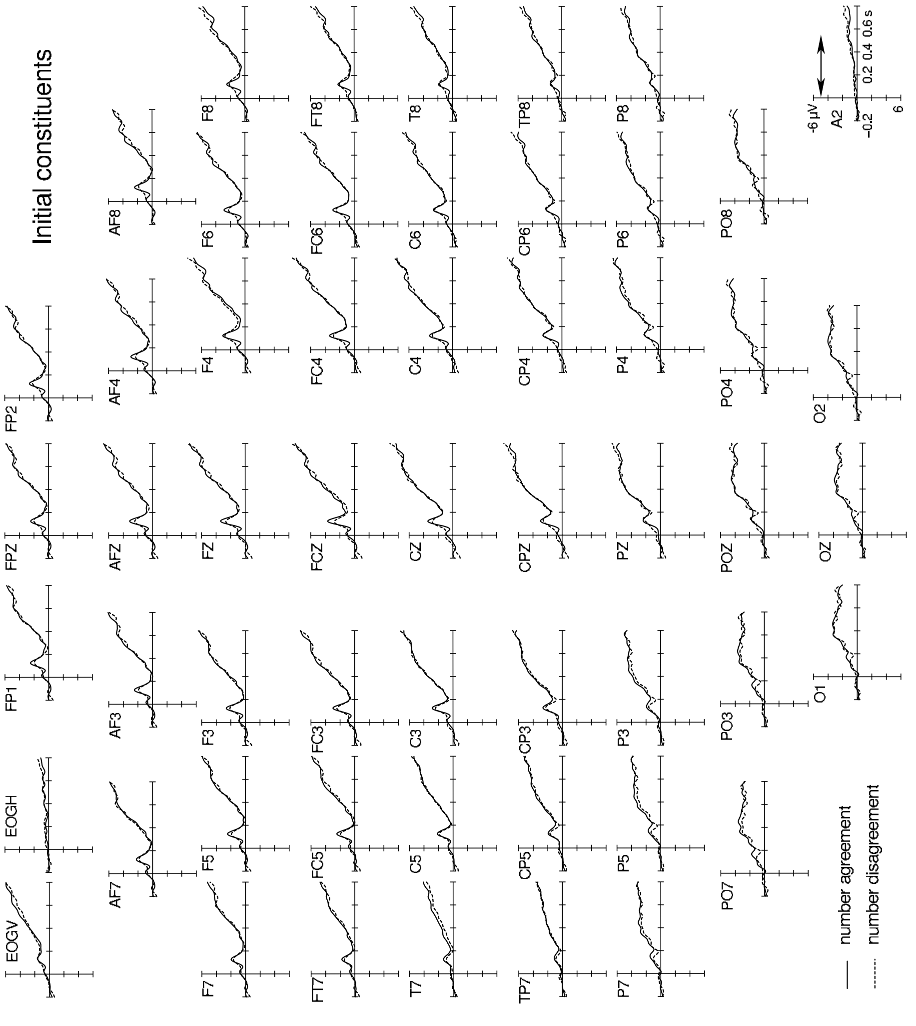

Figure 8.2: ERPs for number congruent (solid line) and incongruent initial constituents (dashed line) of low frequency transparent compounds. The manipulation of *number agreement* via linking elements that are identical in form with plural morphemes, did not yield an ERP effect at any electrode between 200 and 600 ms.

$F(1,23)=12.17$; $p<.01$). In the right-anterior ROI there was only a marginally effect of *C2* ($F(1,23)=3.6$; $p<.10$). No further effect of *C1* could be confirmed.

In addition, a later negativity for number incongruent head constituents was observed extending from 500 to 700 ms. In order to test its reliability an ANOVA ($ROI \times C1 \times C2$) was performed in this time window. A significant main effect of *number agreement* of the head constituent (C2) was obtained ($F(1,23)=16.67$; $p<.001$). No other effect involving *C1* or *C2* reached significance (all $F(1,23)<2.4$; all $p>.1$).

Although the negativities are significant in different ROIs their topography was tested statistically (cf. Fig. 8.3). An ANOVA was performed on the amplitude differences of both effects with the factors *ROI* (4), and *time window* (2: 300-500 ms vs. 500-700 ms). The interaction did not reach significance ($F(3,69)=0.36$; ns).

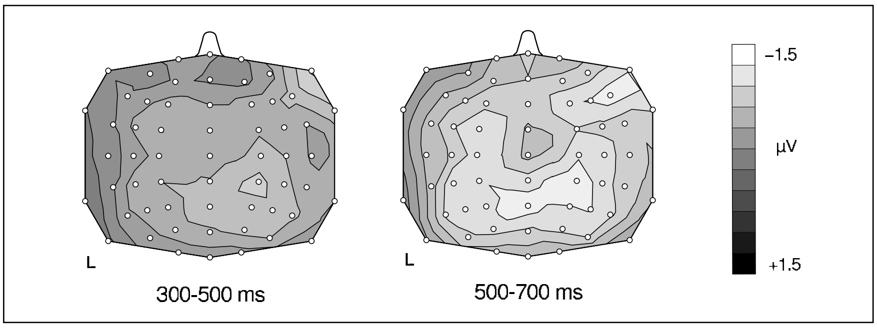

Figure 8.3: The scalp distribution of the negativities in response to number incongruent head constituents. Number incongruent head constituent elicited a negativity between 300 and 500 ms (left map) that was significant in left anterior and both posterior ROIs. A later negativity (500-700 ms) was significant in all ROIs. However, the scalp distributions differed not significantly.

First constituent. An N400 effect was expected in response to number incongruent initial constituents if number is specified for nonhead constituents. The findings from the head constituent suggest an additional late negativity. The ANOVA with the factors *ROI* (4: AL, AR, PL, PR), and *number agreement* (2) yielded neither an interaction ($F(3,69)=0.56$; ns) nor a main effect of *number agreement* ($F(3,69)=0.00$; ns). That is, there was no modulation of the ERP by a number incongruent initial constituent (see Fig. 8.2). Because a statistical null effect does not necessarily show the non-existence of an effect, more detailed analyses were performed. The mean amplitudes of number congruent and incongruent ERPs were compared for each electrode separately in consecutive 50 ms time windows from 200 ms to 600 ms post compound onset. None of the number agreement comparisons gave rise to a significant difference at any electrode in any time window (see Tab. B.2, Appendix B.2). This confirms the null effect of the first analysis.

8.1.4 Discussion

Both tasks were rated to be fairly easy by the subjects. High accuracy rates also show that both tasks were easy and subjects responded reliably.

A centroparietal negativity was found in response to number incongruent head constituents which was independent of the number manipulation of initial constituents. Given the spatiotemporal distribution of the effect it is classified as an N400 effect. The effect peaks somewhat earlier than 400 ms which may be due to the fact that all stimuli were normal existing German compound words. Due to the first constituent the recognition point may be shifted towards the onset within the head constituent. Hence, it is plausible that the N400 show a shorter peak latency.

All plural forms of constituents used are categorised as irregular plurals. Such irregular plural markings elicit an N400 (Weyerts et al., 1997). It is assumed that irregular forms are stored as subnodes of lexical entries because they cannot be derived by rule application (Clahsen, 1999; Wiese, 1996). The attachment of a plural suffix (often an additional syllable) affects coarticulation, assimilation, and may change the stress pattern, i.e. the pitch contour (Kohler, 1995; Pompino-Marschall, 1995; Wiese, 1996). Suprasegmental information (duration and pitch) were also shown to influence the number decisions in behavioural experiments (Kemps, Ernestus, Schreuder, & Baayen, sub.). Such prosodic cues are available before the final segments are perceived which indicate number. That is, prosodic cues and coarticulation effects may misguide the lexical search when perceiving the compound constituent. Here it is argued that the N400 effect reflects an increased effort in lexical search in order to overcome the improper prosodic features of number incongruent singular or plural word forms.

Following the N400 effect, a negativity was observed extending from 500 to 700 ms. The effect is broadly distributed and does not interact with the factor *ROI*. At present it is unclear what cognitive process exactly is indexed by this effect. It is speculation whether it reflects a(n) (intentional) postlexical checking of number agreement due to the task. No other study that investigated plural formation using ERPs, reported this effect so far. Previous studies differed, however, in that they presented their stimuli visually and/or in sentences (Lück, et al., 2001; Weyerts et al., 1997; Kaan, 2002 and Osterhout, McKinnon, Bersick, & Corey, 1996 for number incongruent subject-verb relations). Furthermore, they presented mostly correct and incorrect plural forms, i.e. plural formation alone was investigated. In the present experiment singular forms were also included.

Although it is suggested that the two successive negativities reflect two processes, the scalp distributions are not significantly different from each other. This suggests that the same neural generator(s) underlies both negativities. At present it is unclear which single cognitive process should be reflected by the extended negativity (300-700 ms) instead of the mentioned ones, especially as the effect lasts about 400 ms. Here it is suggested that the negativity (300-700 ms) elicited by number incongruent head constituents, reflects (at least) two processes. That is, the detection of the number feature violation and the processing of the semantic incompatibility between determiner and compound.[2] These processes may overlap partially in time and, on that account, they may not result in a different scalp distribution.

The number agreement manipulation of first constituents yielded neither an N400 effect nor any other ERP effect between 200 and 600 ms after the compound onset. If linking elements are processed as plural morphemes a number incongruity should be established by the manipulations. In this case, an N400 effect was predicted as all nouns used take so-called irregular plural morphemes. Furthermore, number incongruent head constituents showed the predicted N400 effect. The null effect of initial constituents shows, therefore, that linking elements of noun-noun compounds do not establish a number incongruity with the determiner. That is, linking elements do not function as plural morphemes, at least in comprehension.

This finding has two alternative interpretations. On the one hand, it may suggest that no morphological unit is accessed for initial constituents, thereby, lending support to the full-listing hypothesis (Butterworth, 1983). In this case the compound is not decomposed into its constituents and, thus, initial constituents cannot establish a number disagreement. This view contradicts full-parsing approaches (Libben et al., 1999; Taft, & Forster, 1975) and dual-route models (Baayen et al., 1997; Schreuder et al., 1998; Zwitserlood, 1994). On the other hand, the null effect may indicate that linking elements are not processed as plural morphemes (Gawlitzek-Maiwald, 1994; Jarema et al., 2002). Hence, the number feature of nonhead constituents is not influenced by linking elements. As a consequence, the agreement and violation conditions are functionally equivalent. This would suggest that the morphological representations are not marked for number. This means basically that number is not specified in the lexical entries. This is plausible because number is a variable feature; its value may be singular or plural. That is, in order to agree with other words, variable features (e.g. number) must be specified. Number of nonhead constituents is syntactically irrelevant (see Section 3.3.3) and its specification can be spared if there is a cue that indicates compound words. Isel et al. (2003) found that the prosodic cue duration of initial constituents indicates reliably compound words. This may explain why linking elements are not interpreted online as plural morphemes although they are identical in form with plu-

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[2] The processing of prosodic cues may also be involved. Prosodic cues might identify the head constituent. Note the effect at right-anterior electrodes (see Fig. 8.3) which may be related to prosodic processing.

ral morphemes. This interpretation is in accordance with full-parsing and with dual-route models; a morphosyntactic unit may be extracted (morphological decomposition) but since number is not specified, no number incongruity can arise.

At this point it can only be speculated whether the absence of an effect for initial constituents is due to prosodic cues. If that is true, words with a single noun prosody should show an effect of number incongruity. A control Experiment (3b) will check whether or not an effect of number incongruity is modulated by (naturally produced) prosodic cues of initial compound constituents.

8.2 Experiment 3b

8.2.1 Introduction

This control experiment investigates the role of prosody in compound processing. Experiment 3a showed that linking elements cannot, by their presence or absence, establish a number disagreement with a preceding determiner although they are identical in form with plural morphemes. Since the proposed number feature is marked at the surface, and Experiments 1, 2a, and 2b show that morphological decomposition takes place, the question arises: how does the parser know that the just encountered speech sound is a compound constituent?

Prosodic cues may indicate morphological complexity even before the phonemes of a second constituent are detected because prosody is independent of particular phonemes. Words that are onset embedded in other words (”captain”), are produced faster than the same words if they are not embedded (”cap”; Cutler, Dahan, & van Donselaar, 1997; Davis, Marslen-Wilson, & Gaskell, 2002). The same effect was reported for initial compound constituents which are shorter in duration compared with the same words produced as single nouns (Isel et al., 2003). Such prosodic cues can be used to distinguish single nouns from compounds and to adapt processing in order to make it most efficient. (The term ”word” will subsequently be used to refer to an abstract lexical item whereas ”single noun” and ”compound constituent” will be used for the respective parts of speech, incl. prosodic cues.)

Number is a variable morphosyntactic feature, i.e. it needs to be specified for a syntactic word as either singular or plural. The effort of specification can be spared for nonhead constituents because they are syntactically irrelevant and do not need to agree in their morphosyntactic features with other words (cf. Section 3.3.3). The information about the morphological complexity is suggested to be delivered by prosodic cues and, the use of such information may explain why the parser refrains from specifying number for nonhead constituents. Experiment 3b will test whether initial compound constituents and single nouns are prosodically different and, if so, whether prosody can prevent the parser from specifying number for nonhead constituents. Basically, Experiment 3a will be replicated with some changes which put the linking elements into subjects' focus of attention and permit an evaluation of the prosodic impact.

If prosody is indeed the crucial factor, linking elements and plural morphemes should be processed differently although they are identical in phonological form. A number mismatch between a determiner and a single noun (singular or plural) should elicit an N400 for nouns that take an irregular plural morpheme (cf. head constituents in Exp. 3a; Clahsen, 1999; Weyerts et al., 1997). If, on the other hand, a 'number' mismatch has to be detected between a determiner and a nonhead constituent (with or without a linking element) no ERP effect should be observed for initial constituents (cf. Exp. 3a). It is difficult for subjects to ignore a second constituent if the first constituent has to be judged. Therefore, second constituents will be replaced by their amplitude envelopes filled with white noise.[3] Hence, they will not contain any phonemic material. The same noise *constituents* will also be attached to the same words spoken as single nouns. In so doing, subjects are forced to pay attention to linking elements and to plural morphemes because judgement decisions are based on that information.

Besides the target items (words followed by noise) filler items will also be presented to subjects. These filler items will be single nouns and two constituent compounds without any manipulation. That is, subjects will encounter single nouns, compounds, and some words that are followed by noise. This situation is ambiguous with regard to the status of the target items. There will be no bias regarding the interpretation of the target items as either compounds or single nouns. Thus, the parser should be forced to use all information available to disambiguate the target items.

The prosodic parameters that are diagnostic of morphological complexity are not precisely known yet. Hence, they cannot be manipulated artificially. Moreover, artificial manipulation might make speech material sound unnatural. Therefore, all stimuli have to be produced naturally by a professional, naïve speaker. For instance, from the production of "Bilder" (pictures) and "Bilderalbum" (picture[s] album) the constituent "Bilder" can be extracted and then be checked for prosodic differences between "Bilder"$_{single\ noun}$ and "Bilder"$_{compound}$ (see Fig. 8.4). Hence, the stimuli have a high ecological validity apart from the subsequent noise. Compound constituents should be shorter in duration than single nouns and there may also be a difference in pitch although not previously reported.

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[3] Noise having a frequency spectrum that is continuous and uniform over a specified frequency band.

Number incongruent single nouns are predicted to elicit an N400 effect compared with number congruent nouns. For single nouns, number should be specified normally and may disagree with a determiner. In contrast, the parser is predicted to adopt a different processing strategy for compound constituents which reduces processing costs. That is, if number is not specified for compound constituents no number mismatch can occur. As a result no ERP effect is expected between 'number' congruent and incongruent compound constituents. (For the sake of simplicity I will use the terms "plural compound constituent" and "singular compound constituent" for the constituent which have or have not a linking element that is identical in form with a plural morpheme. It is acknowledged that linking elements are not plural morphemes functionally.)

8.2.2 Materials and methods

Subjects. Twenty volunteers (9 male) participated in this experiment who were right handed (lateralisation coefficient 88) and 24;9 yrs. of age (range 21-29). Subjects had normal or corrected to normal visual and auditory acuity and were paid for their participation.

Materials. For Experiment 3b, 176 transparent two-constituent compounds were collected including the 88 from Experiment 3a. All stimuli conformed to the same restrictions as in Experiment 3a.

Only initial constituents are relevant for Experiment 3b. Their average number of syllables was 2.2 and their frequency of occurrence was 11.4 (Quasthoff, 2002). The average frequency was calculated from the constituent form (singular or plural) as it was used in the experiment. Seventy constituents have a neuter gender and 106 are masculine.

A professional female speaker, who was naïve to the manipulation, produced all 176 compounds for recording and, in addition, the 176 initial constituents as single nouns. If the compound contained a linking element, the initial constituent was also produced as a plural noun ("Lotse<u>n</u>boot", pilot[s] boat & "Lotse<u>n</u>", pilots); if it contained no linking element the noun was produced in its singular form ("Abendkleid", evening dress & "Abend", evening). As a result the 176 words were recorded with the same phonological segments once with normal prosody (as single words) and once with compound prosody (as initial constituents). The filler items were 176 different compounds (50% plural) and 176 different single nouns (50% plural). These were not manipulated except for loudness adaptation. The recording procedure was identical to Experiment 1.

The stimuli were electronically edited using two audio software programmes (Johnston, 2000; Boersma, & Weenink, 1992-2003). The constituent boundaries within the compounds were determined as in Experiments 1. If linking elements were present they were included

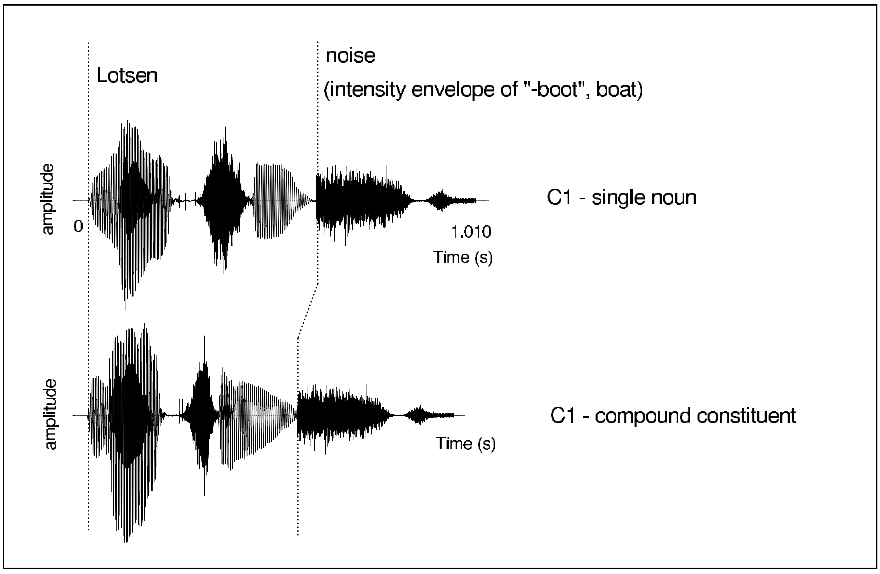

Figure 8.4: Time-amplitude plots for the target items ”Lotsen$_{single\ noun}$-[noise]” (upper part) and ”Lotsen$_{compound}$-[noise]” (lower part). Initial compound constituents (C1) were shorter than single nouns (see Tab. A.1, Appendix A.1). Compound constituents and single nouns differ also in pitch (see text).

in the initial constituent. Subsequently the amplitude envelope of the second constituent was extracted and filled with white noise (using the *Praat* software; Boersma, & Weenink, 1992-2003). In a next step the amplitude envelope that contained white noise, was spliced again onto the initial constituent at the nearest zero-crossing[4] to the constituent boundary. The same amplitude envelope was also spliced to the corresponding single noun. As a result two groups of experimental items were obtained. One group consisted of singular and plural nouns immediately followed by a noise envelope. The other group of stimuli consisted of compound initial constituents with or without linking elements (phonologically identical with plural morphemes). These constituents were also followed by a noise envelope. The noise envelopes had the prosodic contours of constituents that form a compound with the preceding word. For example, the speaker produced ”Lotsen$_{plural\ form}$-boot” (pilot[s] boat) and ”Lotsen$_{plural\ form}$” (pilots). The amplitude course of the constituent ”-boot” was preserved and filled with white noise before it was spliced onto both instances of ”Lotsen”, yielding ”Lotsen$_{compound}$ [noise]” and ”Lotsen$_{single\ noun}$ [noise]”. Hence, both item groups were iden-

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[4] The point in time where the spectrogram crosses the zero sound pressure level (which happens twice per cycle).

tical with regard to the phonological sequences of their words but may differ prosodically (cf. Fig. 8.4). The final adaptation of loudness was identical to Experiment 1.

The determiner assignment was done equivalently for both item groups. Half of the plural marked nouns were assigned a number correct determiner (”zwei”, two) and the other half was assigned a number incorrect determiner (”ein”, a/one). The same was done with the singular nouns, i.e. half of both items groups were correctly marked for number agreement.

Two lists were constructed from these item groups. Each list contained 50% singular nouns, and 50% of the list items had a determiner that agreed in number with the noun. It was made sure that each word appeared only once on a list and that each list contained 50% words with a compound prosody. By assigning these two lists to different subjects it is possible to compare the ERPs in response to the same words with different prosody across subjects.

Additionally, two mirror images of the lists were constructed. One mirror list and the equivalent original list were presented to the same subjects in two experimental sessions. For these lists the number agreement was changed. If a word was number correct on the original lists, it was number incorrect on the mirror image lists, equivalently to the determiner assignment in Experiment 3a. The mirrored lists permitted to evaluated a number mismatch within items.

The filler items (unmanipulated compounds and single nouns) were also assigned indefinite determiners (50% correct) and mixed with the target items. Each list contained ⅓ target items, ⅓ compounds, and ⅓ single nouns.

Procedure. The experimental procedure and tasks were identical to Experiments 3a.

EEG-Recordings. The EEG recording was identical to Experiment 1.

Data analysis. Data analyses were identical to Experiment 2a; the same ROIs were used and analyses are within subject comparisons. Approximately 13% of the trials were excluded due to rejection criteria, movement artefacts, or incorrect responses.

The prosodic parameters duration and pitch were analysed using the *Praat* software (Boersma, & Weenink, 1992-2003). Pitch values were registered for each subsequent 25 ms time window of each target item and were then averaged across all items for each time slot.

8.2.3 Results

All subjects had lived at least one year in the local area. This suggests that they are well acquainted with standard German regarding linking elements.

8.2.3.1 Prosodic parameters

Before analysing the experimental data the stimuli were scrutinised for prosodic differences between single nouns and compound constituents. Note that any word was produced in both prosodic conditions and, therefore the comparison is a within item comparison. The single words (652 ms) were 147 ms longer in duration than compound constituents (505 ms; $t(175)=27.4$; $p<.001$; paired t-test).

Pitch was also tested by paired t-tests for each subsequent 25 ms time slot (see Fig. 8.5). The difference in pitch was marginally significant in the third time window (50-75 ms; $t(99)=1.86$; $p=.06$) and significant in all subsequent time windows, i.e. from 75-100 ms onwards (see Tab. B.3, Appendix B.3.1). Pitch differences were only tested if more than 30 items contributed to the pitch average (all time slots up to 24).

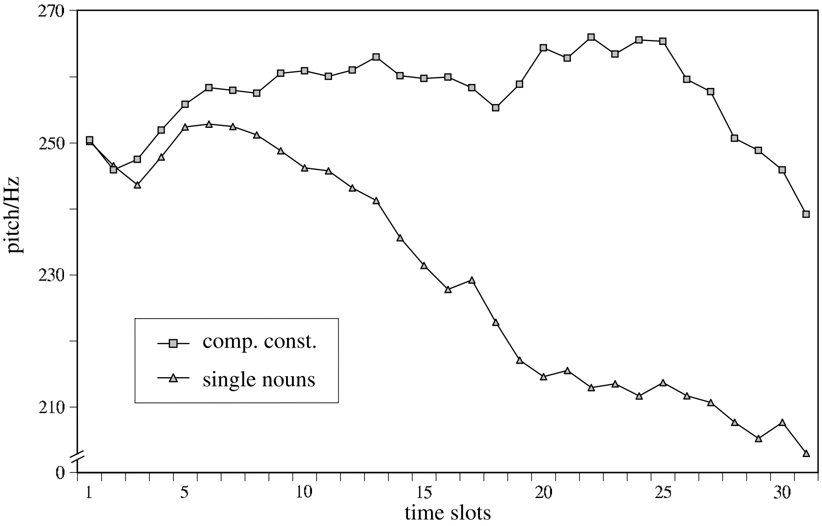

Figure 8.5: The average pitch contour for the same words produced as single nouns and as compound constituents. Each time slot corresponds to 25 ms. Pitch is significantly lower for single nouns from the 3^{rd} time slot onwards (75-100 ms). The difference is also marginally significant in the (2^{nd} time slot (50-75 ms).

The previously unreported pitch difference may be an epiphenomenon of the different durations of single nouns and compound constituents. (Note the different latencies of the early pitch minimum in the second and third time slot.) Therefore, pitch was registered again taking the different durations into account. In this analysis pitch was registered for the same number of time windows still covering the whole word. That is, each time slot represents the same relative proportion of a word for the two prosodic conditions. As a consequence, time windows were 32.5 ms in extent for single nouns but only 25 ms for compound constituents. Although durational differences are accounted for, all paired *t*-tests reached significance subsequent to, and including the sixth time slot (see Tab. B.4, Appendix B.3.1). Disregarding durational differences, the two prosodic item groups begin to differ in pitch between 125 and 162.5 ms after word onset (see Fig. 8.6). All pitch values up to time slot 18 included more than 30 items and were statistically analysed. In both analyses, pitch decreased very early for single nouns compared with compound constituents. It clearly showed a falling contour for single nouns in later time slots.

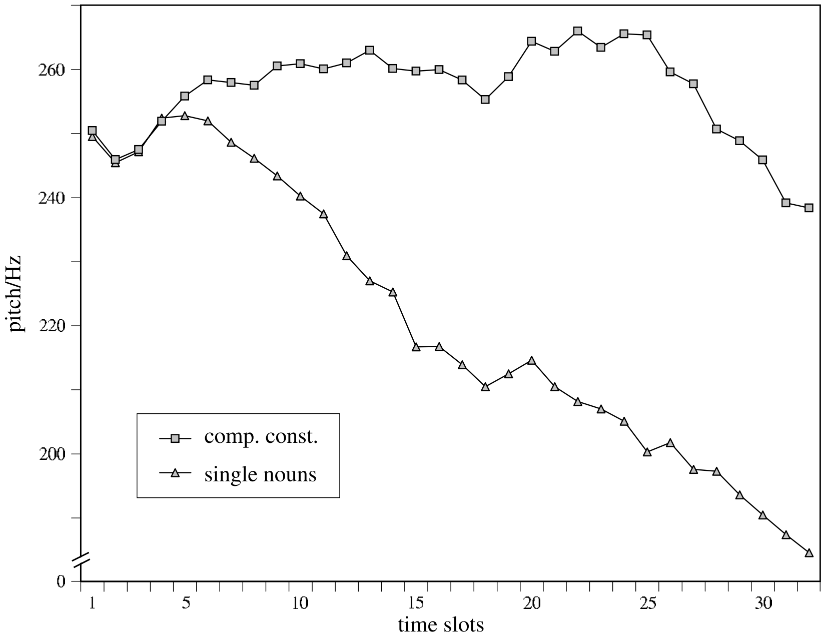

Figure 8.6: The average pitch contour for single nouns and compound constituents after correction for durational differences. Each timeslot corresponds to 25 ms for compound constituents and 32.5 ms for single nouns. Pitch is significantly lower for single nouns from the 6th time slot onwards (onset 125-160 ms).

8.2.3.2 Experimental results

Behavioural data. Subjects reported no problems with the task and performed well as indicated by the high accuracy rates in both tasks (GRA 95%; SEM 94%). Both tasks were judged to be easy during the debriefing session (GRA 1.2; SEM 2.1).

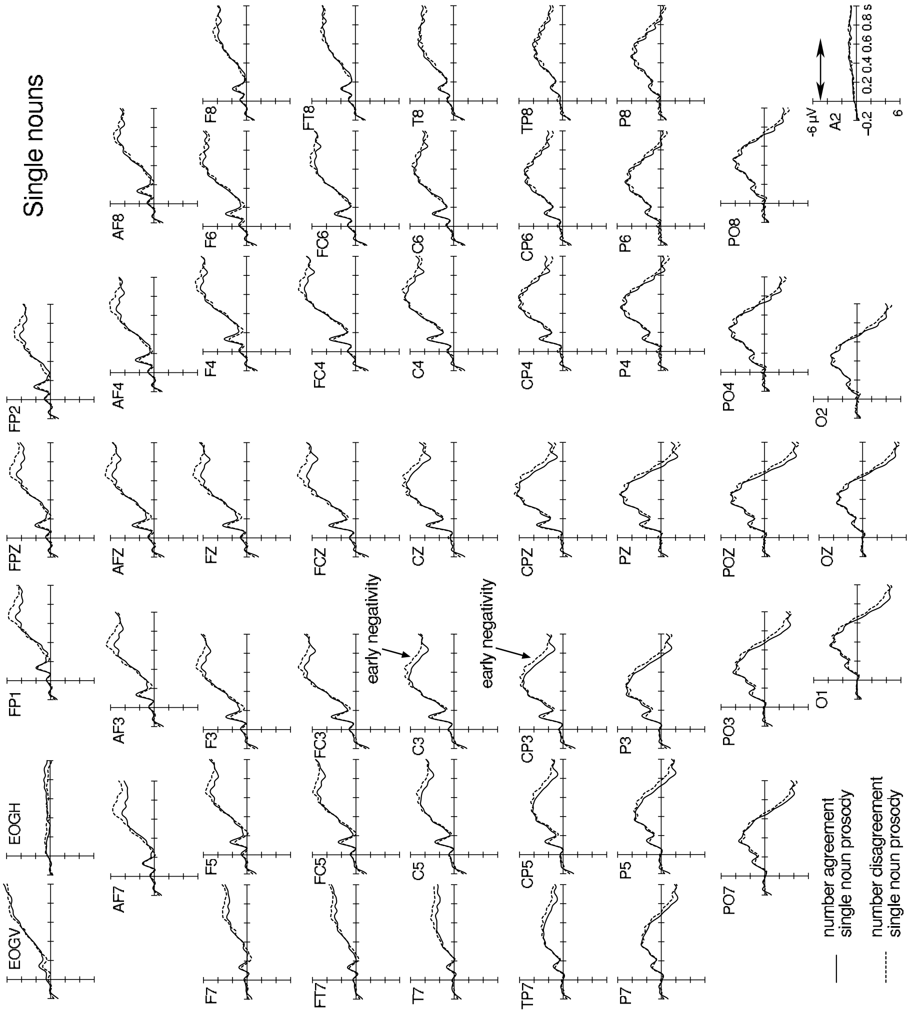

Figure 8.7: The ERPs in response to number congruent (solid line) and number incongruent (dashed line) single nouns. Number incongruent nouns elicit a negativity that is significantly larger in amplitude in the left-posterior ROI between 600 and 900 ms.

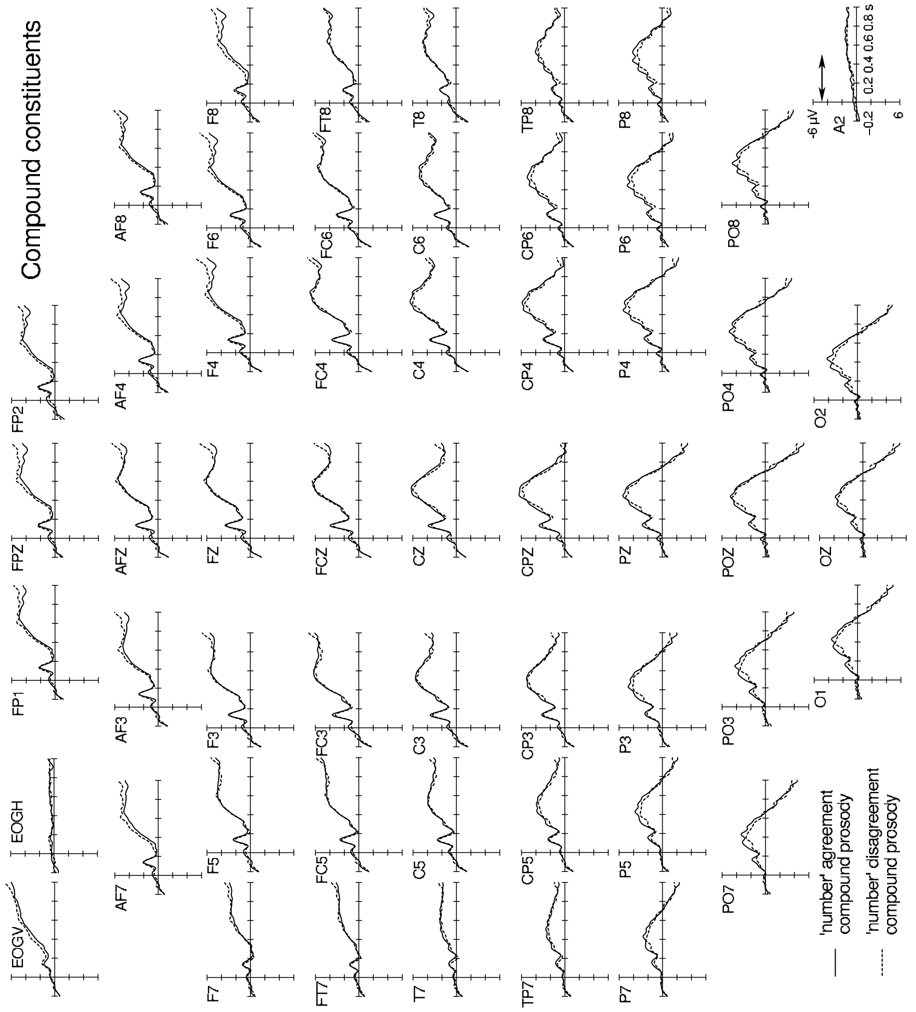

Figure 8.8: The ERPs in response to 'number' congruent (solid line) and 'number' incongruent compound constituents (dashed line). Number agreement was determined by the presence or absence of linking elements. The ERPs did not differ from each other before 1,100 ms. The presence or absence of linking elements was not processed as an indication of number of initial compound constituents.

There was an effect of prosody; subjects were more accurate for words with a single noun prosody (96%) compared with words with a compound prosody (93%; $t(19)=4.23$; $p<.001$). Subjects responded also faster to words with a single noun prosody (649 ms) than to words with a compound prosody (678 ms; $t(19)=2.42$; $p<.05$). Neither of these effects was due to the task. There was no interaction of *task* (2) and *prosody* (2) in an ANOVA, neither for accuracy nor for RT ($F(1,19)=0.00$; $F(1,19)=2.70$; both ns, respectively) although semantic judgements were given slower (770 ms) than grammaticality judgements (557 ms; $F(1,19)=151.4$; $p<.0001$).

ERP data. The prosodic item groups differ regarding their prosodic parameters and behavioural results. This shows that subjects processed stimuli differently. Therefore, the number manipulation was tested separately for prosodic item groups.

Single nouns; early time window: An ANOVA was performed with the factors *AP* (2), *LR* (2), and *number agreement* (2) for single nouns. The number incongruent single nouns elicited a larger negativity between 600 and 900 ms (see Fig. 8.7) and a 3–way interaction of *AP*, *LR*, and *number agreement* was found although the interaction was marginally significant ($F(1,19)=3.99$; $p=.06$). Subsequent ANOVAs were performed with the factor *number agreement* for each ROI separately. The effect of *number agreement* was significant in the left-posterior ROI ($F(1,19)=4.88$; $p<.05$) and marginally significant in the left-anterior ROI ($F(1,19)=3.23$; $p=.088$). The right hemisphere ROIs did not reach significance (AR: $F(1,19)=1.43$; PR: $F(1,19)=0.91$; both ns).

To test whether an earlier effect was overlooked separate ANOVAs were performed for single nouns. The factor *number agreement* (2) was tested for each electrode between 200 and 600 ms. There was no effect that could be interpreted reliably (see Tab. B.5, Appendix B.3.2). That is, no effect preceded the negativity between 600 and 900 ms.

Compounds; early time window: For compound constituents the 3–way interaction of *AP* (2), *LR* (2), and *number agreement* (2) was significant in the time window 600-900 ms ($F(1,19)=6.65$; $p<.05$). The main effect of *number agreement* was not significant ($F(1,19)=0.00$; ns). Subsequent ANOVAs were performed separately for each ROI with the factor *number agreement*. However, none of the ROIs reached significance (AL: $F(1,19)=0.00$; AR: $F(1,19)=0.32$; PL: $F(1,19)=0.00$; PR: $F(1,19)=0.21$; all ns). Since the ROI analysis may have missed an effect of *number agreement*, ANOVAs were performed with the factor *number agreement* for each electrode separately. None of the electrodes reached significance (see Tab. B.6, Appendix B.3.2) except for electrode F8 which showed a marginally significant effect ($F(1,19)=3.54$; $p=.076$). That is, *number agreement* of compound constituents did not yield an effect between 600 and 900 ms (cf. Fig. 8.8).

If the ERPs are plotted for an extended period it appears that the two *constituents* do not elicit one but two slow negative shifts (see Fig. 8.9 & 8.10). For both prosodic item groups there appears to be a late negativity for the violation conditions during the second negative shift. This negativity begins later for single nouns than for compound constituents (Fig. 8.9 & 8.10; e.g. electrode FCZ).

Single nouns; late time window: When testing the beginning slope by an ANOVA (*AP* × *LR* × *number agreement*) for single nouns there was a marginally significant 3–way interaction between 1,100 and 1,200 ms (*F*(1,19)=4.34; *p*=.051) but the effect did not reach significance in any of the four ROIs (AL: *F*(1,19)=1.08; AR: *F*(1,19)=0.18; PL: *F*(1,19)=0.9; PR: *F*(1,19)=1.94; all ns). Single electrode analyses also failed to find a reliable effect between 1,100-1,200 ms for single nouns (see Tab. B.7, Appendix B.3.2). An additional ANOVA (*AP* × *LR* × *number agreement*) was performed for single nouns in the time window 1,200-1,700 ms. There was neither a main effect of *number agreement* (*F*(1,19)=0.26; ns) nor any interaction involving *number agreement* (all *F*(1,19)<2.63; all ns). Single electrode analyses did not find a main effect of *number agreement* between 1,200 and 1,700 ms either (see Tab. B.8, Appendix B.3.2).

Compounds; late time window: The beginning slope was also tested by an ANOVA (*AP* × *LR* × *number agreement*) for compound constituents between 1,100 and 1,200 ms (see Fig. 8.10). There was marginally significant 2–way interaction of *LR* and *number agreement* (*F*(1,19)=3.02; *p*=.098) and also a marginally significant main effect of *number agreement* (*F*(1,19)=3.22; *p*=.088). Subsequent ANOVAs for each hemisphere found no effect for the left hemisphere (*F*(1,19)=2.01; ns) but a main effect of *number agreement* in the right hemisphere that was close to the significance level (*F*(1,19)=4.05; *p*=.058). The 3–way interaction (*AP* × *LR* × *number agreement*) for the late negativity (1,100-1,700 ms) was marginally significant (*F*(1,19)=3.67; *p*=.07). Subsequent ANOVAs for each ROI found a main effect of *number agreement* only in the right-anterior ROI (*F*(1,19)=4.32; *p*=.05).

In order to test the spatial distribution differences between the late effect for compounds (1,100-1,700 ms) and the earlier effect for single nouns (600-900 ms) an ANOVA was performed on the amplitude differences with the factors *AP* (2), *LR* (2), and *time window* (early vs. late). The 2–way interaction of *LR* and *time window* was significant (*F*(1,19)=8.75; *p*<.01), indicating that different neural generators contribute to the effects.

In summary, initial compound constituents are shorter and have a higher fundamental frequency (after about 75-100 ms) than single nouns. If these words have to be judged for number agreement subjects are slower and commit more errors when judging compounds compared with single nouns. Both groups of target items elicit two successive negative

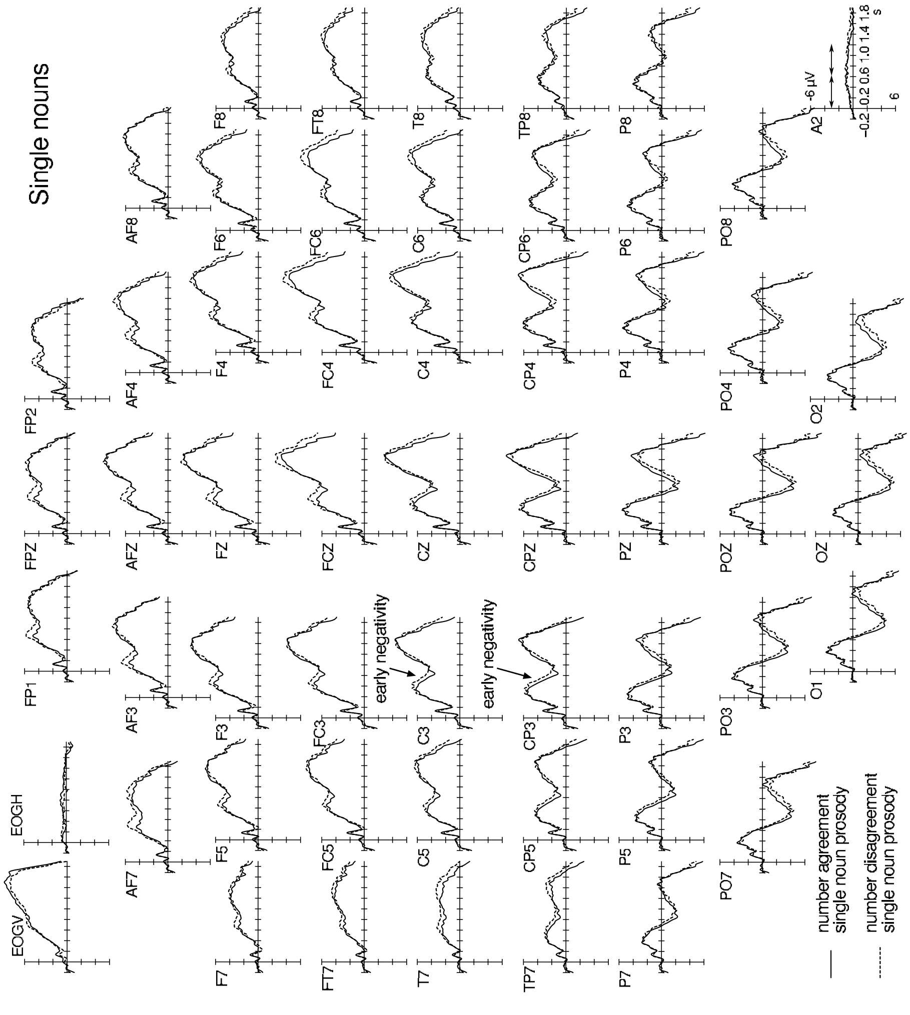

Figure 8.9: An extended plot of the ERPs elicited by number congruent (solid line) and number incongruent (dashed line) single nouns. A later negativity for incongruent nouns during the second negative shift is descriptively present but does not reach significance.

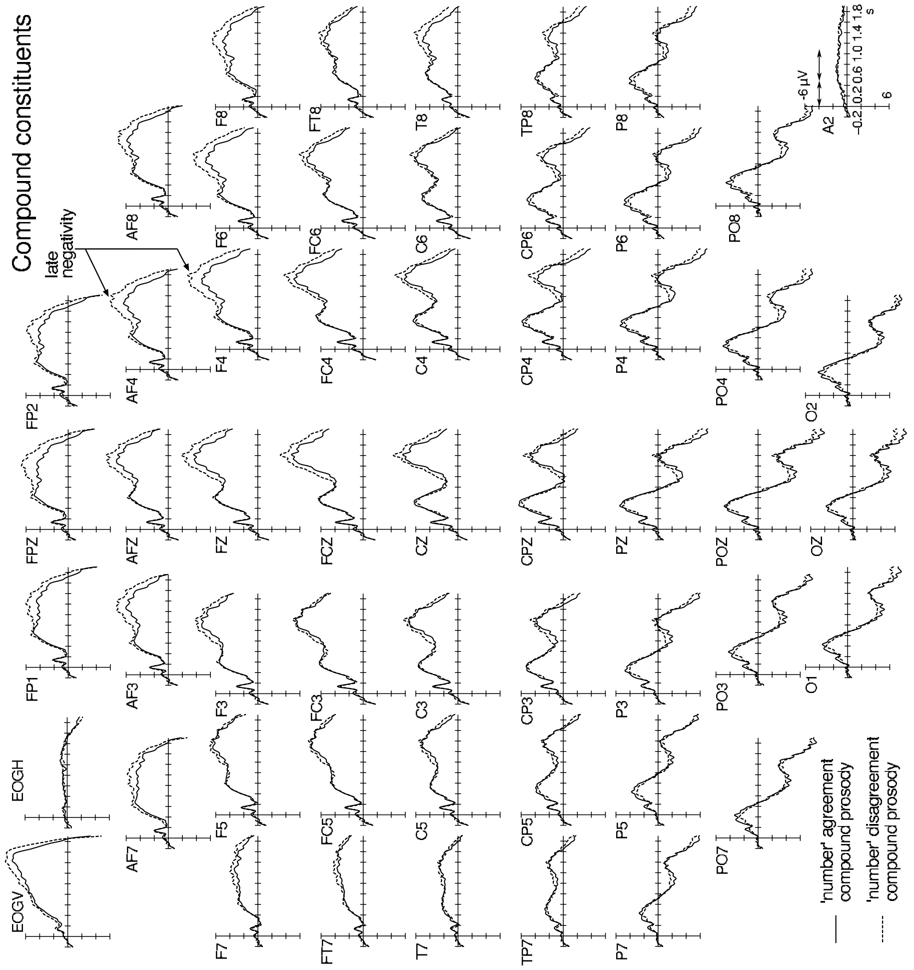

Figure 8.10: The extended ERPs for congruent (solid line) and incongruent compound constituents (dashed line) show a late negativity that is larger for 'number' incongruent constituents (1,100-1,700 ms). This effect is significant over right-anterior electrodes.

shifts in the ERP. Number incongruent single nouns elicit a more negative ERP than number congruent ones between 600 and 900 ms at left-posterior electrodes. Compound constituents do not show an ERP effect in the same time window. However, compound constituents elicit a larger negativity at right-anterior electrodes if 'number' incongruent but this effect was observed only 1,100 ms after constituent onset.

8.2.4 Discussion

8.2.4.1 Prosodic stimulus differences

Compound constituents and single nouns differ clearly in the prosodic parameters duration and pitch. Compound constituents were about 150 ms shorter, and pitch was higher than for single nouns after about 75-100 ms[5]. Duration was expected to be shorter as onset embedded words (Cutler et al., 1997; Davis et al., 2002) and initial compound constituents (Isel et al., 2003) were already reported to be shorter in duration compared with the same words produced as single nouns. Pitch differences, however, between the same words either produced as initial compound constituents or as single nouns are reported here for the first time. Isel and colleagues (2003) did not find differences in pitch between these condition but this may be due to the different analysis method.[6] If pitch registration was corrected for the different lengths of prosodic item groups, pitch differed after about 120-160 ms. The pitch contour of compound constituents is roughly level with an early minimum whereas the pitch contour of single nouns shows also an early minimum but is then falling.

It is unclear at present, whether the difference in pitch between single nouns and compounds constituents per se is the crucial variable or whether the pitch contour is the reliable indicator of morphological complexity, i.e. for compounds. The falling pitch contour on *average* for single nouns might be an epiphenomenon of the acoustic end of speech production. However, initial compound constituents clearly differ from single nouns in duration and pitch (contour). That is, prosody distinguished reliably compounds from single nouns.

8.2.4.2 Behavioural differences

Subjects reported no problems with the task and performed reliably as indicated by the high accuracy rates in both tasks (GRA 95%; SEM 94%). Both tasks were judged to be easy during the debriefing session (GRA 1.2; SEM 2.1).

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[5] Note that a significant difference in physical parameters (fundamental frequency) does not necessarily entail a perceptual change. Here, it is shown that pitch is a reliable cue to morphological complexity 75-100 ms after stimulus onset. At what point in time pitch is used by the parser cannot be inferred from the present data.

[6] The *average* pitch contour was evaluated for successive time windows covering whole compound constituents and single words in Experiment 3b. Isel et al. (2003) tested only the onset, peak, and offset values of the fundamental frequency.

Prosodic item groups did not only differ in prosodic parameters but were also processed differently. Compound constituents elicited more errors than single nouns and reaction times were about 50 ms longer for compound constituents. These results suggest that the compound prosody makes it harder to evaluate the linking elements as plural morphemes (and their absence as indicating singular). The behavioural effects reflect a functional change in processing because the same words were used in both prosody conditions. The fact that it takes longer and is more difficult to interpret linking elements as plural morphemes supports the idea that it is not the function of linking elements to indicate of number. However, accuracy was high in both prosody conditions. That is, linking elements or their absence was detected by subjects, and subjects were able to base their judgement on that information.

8.2.4.3 ERP differences

The ERP results agree with the behavioural data which show that it is more difficult to judge linking elements as number indicators than it is to judge plural morphemes as such. This shows that linking elements are functionally distinct from plural morphemes. However, the high accuracy rates indicate that it is possible for subjects to reinterpret linking elements as plural markers. Accordingly, the ERPs showed different effects for single nouns and compound constituents. The effect of 'number' incongruent compound constituents compared with congruent ones was delayed by about 500 ms in comparison to the effect of number incongruent single nouns. That it, it takes about half a second longer before the agreement between a compound constituent and a determiner is evaluated. This cannot be an effect of reduced attention regarding linking elements because subjects were explicitly instructed to evaluate the agreement relation and the agreement depended crucially on the linking elements. The delayed differentiation suggests, similarly to the behavioural data, that the function of linking elements is not to indicate number. Thus, the ERP results clearly support the interpretation of Experiment 3a that linking elements are not processed online as plural morphemes of initial constituents and that the functional status of the respective phonemes is determined by prosodic cues.

Number disagreement of single nouns was detected between 600 and 900 ms whereas there is no effect in this time window if prosody indicates a compound. Number incongruent single nouns did not elicit an earlier ERP effect (i.e. between 200 and 600 ms). The negativity was only significant in the left-posterior ROI. Such a distribution is suggestive of an N400 effect although the time window is rather delayed. N400 effects were reported to have a longer duration in the auditory modality (Holcomb, & Neville, 1990; Hinojosa, Martín-Loeches, & Rubia, 2001; McCallum et al., 1984), but these effects were elicited by pure semantic incongruities. Here the N400 effect reflects a morphosyntactic mismatch which also entails a semantic incongruity between the determiner and the noun. Previous studies reported N400 effects for violations of plural formation, but they were done in the visual domain (Clahsen, 1999; Weyerts et al., 1997).

The delayed N400 effect may be due to the acoustic presentation. Similar to the study by Weyerts et al. (1997), plural processing was investigated in auditory sentence presentation. The processing of incorrect irregular plural morphemes elicited an N400 effect between 550 and 700 ms (Exp. V, control group; Wolf, submitted.) and between 500 and 700 ms (Lück et al., 2001).[7] In these experiments the N400 effects were also somewhat delayed which fits the time course of the present N400 effect for single nouns. However, Wolf (submitted.) and Lück et al. (2001) investigated sentence processing and manipulated only the plural formation. Although these differences make the experiments less comparable to the present experiment, it is suggested that the auditory presentation accounts for the delay of the N400 effect. It is argued that the negativity reflects the detection of the number violation and the processing of the resulting semantic incongruity.

More importantly, 'number' congruent and incongruent compound constituents were not processed differently before 1,100 ms post compound onset. This suggests that the number marking of single nouns is processed before linking elements can be interpreted as plural morphemes in compound constituents. That is, linking elements are not processed as plural morphemes of initial constituents although they are phonologically identical. The results show that prosodic cues are used for the functional disambiguation of linking elements and plural morphemes.

Accuracy was high in both the single noun and in the compound constituent conditions. The high accuracy rate calls for an explanation of how subjects made the correct responses. If linking elements are not processed online as plural morphemes, they may be re-evaluated by some later process, possibly a rehearsal mechanism. Such an interpretation is in accordance with the late negativity in the compound condition. This negativity is visible at frontal electrodes and was significant in the right-anterior ROI between 1,100 and 1,700 ms. Frontal negativities have been associated with working memory processes (Kluender, & Kutas, 1993; Rösler, Heil, & Hennighausen, 1995; Ruchkin, Johnson, Canoune, & Ritter, 1990, cf. also Curtis & D'Esposito, 2003) and the later re-evaluation of linking elements would clearly involve some form of working memory processes. On the other hand, brain areas in the right frontal and temporal lobe have been found to process preferably prosodic information (Meyer, Alter, & Friederici, 2003; Meyer, Alter, Friederici, Lohmann, & von Cramon,

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[7] Both studies used proper names that were incorrectly marked for number. Lück et al. investigated also loan words and obtained an N400 effect for these stimuli between 450 and 550 ms.

2002; Zatorre, Belin, & Penhune, 2001). In order to evaluate linking elements it may be necessary to correct the initially perceived prosody and such a process may be reflected in the late right-anterior ERP effect for number incongruent compound constituents. It is suggested that the late negativity in the compound condition reflects the evaluation of linking elements. Whether this evaluation involves a rehearsal or the correction of prosodic information cannot be clarified here.

It is unlikely that the late negativity for compound constituents reflects the same process as the earlier negativity for single nouns. First, the late negativity was located at right-anterior electrodes and the early negativity was significant in the left-posterior ROI. Furthermore, the topographical distribution of the effects differed significantly. Second, if the time difference was related to the length of stimuli an earlier negativity should be found for the compound constituents because these were shorter than single nouns. However, this was not the case; the earlier negativity was elicited by single nouns. Third, none of the effects can be due to the acoustic splicing as all stimuli in all conditions were spliced. As a result of the stimulus recording, it is likely that the acoustic intensity decreased for single nouns but not for compound constituents. Hence, it is possible that there was a transient change in acoustic energy at the boundary of word and noise in the single nouns but not in the compound constituents. Although this change in acoustic energy may affect processing it cannot, fourth, explain the late negativity in the compound constituent condition. It is implausible that the equal acoustic energy level delays the negativity about 500 ms but immediately disrupts the LIN. Thus, it is concluded that the evaluation of linking elements involves processes that are distinct from the processing of plural morphemes which furthermore, supports their functional difference.

Two slow negative ERP shifts were found in response to the target stimuli which is in contrast to the previous experiments (1, 2a, 2b, & 3a). This is especially noteworthy for the compound constituents as this effect indicates the disruption of the perceptual compound *unit*. Depleting the second constituent of phonemic content results in a return of the ERP to baseline at posterior electrodes and in a strong decline at frontal electrodes (cf. Figs. 8.9 & 8.10). The disruption of the LIN may be specific to the missing of phonemes because prosodic parameters (intensity envelope & duration) were preserved. Phonemes were removed by erasing systematic frequency patterns, i.e. pitch, which is also a prosodic cue. It is suggested that the decline of the ERP specifically reflects the disturbed compound comprehension and is due to the missing of phonemes. Without extracting phonemes from some noise no lexical entries can be accessed and combined in order to yield a compound.

In summary, the results of Experiment 3b suggest that linking elements are not plural morphemes of preceding constituents. Number incongruities of single nouns elicit a left-posterior negativity between 600 and 900 ms. There is no effect in the same time window if the same words carry a compound prosody. Compound constituents that have to be judged as number incongruent based on linking elements, elicit a right-anterior negativity after 1,100 ms. This late negativity reflects different processes than the earlier negativity for single nouns, possibly processes of re-evaluation of linking elements. Thus, the absence of a number incongruity effect for compounds, particularly in light of the effect for single nouns, suggests that linking elements are not plural morphemes.

Chapter 9

General discussion

The aim of this investigation was to provide a better understanding of the auditory comprehension of compound words. A number of studies suggest that compound words are processed by two routes, a direct mapping of the input to lexical entries and/or a decompositional route that extracts constituents from the compound (both routes may be assumed to work in parallel or alternatively; Baayen et al., 1997; Isel et al., 2003; Sandra, 1990; Schreuder et al., 1998; Zwitserlood, 1994). The present series of experiments supports such a twofold structure of the comprehension system. Morphosyntactic information that is bound to nonhead constituents (gender) was accessed, although this information is syntactically irrelevant in German (Exp. 1, 2a, & 2b). That is, compounds were necessarily decomposed on the morphosyntactic level, as gender of nonhead constituents could not have been retrieved otherwise. Such a decomposition argues against a full-listing of compound forms in the lexicon (Butterworth, 1983; Bybee, 1995). However, when linking elements were tested for a proposed morphosyntactic function – to indicate number of nonhead constituents – no such effect was observed (Exp. 3a). That is, number is not specified for initial constituents although the phonemes that usually mark plural are clearly present as linking elements in many compounds. This null effect disagrees with an extensive morphological analysis during compound comprehension and, thus, against a full-parsing approach (Libben, 1994; Libben et al., 1999; Taft, & Forster, 1976). However, the results of Experiment 3b show that linking elements and plural morphemes are functionally distinct. The functional change of phonological segments that represent linking elements, is due to prosodic cues (Exp. 3b). That is, prosodic cues disambiguate homophonous linking elements in compounds and plural morphemes of single nouns.

Effects of lexical-semantic integration also support dual-route models of compound comprehension but not full-listing and full-parsing models. The latter two models predict that all compounds are processed equally. Hence, they predict no differences between transparent and opaque compounds. Lexical-semantic integration of constituents was suggested to begin during the perception of the last (*head*) constituent (Exp. 1) and this effect was confirmed in Experiments 2a and 2b (cf. Fig. 9.1). In Experiments 2a and 2b an effect of lexical-semantic integration was observed for transparent vs. opaque compounds, i.e. transparent and opaque compounds are processed differently. This finding is contrary to the predictions of full-listing and full-parsing models; it implies two processing routes and supports dual-route models. The major findings are summarised in Table 9.1.

Table 9.1: *Summary of the major findings. Note: LIN – lexical integration negativity; LTN – left temporal negativity; TT & OO – transparent and opaque two constituent compounds.*

		Initial constituent	**Head constituent**	**LIN**
Exp. 1 (gender) novel compounds		LAN	LAN	modulated by difficulty
Exp. 2a (gender) TT & OO compounds		LAN	LAN	modulated by semantic status
Exp. 2b (gender) TT & OO compounds excluding novels		LTN		modulated by semantic status
Exp. 3a number & linking elements		null effect	N400	
	Single nouns	**Compounds**		
Exp. 3b prosody & linking elements	N400	null effect		disrupted by missing phonemes

Although reading and writing is almost ubiquitous nowadays, most communication takes place verbally. That is, visual language processing may be less valid ecologically and is certainly different from auditory language processing. Note that all stimuli were produced naturally and not artificially manipulated except for Experiment 3b.[1] Hence, the results have a high ecological validity. They may, however, be less generalisable to sentence processing.

9.1 The processing of morphosyntactic information

Gender is stored in the lexical entries of nouns and becomes available when such a lexical entry is accessed. The gender of German compounds is determined by the right most constituent (cf. Section 3.3.3) and gender violations were reported to elicit a LAN in sentence contexts (in German; Gunter et al., 2000; Wedel, & Hahne, 2002; Deutsch, & Bentin,

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[1] Only the loudness of stimuli was adapted in all Experiments.

2001, for Hebrew). In **Experiment 1** the gender violations of initial and head constituents of novel three-constituent compounds elicited a LAN. The LAN in response to the gender incongruent head constituent replicates previous findings and shows that the availability of gender information can be detected (by its violation) in minimal phrase contexts such as determiner-compound phrases.

The more interesting result is the LAN in response to gender incongruent initial constituents. Gender is comprised in the morphological representation of the constituent noun and must be available in order to elicit a LAN. Hence, this result shows that a morphological representation of initial constituents is accessed and the logically presupposed decomposition of novel compounds could be verified for the morphosyntactic level. That is, the processing of other morphosyntactic constituent features can be examined since the result shows that compounds are decomposed morphosyntactically. In addition, the time course of morphosyntactic constituent activation can be evaluated with the present method.

The results suggest that the gender information of each constituent was processed independently, i.e. the LAN of the head constituent was not influenced by a preceding gender violation. This suggests that the access of each morphological representation is independent of the processing of preceding constituents' morphological representations. The perception of the constituent onsets may be a crucial factor for initiating a new lexical search for subsequent constituents (Marslen-Wilson, & Zwitserlood, 1989), i.e. decomposing the compound. However, Davis et al. (2002) showed that suprasegmental information is also used for differentiating onset embedded words from non-embedded words.[2] The access of each constituent seems to entail the processing of its respective (morpho)syntactic features, e.g. its gender for nouns. This idea is in accordance with models of incremental language processing (Friederici, 1995, 2002; Gorrell, 1995; O'Seaghdha, 1997). Each perceived compound constituent may be checked for its morphosyntactic features independently of its lexical-semantic relevance for the whole compound.

Although these results show that novel compounds are decomposed morphosyntactically they are compatible with two accounts of decomposition. Morphosyntactic decomposition may occur regularly or be induced by the novelty of compounds. If decomposition is induced

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[2] It is yet unclear how decomposition is achieved. It may be constrained by some principles which require that all input adjacent to a considered constituent boundary must have the status of a word or word stem. That is, decomposition must not occur for so-called pseudo compounds which incidentally contain a free morpheme, e.g. "banshee" because the extraction of "ban" leaves *"shee" as a constituent which is not a word or a word stem (orthographically). Accordingly, incorrect decomposition should not occur for compounds (e.g. *"cable c-lamp" or *"yell-owbelly"). Such constraints may be understood in analogy to the Possible-word Constraint proposed for word recognition in continuous speech (Norris, McQueen, Cutler, & Butterfield, 1997; Norris, McQueen, Cutler, Butterfield, & Kearns, 2001). Since compounding differs among languages these constraints would be language specific; French, for example, is predominantly left-headed.

by novelty (de Almeida, & Libben, 2002), existing compounds should not be decomposed. This matter was explored in the next Experiment.

Experiment 2a investigated existing low frequency compounds[3] and found independent LANs in response to gender incongruent initial and head constituents. Both LANs were also independent of the compound's semantic status (transparent vs. opaque). Since these compounds were not novel the results suggest that morphosyntactic decomposition occurs regularly and is not induced specifically by novelty.

From linguistics it is known that productivity of compounding is high in German, i.e. novel compounds are used frequently (cf. Section 3.3.2 Fleischer, & Barz, 1995; Meyer, 1993). Together with the high agreement among native speakers regarding the interpretation and the form of compounds, this suggests that compounding involves combinatorial rules, and these rules would operate on the compound constituents. The decomposition of compounds as found in Experiments 1 & 2a supports the linguistic view that compounding involves the active combination of lexical entries. It is suggested that decomposition is one mechanism of compound comprehension in German and possibly in other languages with a high productivity of compounding.

Opaque compounds, in contrast to transparent ones, cannot be processed by decomposition and subsequent constituent combination. Opaque compounds must have their own lexical entries because they are not related semantically to their constituents. This implies that a second processing mechanism for accessing the lexical entries of opaque compounds. While compound constituents are extracted (decomposition), a lexical entry must be searched in parallel that matches the whole compound form, i.e. the whole sequence of phonemes. This search is called the direct route. The direct processing route should be faster as no combination of constituents is necessary if *one* matching entry is found. If the direct route is successful the decompositional route may be terminated and its results may be discarded. Although the use of the two routes was not manipulated, the present data generally agree with such an idea. If both processing routes run in parallel, transparent and opaque compounds should be processed equally until a matching entry is found (e.g. for opaque compounds) or a constituent integration is performed (e.g. for non-lexicalised transparent compounds). Transparent and opaque compounds were both decomposed morphosyntactically. In addition, the lexical integration negativity (LIN) may reflect the lexical search and its scalp distribution did not differ for transparent and opaque compounds. Moreover, the LIN was not modulated by integration difficulty (Exp. 1) or semantic status (Exps. 2a & 2b) before the head constituent was perceived (see Fig. 9.1 & 9.2). This suggests that transparent and opaque

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[3] Although these compounds appear in data bases they are assumed not to have a lexical entry due to their low frequency.

compounds are processed equally until the head constituent is identified; they are processed equally with regard to the process(es) reflected by the LIN. Here it is assumed that the LIN reflects the lexical search because it has a rather frontocentral maximum (cf. Fig. 7.5), but this cannot be stated with certainty as it was not directly investigated. All compounds were decomposed morphosyntactically but only opaque compounds require a direct access route in principle.[4] Hence, it is concluded that compound comprehension involves two processing routes.

A gender violation of initial constituents did not influence the subsequent processing of the gender information of the head constituent. This is plausible as the gender of initial constituents is syntactically irrelevant. The LANs for the respective constituents show that the constituents are accessed serially and, moreover, that the morphosyntactic processing of constituents does not interact. This replicates Experiment 1 and extends the finding to existing, i.e. non-novel compounds. This strongly suggests that the morphological representation of each compound constituent is processed individually in all types of compounds.

The compound decomposition was only shown for the grammatical forms (GFs) of constituents but not for the semantic forms (SFs). Grammatical and semantic information are represented distinctly in the lexical entries (cf. Fig. 3.1) whereby the GF is subdivided into a word class representation and a representation of more specific morphosyntactic features. This means that the processing of morphosyntactic and semantic information may be independent. The LANs were independent of semantic status in Experiment 2a and 2b, similar to the independence of integration difficulty in Experiment 1. The ERP effects of semantic status do not reflect the access of SFs but the lexical-semantic integration of constituents (see Section 9.2). However, the independence of morphosyntactic and semantic information processing supports the linguistic conception of lexical entries with their distinct subdivisions. The distinct processing of morphosyntactic and semantic information is supported by the independence of the effects for head constituents because the semantic status of the compound can be determined at that point in time (see footnote 4; p. 133).

Although all stimuli used in Experiment 2a are existing low frequency compounds, one might object that morphosyntactic decomposition does not occur regularly. The mere presence of a considerable amount of novel compounds (1/4 in Exp. 2a) may induce decomposition strategically. Decomposition, then, would be a back-up mechanism for comprehension of unfamiliar, rarely occurring words, i.e. *novel* compounds. This seems rather unlikely in

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[4] For initial constituents it seems unlikely that information about semantic status is already available. For example, while perceiving /ʃneː/ ("Schnee", snow) the parser retrieves a morphological unit including the gender information *masculine* but it is not predictable whether it is part of an opaque ("Schneebesen", "snow broom", egg whisk) or a transparent compound ("Schneebrille", snow goggles).

German because compounding is very productive (Fleischer, & Barz, 1995; Linke et al., 1994; Meyer, 1993).

Nonetheless, the claim was put to the test in **Experiment 2b**. A subset of the stimuli from Experiment 2a was used and presented to subjects without any novel compounds throughout the experimental session. The results, however, clearly show that gender violations of initial constituents affect the ERP and do not yield a null effect.[5] The effect is weaker than in the first two experiments, and it seems to have a focus at left temporal electrodes. The left temporal negativity is slightly more central than the LANs of Experiments 1 and 2a. This may be due to a specific subject group in this experiment. Subjects had to be selected on the basis of their performance due to the reduced number of stimuli.

Note that there is some variation in the spatial distribution of ERP effects of morphosyntactic violations as described in the literature. Left temporal/central negativities were reported in response to morphologically marked tense and subject-verb number agreement violations (Hagiwara et al., sub.; Kaan, 2002). A recent study that investigated the subject-verb number agreement in Italian (De Vincenzi, Job, Di Matteo, Angrilli, Penolazzi, Ciccarelli, & Vespignani, 2003), found however, a left frontocentral negativity. Moreover, if the LANs for nonhead constituents in Experiments 1 and 2a are compared, it also seems that the effect is not distributed identically in the left anterior ROI (see Figs. 6.3 and 7.2). The effect is somewhat shifted to the midline in Experiment 1 and the LAN is more pronounced at lateral electrodes in Experiment 2a. Hence, it is argued that the more temporal focus of the gender violation effect in Experiment 2b is due to a selected subject group and minor distributional variations between subject groups.

In general, based on the result of Experiment 2b it cannot be concluded that the morphosyntactic decomposition of compounds in auditory comprehension is due solely to an induced strategy. The presence of novel compounds in the experimental session alone cannot explain the electrophysiological effects of gender violation of nonhead constituents, suggesting that decomposition occurs indeed regularly.

What may then be the functional relevance of morphological decomposition? The access of GFs seems plausible in light of the results by Isel et al. (2003). In this series of experiments the SFs of initial constituents were not activated at their acoustic end (but see Wagner, 2003, for semantic activation of initial constituents). The SFs were activated later, at the end of the compound, if the head constituent was semantically transparent. It may be assumed that only a morphological unit of initial constituents was accessed in order to access the SF later on if necessary for determining the compound meaning (i.e. for transpar-

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[5] Especially if the effect is compared to the null effect of initial compound constituents in Exp. 3a.

ent compounds). That is, morphological decomposition yields a constituent representation which has to be stored in short-term memory[6] and permits the later access of the respective SF. If the SF of the initial constituent is irrelevant for the compound meaning (i.e. for opaque compounds) the GF may be discarded. A morphological representation may be more efficient to store than a SF, e.g. because the GF is underspecified. That is, the GF may be less demanding to keep in short-term memory. Alternatively, the phonological form (PF) of nonhead constituents may be stored and rehearsed later on. However, this seems less likely because acoustic/phonetic stimulation progresses and the additional rehearsal of PFs would increase work load (phonological suppression effect; Baddeley, 1986). Thus, morphological decomposition may reduce processing/storage costs of compound perception. Furthermore, it permits semantic information (SFs) to be accessed after some time has elapsed (about 450 ms per nonhead constituent).

More generally, the described retrieval mechanism may only be correct for the most common compounds.[7] For instance, novel compounds or compounds which create semantic ambiguity by their first constituent may induce full decomposition, incl. immediate access of SFs (cf. Wagner, 2003). Compounds with more than four constituents may also be processed differently because such compounds become increasingly rare the more constituents they contain, especially in spoken language (in German; Becker, 1992; Fleischer, & Barz, 1995). In these two cases, more controlled processes may be employed for comprehension, e.g. a rehearsal for longer compounds. Note that in sentence comprehension the syntactic analysis and the calculation of the sentence proposition also has to pause until the head constituent is available. Hence, a mechanism that reduces processing costs would be valuable, at least for the most common compounds.

9.1.1 Prosody and morphosyntactic feature specification

Experiments 3a and 3b were designed to answer the question whether the morphological representations of constituents are fully specified or underspecified regarding morphosyntactic number information. The descriptive term ”grammatical form” originates from linguistic theory and comprises all morphosyntactic information. The term ”morphological unit” stems from psycholinguistic research and is not yet fixed in its precise theoretical extent. It does not necessarily imply a fully specified morphosyntactic representation. That is, a morphological unit may contain only invariable information of an entry, e.g. inflectional class, or gender for

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[6] Here it is not distinguished conceptually between working memory and short-term memory. The term ”short-term memory” is preferred to emphasise the means of keeping information available through a short period of time.

[7] Unfortunately, this set cannot be defined precisely. It may be delimited very crudely to existing low frequency compounds.

nouns, and number of arguments for verbs[8]. Such an underspecified representation may not include variable morphosyntactic information such as number, or case for nouns, and tense for verbs.

Linking elements were proposed to indicate the morphosyntactic feature number of initial constituents (Bartke, 1998; Clahsen, 1999; Clahsen et al., 1996; Wiese, 1996). This function was tested in **Experiment 3a**. As Experiments 1, 2a, & 2b showed that compounds are decomposed morphosyntactically, a violation of number agreement should be detected if linking elements are processed as plural morphemes. The number agreement between an indefinite determiner and both the initial and the head constituents of low frequency compounds was manipulated. Since only so-called irregular plural morphemes can appear within German compounds, only constituents were used that take such irregular plural morphemes. Hence, the effects for head constituents should be comparable to initial constituents.

Number incongruent head constituents elicited an N400 that was followed by an broadly distributed negativity (cf. also Weyerts et al., 1997). However, no effect was observed for initial constituents although the presence or absence of linking elements might mark number at the surface, i.e. overtly at the constituent form. The ERPs for initial constituents that were supposed to be number incongruent and number congruent, showed virtually no divergence from each other. That is, linking elements do not establish a number incongruity with a preceding determiner. Hence it is concluded that linking elements do not have the function of plural morphemes and it is suggested that number is not specified for nonhead constituents of German compounds.

There are a number of differences between the experiments that manipulated gender agreement or the proposed plural function of linking elements. These will be discussed consecutively. The crucial property, however, seems to be the different status of the morphosyntactic features gender and number; gender is fixed whereas number is variable.

The most obvious difference is that number but not gender is overtly marked on the noun. The linking elements in question are identical in their phoneme sequence with the respective plural morphemes. (This is the reason that they are proposed to serve this function.) However, this superficial difference in marking cannot explain the different effects. The overt marking of number would predict easier processing of this morphosyntactic feature and more difficult processing of gender. Hence, an effect for number manipulations and possibly no effect for gender disagreement might be expected. But, the effects observed for gender and linking elements ('number' of initial constituents) show a reversed pattern.

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[8] More precisely the maximal number of arguments. Some verbs do not require all arguments to appear in a sentence.

Another difference is that the manipulations used definite determiners in the gender experiments and indefinite determiners in the number experiment. However, it is unclear how this difference might explain the diverging results. Both types of determiners are used constantly in language and both occur regularly in such noun phrases that were used in the experiments. In addition, both types of determiners are clearly marked for the morphosyntactic feature in question. Therefore, it is highly improbable that the diverging results for both morphosyntactic features are due to the different forms of determiners.

One may object generally that the morphosyntactic features of initial constituents are syntactically irrelevant in any case (in German). The gender effects found in Experiments 1 through 2b, however, show that they are processed. Note that the effects of gender incongruity were replicated twice. In addition, the effects obtained for nonhead constituents are highly similar to the effects obtained for the syntactically relevant head constituents.

The most important difference between the experiments that manipulated gender (1, 2a, & 2b) and Experiment 3a is the different status of the morphosyntactic features gender and number. Gender is a fixed feature of lexical entries whereas number is variable and, thus, needs specification. In addition, number but not gender has a semantic aspect, i.e. it entails also some semantic specification. If the morphosyntactic feature number is set to, say, plural then the semantic feature *amount of* has to be adapted to *more than one*. The null effects for initial compound constituents (Exps. 3a & 3b) suggest that number is not specified for nonhead constituents. Since these constituents are syntactically irrelevant the presumably costly morphosyntactic and semantic specification of number can be spared. In addition, the semantic interpretation of nonhead constituents with regard to number cannot always be determined by the linking element alone but the (rather explicit) interpretation may vary with the number value of the head constituent (cf. Section 3.3.3). That is, even if number of nonhead constituents were specified by linking elements online, it may have to be corrected after the head constituent is processed. In general, number, as a variable feature, needs specification which is spared for nonhead constituents, possibly for reasons of computational economy. Gender, on the contrary, is a fixed feature; it is an essential part of lexical entries and does not need to be specified. Accordingly, gender information becomes available during the access of a morphological unit and, hence, may disagree with a determiner. Such a disagreement is then detected by the parser as it was found in Experiments 1, 2a, & 2b.

From Experiments 1 through 3a it is concluded that linking elements are not processed online as plural morphemes, as previously suggested in a patient (Costard, 2001) and a number of behavioural studies (Dressler et al., 2001; Haskell et al., 2003; Jarema et al., 2002; Libben et al., 2002). Although linking elements contain the same phonemes they are functionally distinct from plural morphemes. That is, the assumption that plural morphemes[9] appear within compounds cannot be supported. These elements may be identical in form with plural morphemes but they bear a different function at least in comprehension. Which function they subserve cannot be decided on the basis of the present data.

According to this view, the manipulation of nonhead constituents was not a manipulation of the number agreement and therefore, no number violation effect was observed for nonhead constituents. This view entails that nonhead constituents cannot be marked for plural because the linking elements are the only possibility to mark constituents formally for plural. However, one might object that the null effect in Experiment 3a is due to a lack of attention to linking elements. Indeed linking elements were not relevant for subjects' tasks in Experiment 3a. Although it is not clear why subjects should not pay attention to linking elements in the experiment but do so in normal conversations, the argument cannot be ruled out theoretically. If the null effect is due to a lack of attention, a number violation effect should appear if linking elements are relevant for the task and, hence, are attended to. If, on the contrary, linking elements are functionally distinct from plural morphemes the null effect should persist under such an attended condition.

In case the conclusion is correct that linking elements are functionally distinct from plural morphemes, the information is essential whether or not a perceived speech sound is part of a compound. Otherwise, linking elements could not be distinguished from plural morphemes. Prosodic parameters seem to be an important cue to morphological complexity, and duration of initial constituents was shown to be a reliable prosodic cue (Isel et al., 2003). Words produced as initial compound constituents are shorter compared with the same words produced as single nouns. This was confirmed in **Experiment 3b** which investigated the role of prosodic cues for the specification of number in single nouns and initial compounds constituents. The same words were produced naturally but differed in duration and pitch depending on whether the word was produced as a single noun or as an initial compound constituent. Subjects had to judge the number agreement between a determiner and either initial compound constituents or single nouns. For compound constituents the judgements were based on the presence or absence of linking elements. Therefore, linking elements were attended to, which was confirmed by the high accuracy rates.

If prosodic parameters indicated a single noun, the plural morphemes were processed as such. This is suggested by the high accuracy rate and a negativity at posterior left electrodes between 600 and 900 ms. Given its modulation and the scalp distribution of the effect it is interpreted as an N400 effect. In addition, similar effects were reported for incorrect irregu-

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[9] Only irregular plural morphemes are assumed to appear inside compounds. However, the point is that these elements are not *plural* morphemes.

lar plural morphemes (Lück et al., 2001; Weyerts et al., 1997; Wolf, submitted.). Remember that an N400 effect was also found in response to number incongruent head constituents in Experiment 3a but it appeared earlier. The head constituent violation is not directly comparable to the single noun condition in Experiment 3b with regard to the time courses of processing. In Experiment 3a the recognition point of the compound is presumably shifted to the constituent boundary and, thus, the N400 may have appeared earlier. In Experiment 3b the recognition of single nouns is not facilitated by a preceding constituent.

If prosody indicated compounds, no ERP effect occurred for the 'number' manipulation via linking elements before 1,100 ms. That is, the null effect of 'number' incongruity (Exp. 3a) was replicated in Experiment 3b. Only a later negativity was found to be significant over right anterior electrodes between 1,100 and 1,700 ms. The negativity shows that the proposed number violation can be detected by subjects if instructed so. The ERP effect and the high accuracy rate for the compound condition show that subjects paid attention to the linking elements and were able to judge them correctly. However, the correct and incorrect conditions were not distinguished up to 1,100 ms post onset, i.e. 500 ms later compared to single nouns. On top of that, compound constituents are also about 150 ms shorter in duration which further increases the time difference between the processing of single nouns and compound constituents. Together with the behavioural results the delayed ERP effect suggests that it is more difficult and takes longer to interpret linking elements as plural morphemes than plural morphemes themselves. That is, it is not the normal function of linking elements to index the morphosyntactic feature number of nonhead constituents; linking elements and plural morphemes are disambiguated in their function by prosodic cues.

The diverging ERP effects for single nouns and compound constituents are suggested to reflect different cognitive processes, especially as the effects differ in their scalp distributions. The ERP effect for compound constituents does not reflect the same cognitive process as the effect for single nouns, which is only delayed in time (cf. Section 8.2.4.3). The left posterior negativity for number violations of single nouns is interpreted as an N400 and is suggested to reflect the processing of the semantic incongruity between the determiner and the noun. The later, right anterior negativity for compound constituents is suggested to reflect the evaluation of linking elements. This, rather controlled, evaluation might be achieved by (one of) two processes. Linking elements may be rehearsed, i.e. involving working memory processes. Alternatively, linking elements may be turned into plural morphemes functionally by changing the prosodic parameters from *compound* to *single noun*. The latter case may be understood as a correction or re-evaluation of prosodic parameters.

In light of Experiment 3b, it seems unlikely that the null effect for nonhead constituents in Experiment 3a is due to a lack of attention. Experiments 3a and 3b are similar enough to be compared. In both experiments ’number’ incongruent compound constituents did not yield and ERP effect as it was found for single nouns in Experiment 3b. However, in Experiment 3b subject paid attention to linking elements and hence, it is unlikely that the null effect in Experiment 3a was due to inattentiveness. When subjects paid attention to linking elements (Exp. 3b) and prosodic cues indicated compounds, the differentiation of correct and incorrect ’number’ agreement was delayed by more than 500 ms. This shows that linking elements are not processed as plural morphemes, i.e. number is not specified for nonhead constituents as it is done for single nouns. Although the later negativity for compound constituents may be induced by the task and hence, may not be valid ecologically,[10] it shows that nonhead constituents can be interpreted in principle as being marked for number. However, the evaluation of linking elements involves different cognitive processes. If these processes are more controlled they may explain why the interpretation of nonhead constituents regarding their morphosyntactic feature number, is rather variable; they may explain why a ”Buch$_{singular\ form}$regal$_{singular}$” (bookshelf) may be understood to contain numerous books without being mistakable (cf. Section 3.3.3). That is, Experiment 3b shows that prosodic cues can modify the morphosyntactic processing of compounds; they can suppress the specification of the number feature of nonhead constituents as it would be done for single nouns.

It should be noted that the results (Exps. 3a & 3b) are not at odds with the findings of Schreuder et al. (1998) who found that Dutch linking elements, which are identical in form with plural morphemes, elicit a plural meaning in different judgement tasks. These judgements may be postlexical assignments and need not reflect the online processing of compounds. It is not unreasonable if one ponders about the meaning of ”Lied$\underline{\text{er}}_{plural\ form}$-abend$_{singular}$” (”song[s] night”, recital), to conclude that there is more than one song sung at such an event. Moreover, Schreuder et al. made use of visual presentation which lacks (prosodic) cues of morphological complexity. Although it was shown that compounds are decomposed during visual presentation and reading (Andrews, 1986; Inhoff et al., 2000; Pollatsek et al., 2000; Sandra, 1990; Zwitserlood, 1994) it was not shown that the extracted morphological representations are fully specified. Hence, from Schreuder et al.’s data no claim can be made about online specification of number in compound comprehension.

In general, the results suggest that morphological representations are morphosyntactically underspecified when they are accessed for each compound constituent. This view agrees with the claim that the mental lexicon contains a morphological level on which

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[10] If so, the effect should disappear if linking elements are task irrelevant. Post-hoc inspection of the data from Experiment 3a did not find such an effect, but Experiments 3a and 3b are not directly comparable.

the constituent information of morphologically complex words are stored (Schriefers et al., 1991). It was shown that morphological representations of compound constituents are accessed (Exp. 1, 2a, & 2b) but the variable feature number is not specified (Exp. 3a & 3b). Broadly speaking, the results suggest that morphological representations contain only fixed morphosyntactic features (e.g. gender or number of arguments) but not variable features (e.g. number, case, or tense). This interpretation suggests that the plural forms of German nouns are not stored in the mental lexicon, at least not in the morphological representations. This stands in sharp contrast to the proposal that the plural forms of nouns that take so-called irregular plural morphemes, are stored (Clahsen, 1999; Weyerts et al., 1997) and casts some doubt on the classification of the plural morphemes in question as being irregular (Bartke, 1998; Clahsen et al., 1992; Wiese, 1996). The incorrect application of so-called irregular plural morphemes was shown repeatedly to elicit an N400 effect (Clahsen, 1999; Lück et al., 2001; Weyerts et al., 1997; Wolf, submitted.) and the violation of the number agreement for equivalent nouns also elicit an N400 effect (Exp. 3b & for head constituents in Exp. 3a). The N400 effects were interpreted to reflect the increased difficulty of a lexical search. Since the present experiments suggest that the plural forms are not marked in the lexical entries this interpretation of the N400 effect seems to require at least some modification. If number is not marked in the lexical entries the N400 effect cannot reflect the lexical search of the number marked words. In contrast, the N400 effects in the present experiments and in sentence comprehension may reflect the processing of the semantic incongruity between two words, here between a determiner and a noun/constituent. This interpretation seems plausible as number entails semantic consequences. Its processing may be conceptually driven as it is determined extrinsically under normal circumstances, i.e. by the number of denoted objects. It is, however, unclear how the formal incongruity between the determiner and the noun is detected and processed.

9.2 Lexical-semantic integration

With the paradigm used, not only morphosyntactic feature processing can be examined but also processes of lexical-semantic constituent integration. The dual-route account as it is pursued here predicts first of all that compounds without a lexical entry are processed by decomposition and, second, that lexicalised compounds are accessed via a direct route. That is, novel, and low frequency transparent compounds should be decomposed and opaque compounds should be accessed directly from the mental lexicon. Decomposition of compounds entails a composition of the constituents in order to compute the compound meaning. In transparent compounds the head constituent determines the semantic category of the denoted object; it carries the meaning-defining information. This information is only modified by the nonhead constituents. Thus, the integration of constituents or, in other words, the modification of the head constituent's meaning cannot be achieved before the head constituent is available. Hence, the head constituent must be available for the semantic computation of the compound, i.e. for the constituent integration.

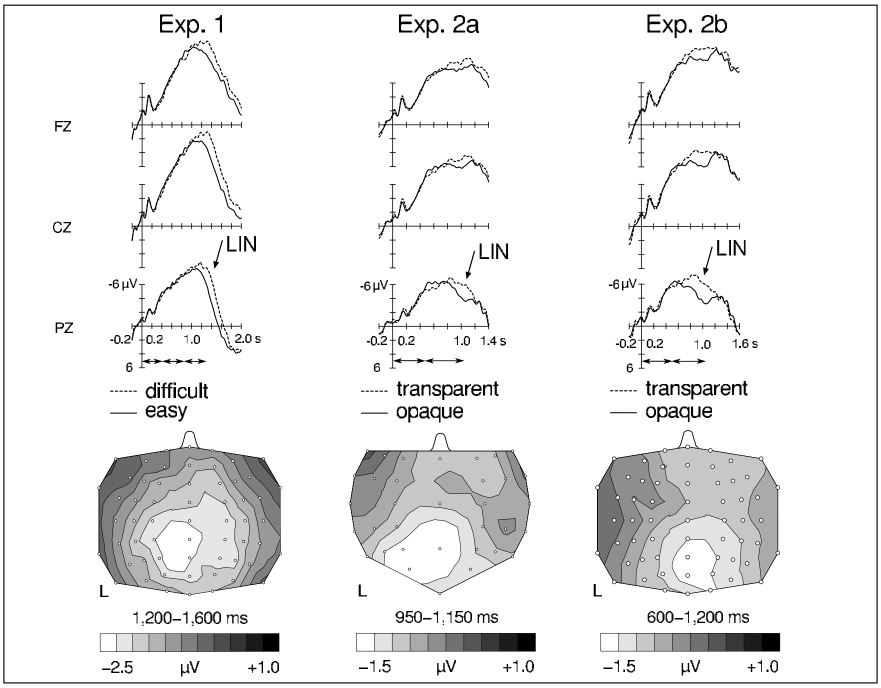

Figure 9.1: The lexical integration negativity at three selected electrodes and the according scalp distributions of the LIN effect for Experiments 1, 2a, and 2b (voltage difference maps). Horizontal arrows indicate the approximate constituent lengths.

Although semantic factors were not experimentally manipulated in Experiment 1, a post-hoc comparison was suggestive of a lexical-semantic constituent integration for novel compounds. Compounds that are more difficult to interpret elicited a larger negativity than compounds that are easy to interpret. When differences between transparent and opaque compounds were investigated in Experiments 2a and 2b the effect was confirmed with these low frequency compounds. Transparent compounds elicited also a larger negativity in comparison to opaque compounds. Hence, these three experiments support the interpretation of the LIN effect as reflecting the lexical-semantic integration of constituents.

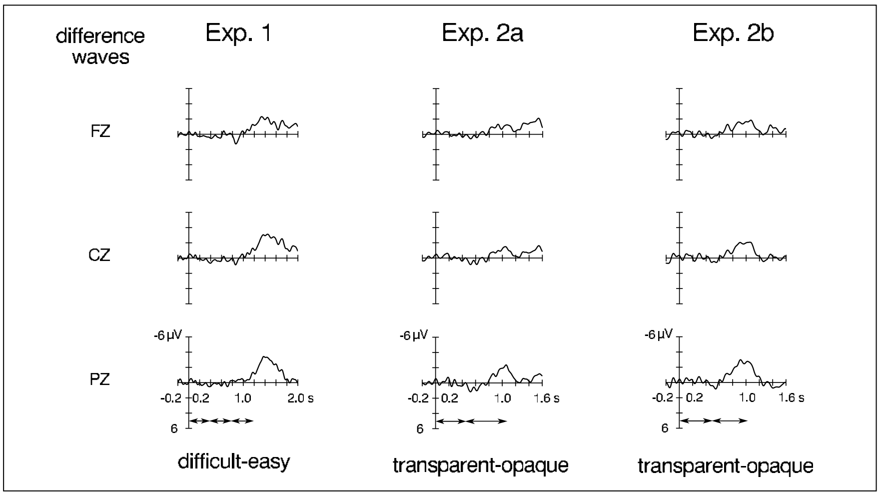

Figure 9.2: The difference waves for the LIN effect at three selected electrodes. The difference waves were calculated for difficult-easy compounds (Exp. 1), and transparent-opaque compounds (Exps. 2a & 2b). For a plot of all electrodes see Appendix A.2. Horizontal arrows indicate the approximate constituent lengths.

The lexical integration negativity does not reflect directly semantic decomposition or the activation of a particular constituent. Instead, it presupposes such a decomposition; if no constituents are accessed separately as suggested by the full-listing hypothesis, no integration would be possible. The LIN effect does not indicate *when* the SF of a given constituent is accessed but *when* constituents are integrated in order to yield the compound meaning.

The LIN is sensitive to the integration difficulty of constituents (Exp. 1) and to the semantic status of compounds (Exp. 2a & 2b) but it was found to be independent of the processing of gender violations. In all three experiments the effect of lexical-semantic integration (LIN effect) was observed during the perception of the head constituent. This is in accordance with the suggestion that the construction of a unified compound concept requires the availability of the head constituent meaning. The LIN effect had a similar scalp distribution with a centroparietal maximum in all three experiments (cf. Fig. 9.1). In addition, it resulted from the manipulation of the semantic status in Experiments 2a and 2b. Based on these facts and the appearance of the LIN effects during the head constituents (cf. Fig. 9.2 and Figs. A.1 to A.3 in Appendix A.2), it is concluded that the LIN effects reflect the lexical-semantic integration of compound constituents. If compounds have no lexical entry such an integration is necessary, but it is not required if compounds are lexicalised. In Experiment 2a there was also an earlier effect of semantic status; a negativity for opaque compounds. This earlier effect is suggested to be an epiphenomenon of the different peak latencies because it was not replicated in Experiment 2b[11] and the scalp distribution of the LIN did not differ between transparent and opaque compounds.

As was said before, neither the LIN itself nor the LIN effect reflect the semantic decomposition, i.e. the access of the SFs of constituents. Previous findings were not consistent regarding semantic decomposition of compounds during auditory comprehension (see Sections 4.2.2 & 4.4). Wagner (2003, Ch. 6 & 7) reported behavioural and electrophysiological evidence for semantic decomposition of novel compounds that contained a semantically ambiguous initial constituent. Initial constituents were semantically activated at the constituent boundary in a cross-modal priming paradigm. Another, behavioural study found no effects of semantic decomposition for low frequency compounds at the end of the initial constituent irrespective of semantic status (Isel et al., 2003).

Non-lexicalised transparent compounds require a lexical-semantic integration of their constituents whereas opaque compounds do not; opaque compounds must have their own lexical entry. Experiments 2a, and 2b found a modulation of the LIN during the head constituent which is interpreted to reflect the lexical-semantic constituent integration.[12] Such an integration presupposed a semantic decomposition, but the LIN effects do not indicate when this happened. Wagner's (2003) data argue for an immediate semantic decomposition. Decomposition, as found by Wagner, may be induced by the novelty of compounds or by the ambiguity of initial constituents. Experiment 1 used novel compounds but initial constituents were not ambiguous. Since, it is unclear whether novelty or ambiguity triggers immediate decomposition, it remains unknown whether compounds in Experiment 1 were immediately decomposed. It is possible that the SFs of constituents were accessed in all conditions and, therefore, did not result in an ERP difference. The null effect reported by Isel et al. (2003) suggests that semantic decomposition does not take place regularly for low frequency compounds. In Experiments 2a and 2b low frequency transparent and opaque compounds were investigated. Obviously, no ERP effect would be expected if the SFs had not been accessed immediately for these compounds. However, if SFs of constituents were accessed for both transparent and opaque compounds, the ERP should not be affected differently. After all, novel compounds may be processed differently than existing, low frequency

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[11] Opaque compounds are accessed by the direct route according to the dual-route model. The relative proportion of opaque compounds increased in Experiment 2b after the exclusion of novel compounds with respect to the overall number of stimuli. Thus, the direct processing route should be stressed even more and the ERP effect for opaque compounds should not decrease. However, this was not the case; the effect was not found in Experiment 2b.

[12] The LIN effect in Exp. 1 is interpreted similarly.

compounds. However, when checking the ERPs elicited by novel and low frequency transparent and opaque compounds virtually no difference was apparent for the first few hundred milliseconds. If semantic access occurs immediately upon perception, the LIN effect would reflect only the lexical-semantic integration. If, in contrast, semantic access is postponed, the LIN effect would reflect the semantic access of constituents in addition to the lexical-semantic integration. In the latter case prosodic cues may trigger (and possibly control) the delayed semantic access. In the present thesis, it cannot be clarified when the constituents are accessed semantically.

From Experiment 3b it appears that even the rise of the LIN is sensitive to the ongoing compound processing. In Experiment 3b initial compound constituents were presented and the second constituent was replaced with white noise. These noise 'constituents' still contained the prosodic cues duration and intensity contour of the respective compound constituent. There was no silent gap between the initial constituent and the noise 'constituent' but around the acoustic end of the initial constituent the ERP showed an uncharacteristic drop not seen in any of the previous experiments. At posterior electrodes the ERP even returned completely to baseline (see Fig. 9.3, right panel). It was suggested that the rise of the LIN reflects the lexical search of the compound and the constituents which is done in parallel. Such a lexical search crucially depends on the serially incoming phonemes. This series of phonemes was disrupted in Experiment 3b which supports the interpretation that the LIN reflects a lexical search process. The disrupted LIN for compound constituents in Experiment 3b in comparison to the LIN in Experiment 3a shows that the LIN is related in all parts to the compound processing and is not an epiphenomenon of, for instance, the duration of acoustic stimulation. The amplitude and peak latency of the LIN also support the lexical search interpretation. The lexical search should be longer and/or more effortful the longer the compound is. Both amplitude and peak latency increase with the number of constituents (see Fig. 9.3, left panel). This observation concurs with the suggestion that the lexical search should be prolonged and/or more effortful for longer compounds. Hence it is concluded that the rise of the LIN reflects a substantial (sub)process of compound processing. However, the series of phonemes may not be the only cue for a lexical search. Some prosodic cues were retained for the noise 'constituents' in Experiment 3b. In the single noun condition as well as in the compound condition of Experiment 3b, a second slow negative shift was observed (cf. Figs. 8.9 and 8.10). Since the second 'constituents' did not contain any phonemic information the negativity must be due to the remaining prosodic cues if it reflects an attempt to search the mental lexicon. Further research has to concentrate on the precise functional interpretation of the rise of the LIN and the employment of prosodic cues.

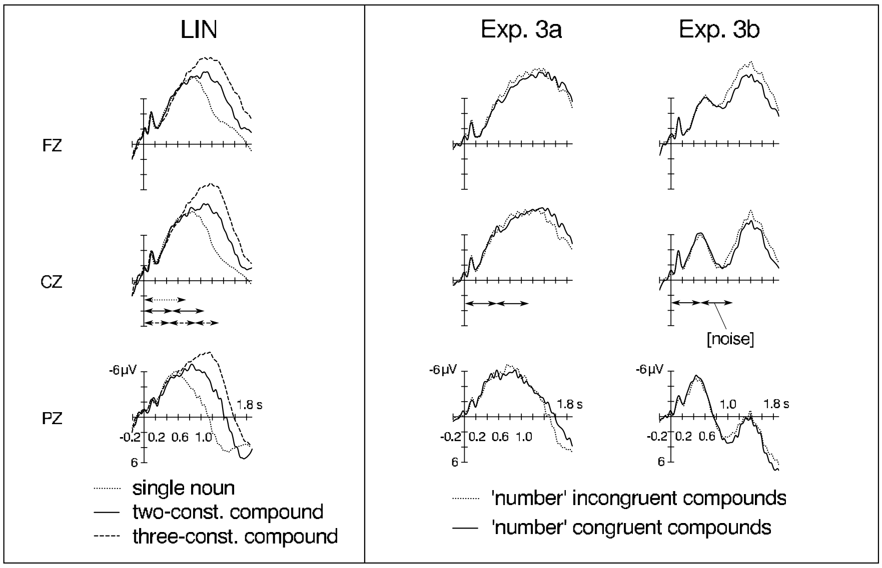

Figure 9.3: The lexical integration negativity at three selected electrodes and how it is affected by depleting the second constituent of phonemic content (right panel). The LIN is plotted for number congruent and incongruent two-constituent compounds in Experiment 3a. In Experiment 3b the 'number' congruent and incongruent compound constituents were followed by a white noise 'constituent'. The left panel shows the ERP/LIN for single nouns (filler items; Exp. 2a), two- and three-constituent compounds (Exps. 2a and 1). The LIN increases in amplitude and in peak latency with increasing number of constituents.

It is suggested that the lexical integration negativity is not identical to the N400. One prominent concept of the N400 relates to the semantic integration of a word into an established (sentence) context (Kutas, & Hillyard, 1984; Van Petten, & Kutas, 1990; Brown, & Hagoort, 1993). None of the present experiments provided a propositional context in which the compounds might have been integrated. Nevertheless, initial compound constituents can be seen as a semantic context for following constituents if they are activated. In this sense the semantic integration of constituents is similar to the semantic integration concept of the N400. However, the semantic processes reflected in the N400 are not restricted to language (cf. Section 4.4). Although it does not follow from the present experiments that the LIN (effect) is language specific, the LIN is suggested to reflect processes of compounding (lexical search and lexical-semantic integration). These processes should be language specific because compounding provides *one* unit, a syntactic word that can be used by other language modules (syntax and/or semantic system). If the LIN is language specific, the N400 concept of (domain general) semantic integration does not apply. What LIN and N400 have in common is that both are suggested to reflect several processes (cf. Pylkkänen, & Marantz, 2003). The lexical-semantic integration also entails conceptual processes, and such conceptual processes may in principle also be reflected in the LIN effect. Such an influence would be similar to the N400 concept but lexical-semantic and conceptual processing cannot be disentangled here. Another conception relates the N400 to the difficulty of lexical search processes (Deacon et al., 2000; Fischler, Bloom, Childers, Arroyo, & Perry, 1984; Kiefer, 2002; Rugg, 1990). Neither easy nor difficult compounds in Experiment 1 had a lexical entry as they were all novel compounds. That is, the effect of integration difficulty cannot be due to the difficulty of the lexical search. Experiments 2a and 2b used existing compounds, and even if it is assumed that they have lexical entries the LIN effect cannot be explained with lexical search difficulty. Transparent and opaque compounds were of similar frequencies and none of these compounds should be more difficult to find in the lexicon (if transparent compounds had lexical entries). Thus, the lexical search conception does not apply to the LIN effect, and both discussed concepts of the N400 component seem not to be adequate for the LIN (effect). Additionally, the peak latency is not related to the compound onset but varies with the length of the compound or the number of constituents (see Fig. 9.1). That is, the LIN is related to the processing of the whole compound. Hence, the average latency in the component label (”400”) would be deceptive. Calculating the effect with respect to the onset of the head constituent might save a constant peak latency, but would ignore the contribution of preceding constituents. In conclusion, the N400 label does not seem to be justified for the observed effects conceptually or descriptively.

More generally, how do the present results fit the findings from the visual domain? Investigations in the visual domain found that transparent and opaque compounds are decomposed morphologically, but only transparent compounds are also decomposed semantically (Sandra, 1990; Zwitserlood, 1994). These findings can be extended to the auditory modality with regard to morphosyntactic decomposition. Transparent and opaque compounds were decomposed morphosyntactically, but on the basis of the present data it remains unclear whether compounds are immediately decomposed on the semantic level. Studies that investigated compound comprehension by means of eye tracking also suggest a two-fold processing mechanism. Two of these studies argue that the whole compound form is processed in parallel to the processing of constituents (Hyönä, & Pollatsek, 1998; Pollatsek et al., 2000). This interpretation is in accordance with the assumption of a direct access route and a decompositional route. Inhoff and colleagues suggested that accessing constituent representations is followed by the computation of the compound meaning (Inhoff et al., 1996, 2000; Juhasz et al., 2003). The present results concur with these findings; compounds were found to be decomposed morphosyntactically and the LIN effect strongly suggests that compound constituents are integrated during the perception of the head constituent, i.e. at a late stage as proposed by Inhoff et al. for the visual modality. However, if the access of SFs is postponed until the head is processed the question arises as to how the SFs of constituents are located in the mental lexicon. The GF, i.e. the underspecified morphological representation is suggested to serve as an access code for nonhead constituents during the later perception of the head constituent (cf. Fig. 9.5).

9.3 Concluding remarks

The results of this thesis strongly suggest that a morphological representation is accessed for each and every compound constituent independently. In Experiments 1, 2a, and 2b it was shown that novel and low frequency compounds are decomposed morphosyntactically. The gender information of each constituent is made available during auditory comprehension. However, number is not specified for nonhead constituents by the presence or absence of linking elements, although the investigated linking elements are phonologically identical

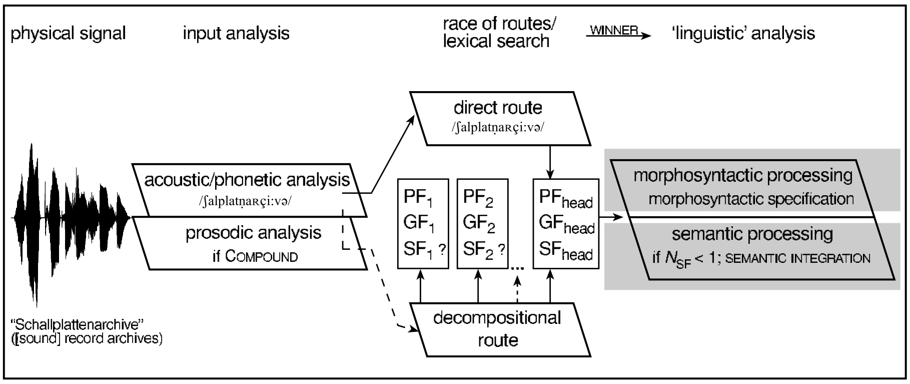

Figure 9.4: The model of auditory compound comprehension. The physical signal is analysed acoustically/phonetically and in parallel prosodically. The acoustic/phonetic analysis delivers the phoneme sequence whereas the prosodic analysis indicates morphological complexity (compounds). If prosodic cues detect a compound as opposed to single nouns the decompositional processing route is called up. The decompositional route extracts the compound constituents and works in parallel to the direct route which matches the complete phoneme sequence to lexical entries. When the head constituent is determined, variable morphosyntactic features are specified. The compound meaning is computed in parallel from the constituents if no lexical entry matched the whole phoneme sequence.

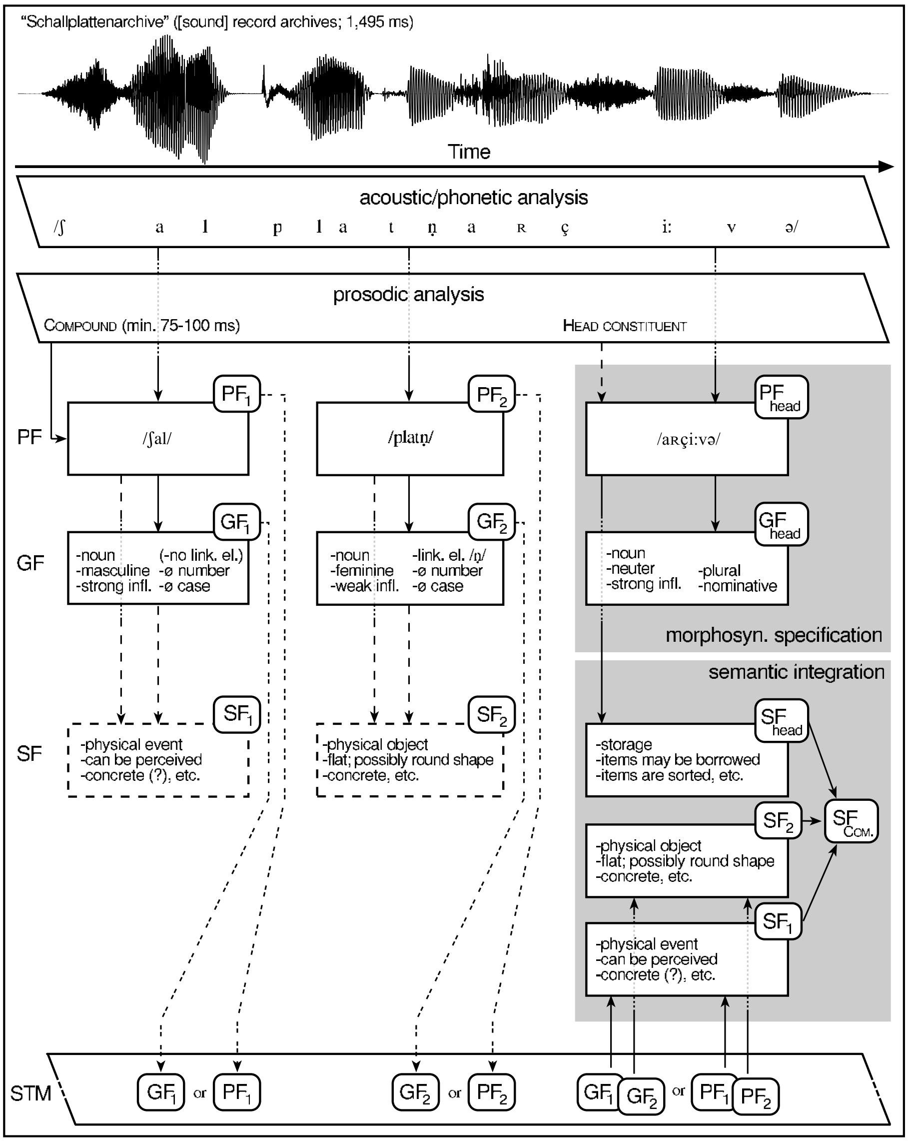

Figure 9.5: The decompositional route. Oblique boxes represent processes and rectangles depict representations. The sequence of boxes suggests the chronological order of constituent activation (from left to right). Arrows indicate information flow whereby, dashed lines represent yet unknown ways of semantic form activation. Double dashed lines suggest the storage of grammatical or phonological forms. For more details see text; STM-short term memory.

with plural morphemes (Exp. 3a), presumably for reasons of computational efficiency. This suggests that morphological representations of constituents (nouns) are stored in an underspecified form. They are suggested to contain only invariable morphosyntactic information (e.g. gender or inflectional class) but not variable information (e.g. number, case, or tense). The prosodic cues duration of initial constituents and pitch (contour) are diagnostic of morphological complexity, i.e. whether an upcoming word is a compound constituent or a single word (Exp. 3b;) as it was proposed earlier by Isel and colleagues (2003). The results of Experiment 3b suggest that the parser uses these prosodic cues to distinguish linking elements and plural morphemes. That is, linking elements are not used to morphosyntactically specify number in nonhead constituents in the same way as plural morphemes are used to specify number in single nouns. Fixed features are suggested to be part of the lexical entry and cannot be specified. They become available automatically when the lexical entry is accessed morphosyntactically.

Effects of lexical-semantic integration of constituents were observed during the perception of head constituents. These effects presuppose semantic decomposition at some point. They imply that the compound meaning is constructed at a late stage if compounds have no lexical entry, i.e. for novel and low frequency transparent compounds (cf. Fig. 9.4). Opaque compounds were found to be processed differently at that stage; their meaning must be accessed from the lexicon by matching the whole compound form onto lexical entries. Hence, the results support serial and cascading dual-route models which were promoted previously (Andrews, 1986; Baayen et al., 1997; Caramazza et al., 1988; Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994). These models assume that alternative processing mechanisms are employed only one after the other or partially overlapping in time.

Here, it is argued that the prosodic cues change the configuration of the parser. A decompositional route is activated if prosodic cues indicate a compound word (cf. Isel et al., 2003). Experiment 3b showed that variable morphosyntactic features are specified if prosodic cues indicate a single noun, but they are not specified for the same word as a nonhead compound constituents. Thus, it is concluded that single nouns and compounds are not processed by the same set of processing mechanisms.

The current results contradict the full-listing hypothesis (Butterworth, 1983; Bybee, 1995) and full-parsing models (Libben et al., 1999; Taft, & Forster, 1976). The full-listing approach predicts an additional lexical entry for compounds besides the entries for their constituents. Apart from the fact that such a theory cannot explain how novel compounds are processed, morphosyntactic decomposition was also found for existing compounds and even for opaque compounds that must have their own semantic entry (Exp. 2a & 2b). Therefore, the data are not compatible with the full-listing hypothesis. Full-parsing models propose that any compound is decomposed. However, the LIN effect shows that transparent compounds require an additional lexical-semantic integration that is not necessary for opaque compounds (Exp. 2a & 2b). This processing difference suggests that opaque compounds are processed by an alternative processing route and, thus, argues against full-parsing models.

The results are compatible with dual-route models. Such models postulate a decompositional route and a direct route to process compound words. Compounds that have no lexical entry are processed by decomposition. Morphosyntactic decomposition was found for novel compounds which cannot have a lexical entry (Exp. 1). Dual-route models also predict that lexicalised compounds are accessed by a direct route. Opaque compounds must have a lexical entry as opposed to low frequency transparent compounds. These transparent compounds involve a lexical-semantic integration of their constituents in order to yield the compound meaning. A LIN effect was observed for transparent compared with opaque compounds which reflects the constituent integration for transparent compounds (Exp. 2a & 2b). This LIN effects suggests a direct processing route in addition to the decompositional route. Hence, the results support dual-route models.

The envisaged processing of acoustically presented compounds is depicted in Fig. 9.4. The default configuration of the parser is the direct route. Along this route, the acoustic signal is analysed phonetically/phonologically and the phonological form (PF) of the whole word is then used to retrieve the corresponding entry from the lexicon. The processing of word class information precedes the processing of morphosyntactic and semantic information (cf. Friederici, 2002). Morphosyntactic and semantic information is processed in parallel and independently; the morphosyntactic processing also entails the specification of variable morphosyntactic features besides a checking of agreement relations.

The prosody of the perceived words is evaluated in parallel to the acoustic/phonetic analysis as proposed earlier (Isel et al., 2003). If prosodic cues indicate a compound the configuration of the parser is changed and an additional decomposition route is called up. By decomposition the PF of each constituent is recovered and the respective morphological units are accessed from the mental lexicon (see Fig. 9.5). The present thesis suggests that these morphological units are underspecified, i.e. variable morphosyntactic features are not specified for nonhead constituents. Whether the semantic forms (SFs) of constituents are also accessed immediately is not yet clear. The SFs are suggested to be accessed for novel compounds and/or if initial constituents are semantically ambiguous (Wagner, 2003). For low frequency compounds, however, the access of the respective SFs seems to be postponed (Isel et al., 2003). The LIN effects as found in the present thesis, suggest that the lexical-semantic integration of constituents begins during the head constituent, i.e. at a late stage of compound processing. If the SFs of constituents are accessed later on (during the perception of the head constituent), either the PF or the morphological representation may serve as an access code. In that case these access codes need to be stored in short-term memory. A delayed access of the nonhead SFs may reduce storage load for several hundred milliseconds if an informationally smaller access code is sufficient for later retrieval, e.g. the underspecified morphological unit. When the head constituent is encountered the SFs of all constituents are accessed (at the latest), and the compound meaning is constructed as suggested by the LIN effects in Experiments 1 through 2b. This construction of a unified compound meaning has to respect the order of constituents and (im)possible semantic relations among them. In parallel and independently of the meaning construction, the morphological representation of the head constituent is fully specified in order to permit the appropriate binding of the compound into a syntactic structure. In order to identify the head constituent it is apparently not necessary to wait for the offset of the compound. Again, prosodic cues may mark a constituent as the head, e.g. by a falling pitch contour (at least in single word presentation) and possibly by prominence patterns (see Wiese, 1996, pp. 296 for a description of regular stress patterns in German compounds).

The direct and the decompositional route run in parallel and are in direct competition with one another (race model). The model can be described as cascading because the decompositional route is only employed for compound words, i.e. after detecting a compound. It is also described as a race model; as soon as one route delivers a syntactic word the other route is discarded unless an integration problem occurs regarding the syntactic structure or propositional content. Opaque compounds are processed successfully by the direct route because the constituent representations are not linked to the opaque compound meaning and, therefore, the constituents representations cannot activate the compound entry. Novel and low frequency compounds are processed successfully by the decompositional route because these compounds have no entry in the mental lexicon. For high-frequency compounds the speed of the two processing routes is crucial in determining which route will win the race, i.e. achieve lexical access.

Chapter 10

Summary and perspectives

The present Ph.D. thesis investigated morphosyntactic and lexical-semantic aspects of German compound comprehension. Previous studies, on one hand, provide inconclusive evidence for semantic decomposition of nominal compounds during acoustic presentation (Isel et al., 2003; Pratarelli, 1995; Wagner, 2003). On the other hand, morphological effects of decomposition have only been investigated in the visual modality which cannot be generalised to the auditory modality (Andrews, 1986; Sandra, 1990; Zwitserlood, 1994). The purpose of the present experiments was to answer the question of whether and how compound constituents are accessed from the mental lexicon during auditory comprehension, i.e. whether or not compounds are decomposed.

Experiment 1 investigated whether gender information of constituent nouns is accessed by manipulating the gender agreement between a definite determiner on one hand, and initial and head constituents of novel compounds on the other. Previous experiments showed that the left-anterior negativity (LAN) is a reliable indicator of the detection of gender violations (Deutsch, & Bentin, 2001; Gunter et al., 2000), and for both the initial and the head constituent of the three-constituent compounds a LAN was observed. The results show that gender of syntactically irrelevant (initial) and relevant (head) constituents is accessed. Furthermore, the gender processing of both constituents in the compound is independent of the other. In addition, a post-hoc analysis suggested that lexical-semantic information of constituents is integrated during the perception of the head constituent. A more negative ERP was observed for semantically difficult compounds compared with easy compounds and the effect had an N400-like scalp distribution (termed lexical integration negativity (LIN) effect). That is, once the head constituent is identified the compound meaning is constructed from the meaning of the constituents.

Experiment 2a replicated the independent gender processing for initial and head constituents using low frequency two-constituent compounds. Again, initial and head constituents both elicited a LAN, which was independent in each constituent. **Experiment 2b** excluded the possibility that morphosyntactic decomposition was solely induced by the novelty of compounds. Experiments 2a and 2b investigated semantically transparent and opaque compounds which were processed equally with regard to morphosyntactic features. Although both transparent and opaque compounds are decomposed morphosyntactically, their semantic status (transparent vs. opaque) resulted in a processing difference during the head constituent. Transparent compounds consistently elicited a larger negativity than opaque compounds with a similar scalp distribution as found for the LIN effect in Experiment 1. The meaning of transparent but not of opaque compounds is semantically related to the meaning of their constituents. Therefore, the more negative ERP is interpreted to reflect the lexical-semantic integration of constituents in order to construct the meaning of transparent compounds which is not possible for opaque compounds.

Experiment 3a tested, in analogy to the preceding experiments, whether linking elements function as plural morphemes of initial constituents. The processing of incorrect irregular plural morphemes was shown to elicit an N400 effect (Clahsen, 1999; Weyerts et al., 1997). Although number incongruent head constituents elicited an N400 effect in Experiment 3a, no effect at all was seen for number incongruent initial constituents. (All compound constituents were irregular nouns.) That is, linking elements are not processed as plural morphemes of initial constituents during auditory comprehension. This is astonishing, especially as linking elements are phonologically identical with the respective plural morphemes. It requires the parser to have the information that the word in question is a nonhead compound constituent. As these constituents are syntactically irrelevant, number does not need to be specified.

Experiment 3b examined whether information about morphological complexity is carried by prosodic cues and, if so, whether this information is used by the parser. A professional, naïve speaker produced the same words twice, once as initial compound constituents and once as single nouns. Words with compound prosody differed from words with single noun prosody in duration and fundamental frequency. These stimuli were judged by subjects for the number agreement between the word and a preceding indefinite determiner. Number violations of words with single noun prosody elicited an N400 effect. In contrast, the same words with a compound prosody, did not elicit an ERP effect before 1,100 ms post onset, thus, replicating the null effect of Experiment 3a. That is, if a word is prosodically marked as a compound constituent, linking elements cannot establish a number incongruity with a preceding determiner; linking elements differ functionally from plural morphemes. A later ERP effect for compound constituents (1,100-1,700 ms) shows that linking elements can be accessed for explicit judgements.

It is argued that German compounds are prosodically marked. Prosodic cues trigger an additional decompositional processing route that competes with a direct access route. That is, the faster route discards the results of the alternative route (cf. Isel et al., 2003). The direct route matches the whole compound form (its phoneme sequence) onto lexical entries and exits the lexical search if successful. The decompositional route decomposes the compound into its constituents and accesses a morphological unit for each constituent. The present results suggest that these morphological units are underspecified, i.e. they contain only fixed morphosyntactic features (e.g. gender). Variable features (e.g. number) are only specified if the head constituent is identified, or after a word has been retrieved via the direct route. The unified compound meaning is constructed for low frequency, transparent compounds from the meaning of the constituents when the head is identified. Whether or not the meaning of nonhead constituents is accessed immediately upon perception is not yet clear. Previous studies are inconclusive and the present findings only suggest that the lexical-semantic integration of constituents, i.e. the construction of the compound meaning begins during the head constituent. However, if the semantic access of a nonhead constituent is postponed until the head is identified, an interim access code must be stored in short-term memory. The underspecified morphological unit provides an efficient access code because it is less storage demanding and the alternative rehearsal of the phonological form seems to be difficult due to the ongoing acoustic/phonetic stimulation.

10.1 Perspectives

Future research will have to investigate the function of linking elements, other functions of prosodic cues, and the neurological substrate of compound comprehension. To determine whether and how whole-compound representations are used in compound production is a far more distant goal (cf. Badecker, 2001; Zwitserlood, Bölte, & Dohmes, 2000, 2002).

Linking elements that are homophonous with plural morphemes, were shown not to function as plural morphemes within compounds. Another proposed function is to indicate a possessive relation between constituents, e.g. in ”Königstochter”, (king’s daughter; Fuhrhop, 1998, 2000). The function to mark case (genitive) may be tested by manipulating the proposed case agreement between a definite determiner and the initial constituent. Case violations were shown to elicit a LAN (Coulson et al., 1998). Focusing on the first constituent, one may compare the case agreement of *”des$_{genitive}$ Königs$_{genitive}$tochter” with a case violation such as *”der$_{nominative}$ Königs$_{genitive}$tochter”. If the linking element -s- subserves a genitive marking function a LAN is predicted for the case violation condition. Note that the examples are ungrammatical with regard to the head constituent. Thus the head constituents cannot be evaluated. In addition, the compounds have to be produced with a unequivocal compound prosody (KÖnigstochter); otherwise they might be understood as a correct genitive phrase ”[des] Königs Tochter” (königsTOCHter).

At present it is only assumed that prosodic cues indicate the appearance of head constituents. These cues may be available early on but in principle it is possible that the head constituent is identified by its offset. In order to test the hypothesis that prosodic cues are used to detect head constituents, number violations of two-constituent compounds can be tested. An experimental design is required which manipulates two factors for second constituents of three-constituent compounds, namely number agreement (congruent vs. incongruent) and prosody (nonhead vs. head). The number violations must be compared between compounds that are onset embedded in three-constituent compounds and compounds to which a third constituent is artificially spliced. For example, ”Lotsenboot” (pilot boat) is produced once as onset embedded in ”Lotsenbootkapitän” (pilot boat captain) and once as a two-constituent compound. Then ”Kapitän” is spliced onto the two-constituent compound and the number agreement between a determiner and the constituent ”-boot” is compared. If prosodic cues indicate the head constituents, an N400 effect should be found for the two-constituent compound prosody, i.e. for *”zwei$_{plural}$ Lotsenboot$_{singular/compound}$-kapitän$_{single\ noun}$” (two pilot boat captain; the critical word is underlined) compared with ”ein$_{singular}$ Lotsenboot$_{singular/compound}$-kapitän$_{single\ noun}$” (one pilot boat captain). No effect should be found if the same comparison is made for items with a three-constituent compound prosody, i.e. for *”zwei$_{plural}$ Lotsenboot$_{singular\ form}$-kapitän$_{compound}$” compared with ”ein$_{singular}$ Lotsenboot$_{singular\ form}$-kapitän$_{compound}$”. Of course, all compounds have to be spliced technically to avoid artefacts and plural forms have also to be investigated to avoid a confound of number agreement with the determiner form.

In order to investigate *when* compound constituents are accessed semantically I would propose an intra compound priming experiment. The semantic expectancy of particular compound constituents may be manipulated within three-constituent compounds. First, the cloze probability of the second constituent has to be varied (high vs. low), for instance, ”Blumentopf” (flower pot; second constituent (C2) high cloze probability) vs. ”Blumenfeld” (flower field; C2 low cloze probability). Second, the cloze probability of the third constituent has to be varied for both sorts of compounds, e.g. ”Blumentopferde” (flower pot soil; *C2 high*, *C3* *high*), "Blumentopfgröße" (flower pot size; *C2 high*, *C3 low*), "Blumenfelddünger" (flower field fertiliser; *C2 low*, *C3 high*), and "Blumenfeldwächter" (flower field guard; *C2 low*, *C3 low*). Previous and the present experiments show that the semantic information of compound constituents is available during the head constituent. Hence, a semantic priming effect for the last constituent is expected if the conditions *C3 high* and *C3 low* are compared, similar to the LIN effect found in the present thesis. If initial constituents are accessed immediately they should prime the second constituent, and in this case a similar effect is expected during the second constituents if the conditions *C2 high* and *C2 low* are compared. The comparison of *C2 high* and *C2 low* should not yield an effect if semantic constituent access is postponed until the head is identified. Since such an experiment involves a between item comparison the constituents should be matched at least in their frequency of occurrence and their number of syllables.

Nowadays, compounding is generally assumed to be a lexical process. However, previously it was assumed to be achieved through application of transformational rules, i.e. syntactic operations (Chomsky, 1965; Chomsky, & Halle, 1968), and it was suggested that novel compounds are interpreted postlexically (Coolen et al., 1991). Hence, one may ask the question whether compounds are processed in a manner similar to minimal phrases. If so, that is, if the same cognitive processes are involved in phrase structure processing and compound comprehension, the same neurological substrate should be involved. An experiment using functional magnetic resonance imaging may reveal which neurological substrate is specifically related to the processing of the internal compound structure. These neurological substrates may be evaluated in a comparison of frequency and length matched compounds and single words. One may expect regions in the left temporal lobe to be involved in compound comprehension if compounds are processed using phrase structure rules. The processing of sentence structure has been shown to involve the superior temporal gyrus, superior temporal sulcus, and the middle temporal gyrus of the left hemisphere (Kaan, & Swaab, 2002; Friederici, 2002; Meyer, Friederici, & von Cramon, 2000). If the comprehension of compounds is a pure lexical process, more posterior cortical regions and possibly inferior frontal areas may be activated. The left middle temporal gyrus, angular gyrus, and left inferior frontal gyrus were found to be active in the processing of word semantics (Démonet et al., 1992; Price et al., 1997; Wise et al., 1991, cf. also Ullman, 2001).

Part III

Appendix

Appendix A

Descriptive data

A.1 Stimulus and behavioural data

Table A.1: *The durations of compounds and their constituents (*C1*–initial,* C2*–second, and* C3*–third) in ms (standard deviation in brackets). Except for Experiment 1 compounds consisted of two constituents.* C2 *in Experiment 3b was white noise with the intensity contour of an acceptable second constituent. Note:* EASY*–easy compounds,* DIFF*–difficult compounds,* TT*–transparent compounds,* OO*–opaque compounds,* SIN*–single noun condition, and* COM*–compound constituent condition.*

	length/ms			
	C1	C2	C3	total
Exp. 1	451 (107)	421 (108)	514 (125)	1,386 (188)
EASY	436 (113)	415 (110)	513 (126)	1,364 (196)
DIFF	466 (98)	427 (106)	515 (124)	1,408 (176)
Exp. 2a	500 (109)	554 (107)		1,054 (131)
TT	528 (113)	556 (118)		1,084 (145)
OO	472 (98)	553 (95)		1,025 (110)
Exp. 2b	513 (113)	538 (92)		1,051 (123)
TT	535 (126)	537 (106)		1,072 (142)
OO	491 (95)	538 (78)		1,029 (98)
Exp. 3a	559 (160)	582 (121)		1,142 (203)
Exp. 3b				
SIN	652 (149)	[584 (124)]		1,236 (201)
COM	505 (140)	[584 (124)]		1,090 (182)

Table A.2: *Summary of behavioural data. Given are reaction times (RT), accuracy (% correct), and difficulty ratings (on a 4–point scale; 1–easy, 4–difficult) for the grammaticality (*GRA*) and the semantic judgement tasks (*SEM*); the standard deviation is given in brackets. Both tasks are not strictly comparable across experiments. Note:* EASY*–easy compounds,* DIFF*–difficult compounds,* TT*–transparent compounds,* OO*–opaque compounds,* SIN*–single nound condition, and* COM*–compound constituent condition.*

	RTs/ms		**Accuracy/%**		**Rating**	
	GRA	SEM	GRA	SEM	GRA	SEM
Exp. 1	413 (168)	1,226 (302)	95 (2.5)	95 (6.8)	1.4 (0.56)	1.7 (0.65)
EASY	391 (156)	1,190 (297)	96 (2.6)	96 (6.3)		
DIFF	438 (182)	1,263 (327)	94 (3.3)	93 (10.7)		
Exp. 2a	618 (114)	845 (104)	96 (3.9)	91 (4.7)	1.5 (0.51)	2.1 (0.63)
TT	624 (112)	848 (104)	96 (3.8)	92 (4.6)		
OO	610 (119)	843 (105)	96 (4.2)	91 (5.1)		
Exp. 2b	695 (154)	981 (176)	91 (6.3)	83 (7.9)	1.4 (0.53)	2.2 (0.74)
TT	693 (147)	971 (180)	91 (6.7)	91 (9.7)		
OO	698 (168)	990 (178)	92 (8.4)	75 (9.7)		
Exp. 3a	604 (110)	865 (132)	95 (4.1)	95 (4.9)	1.4 (0.49)	2.0 (0.67)
Exp. 3b	557 (120)	770 (144)	95 (4.7)	94 (2.4)	1.2 (0.41)	2.1 (0.78)
SIN	535 (119)	763 (133)	97 (3.0)	95 (2.5)		
COM	579 (136)	776 (155)	93 (7.2)	92 (3.5)		

A.2 ERP data

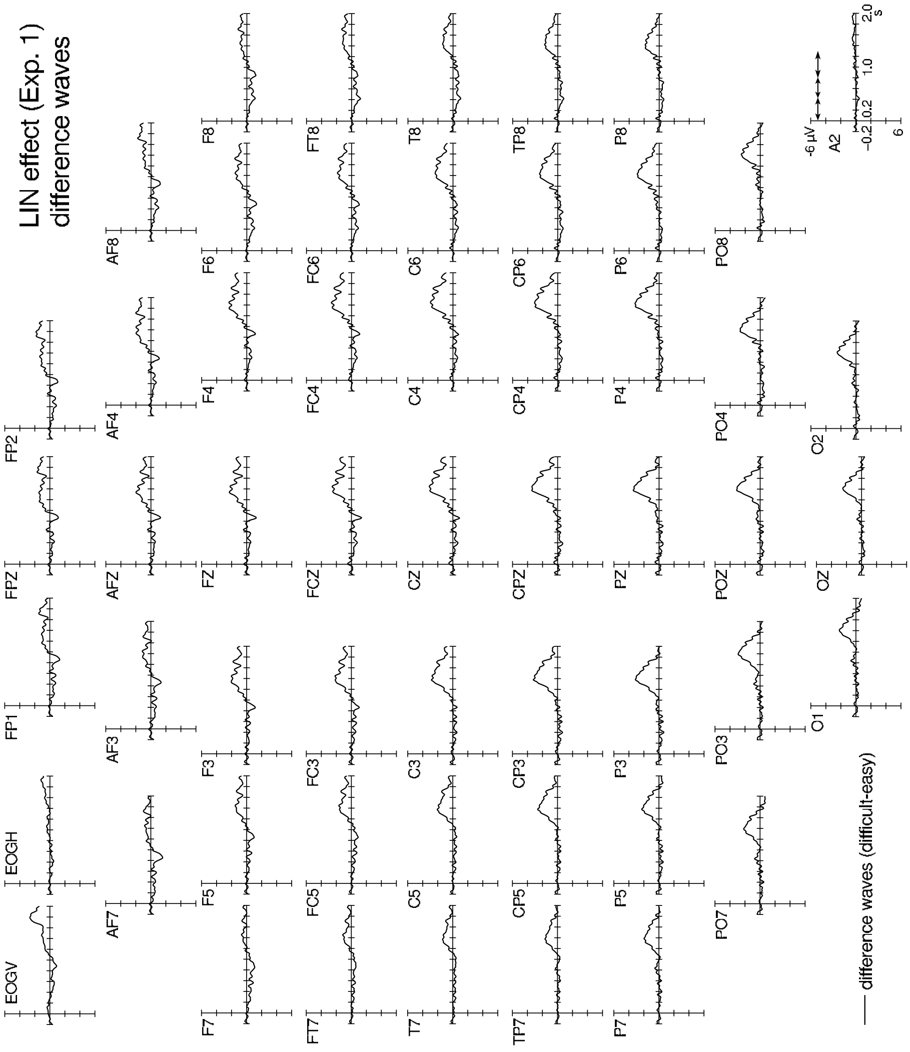

Figure A.1: Difference waves of the ERPs for difficult and easy compounds in Experiment 1 (difficult-easy). The effect reflects the semantic integration difficulty, i.e. the LIN effect.

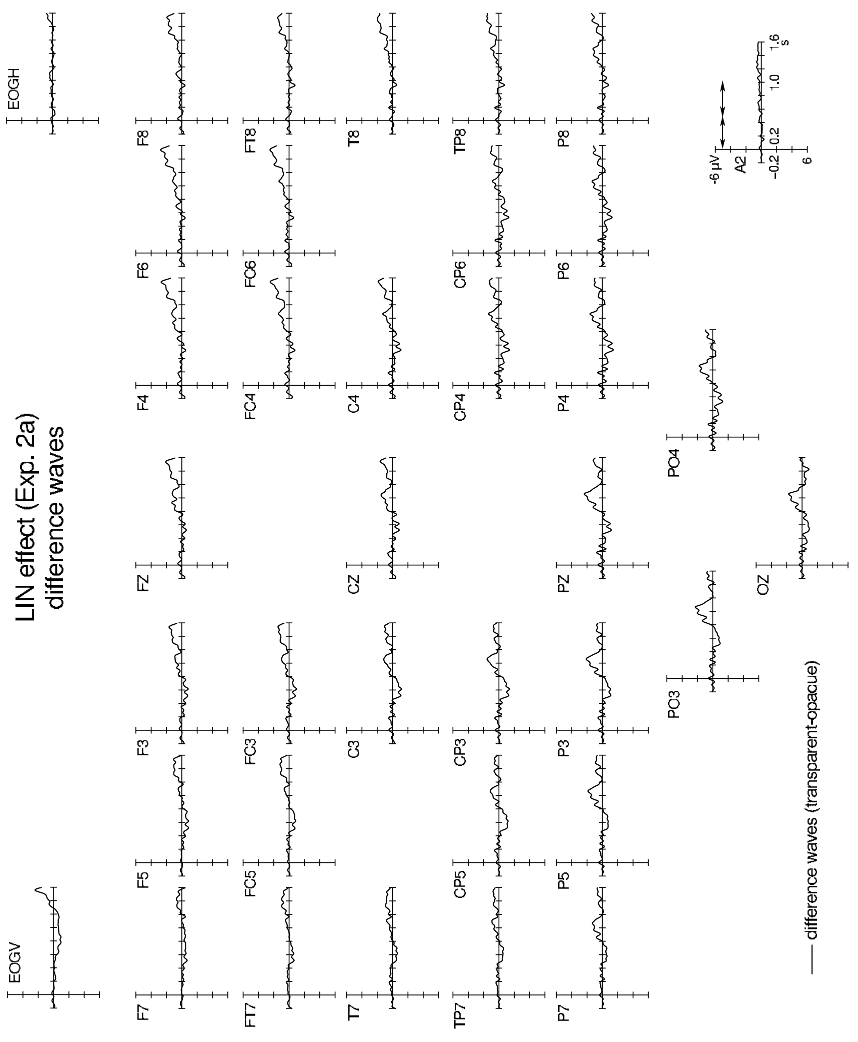

Figure A.2: Difference waves of the ERPs for transparent and opaque compounds in Experiment 2a (transparent-opaque). The effect reflects the lexical-semantic integration for transparent compared with opaque compounds.

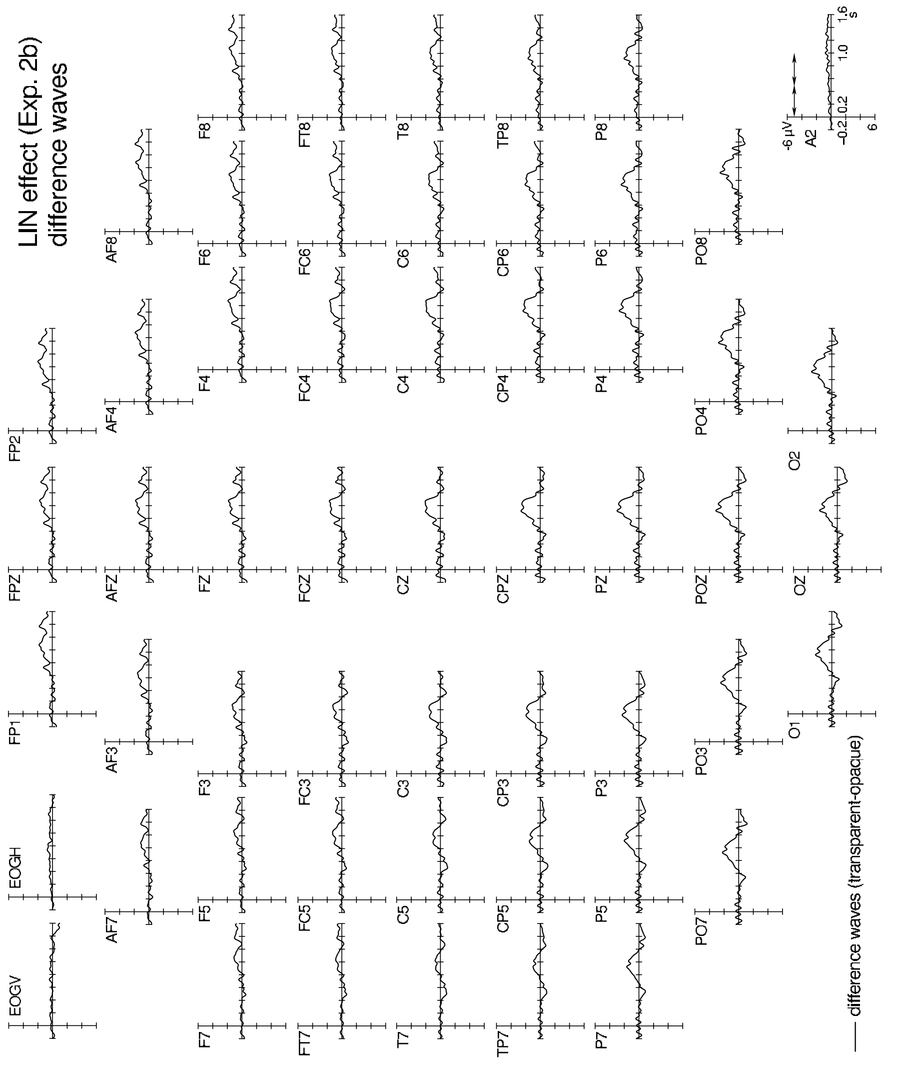

Figure A.3: Difference waves of the ERPs for transparent and opaque compounds in Experiment 2b (transparent-opaque). The effect reflects the lexical-semantic integration for transparent compared with opaque compounds.

Appendix B

Supplementary statistics

B.1 Experiment 2b

Table B.1: *Separate ANOVAs for single electrodes in Experiment 2b. The factor* gender agreement *of initial constituents was tested between 400 and 500 ms. Note:* ** p<*.01;* * p<*.05;* $^{+}$ p<*.10.*

time window 400-500 ms					
Electrode	$F(1,39)$	Electrode	$F(1,39)$	Electrode	$F(1,39)$
AF3	0.87	F5	2.00	OZ	1.21
AF4	0.18	F6	0.05	P3	3.57^{+}
AF7	0.06	F7	4.29^{*}	P4	2.67
AF8	0.59	F8	0.09	P5	2.87^{+}
AFZ	0.91	FC3	2.31	P6	1.25
C3	2.16	FC4	1.05	P7	1.79
C4	1.91	FC5	7.54^{**}	P8	1.48
C5	7.09^{*}	FC6	1.03	PO3	1.80
C6	2.92^{+}	FCZ	3.73^{+}	PO4	0.86
CP3	3.82^{+}	FP1	0.51	PO7	1.52
CP4	1.50	FP2	0.01	PO8	2.33
CP5	4.63^{*}	FPZ	0.57	POZ	1.18
CP6	1.81	FT7	7.68^{**}	PZ	1.52
CPZ	2.24	FT8	0.66	T7	6.42^{*}
CZ	4.10^{*}	FZ	2.99^{+}	T8	2.89^{+}
F3	1.40	O1	1.40	TP7	5.97^{*}
F4	0.53	O2	0.58	TP8	2.21

B.2 Experiment 3a

Table B.2: *Results of ANOVAs with the factor* number agreement *of initial constituents. Successive 50 ms time windows were tested between 200 and 600 ms. Listed are the* F*(1,23) values for each electrode and each time epoch. Note: all* p*>.10.*

Electrode	**time window/ms**							
	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600
AF3	0.04	0.05	0.00	0.40	0.01	0.30	0.67	0.00
AF4	0.03	0.15	0.00	0.01	0.07	0.01	0.63	0.08
AF7	0.00	0.06	0.05	1.13	0.44	1.01	0.05	0.43
AF8	0.15	0.19	0.02	0.11	0.08	0.00	1.06	0.01
AFZ	0.07	0.04	0.04	0.17	0.01	0.73	0.81	0.00
C3	0.09	0.00	0.10	0.04	0.00	0.17	0.50	0.14
C4	0.00	0.03	0.16	0.03	0.01	0.22	1.03	0.00
C5	0.07	0.04	0.06	0.10	0.02	0.20	0.60	0.06
C6	0.00	0.00	0.16	0.01	0.01	0.31	1.02	0.02
CP3	0.34	0.13	0.58	0.18	0.07	0.00	0.90	0.03
CP4	0.01	0.01	0.23	0.00	0.00	0.14	0.58	0.01
CP5	0.44	0.17	0.52	0.14	0.40	0.02	1.31	0.01
CP6	0.03	0.00	0.10	0.00	0.01	0.14	0.41	0.03
CPZ	0.00	0.06	0.02	0.02	0.05	0.62	0.28	0.28
CZ	0.08	0.00	0.09	0.05	0.04	0.76	0.39	0.08
F3	0.05	0.04	0.07	0.94	0.00	0.33	0.48	0.01
F4	0.62	0.83	0.23	1.09	0.30	1.29	0.13	1.05
F5	0.11	0.00	0.02	0.39	0.00	0.42	0.46	0.02
F6	0.00	0.04	0.01	0.07	0.00	0.14	0.93	0.18
F7	0.04	0.02	0.04	0.17	0.01	0.02	0.22	0.04
F8	0.12	0.26	0.10	0.51	0.08	0.98	0.01	1.42
FC3	0.07	0.00	0.16	0.02	0.06	0.01	1.70	0.02
FC4	0.08	0.03	0.08	0.03	0.00	0.53	1.31	0.08
FC5	0.48	0.37	0.47	0.01	0.20	0.07	2.76	0.58
FC6	0.02	0.05	0.04	0.09	0.00	0.27	1.20	0.17
FCZ	0.36	0.08	0.44	0.02	0.01	0.37	0.83	0.01
FP1	0.22	0.02	0.08	0.30	0.10	0.84	0.02	0.51
FP2	0.00	0.08	0.00	0.01	0.00	0.16	0.43	0.01
FPZ	0.00	0.15	0.00	0.43	0.04	0.51	0.20	0.38
FT7	0.60	0.32	0.40	0.03	0.02	0.03	0.71	0.00
FT8	0.13	0.19	0.00	0.43	0.13	0.37	0.12	0.33
FZ	0.06	0.03	0.08	0.13	0.02	0.40	0.81	0.00

Tab. B.2 cont.

Electrode	**time window/ms**							
	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600
O1	0.05	0.48	0.20	0.05	0.01	0.02	0.09	0.48
O2	0.02	0.48	0.16	0.04	0.00	0.05	0.95	0.00
OZ	0.00	0.55	0.39	0.27	0.04	0.31	0.72	0.03
P3	0.27	0.46	1.59	0.93	0.53	0.33	2.05	0.07
P4	0.01	0.24	0.49	0.34	0.05	0.24	1.25	0.11
P5	0.23	1.06	1.77	1.31	0.66	0.51	1.75	0.05
P6	0.00	0.05	0.31	0.06	0.00	0.16	1.16	0.31
P7	0.07	0.90	1.70	1.15	0.31	0.30	0.37	0.01
P8	0.02	0.04	0.05	0.00	0.04	0.01	1.02	0.09
PO3	0.01	0.67	0.86	0.48	0.07	0.15	0.25	0.08
PO4	0.01	0.30	0.04	0.04	0.12	0.02	0.48	0.00
PO7	0.02	0.81	0.98	0.78	0.42	0.47	1.07	0.00
PO8	0.03	0.22	0.03	0.06	0.43	0.11	0.25	0.09
POZ	0.08	0.01	0.05	0.00	0.32	0.18	0.08	0.16
PZ	0.00	0.01	0.08	0.00	0.03	0.38	0.36	0.13
T7	1.49	0.72	0.92	0.62	0.54	0.28	1.41	0.63
T8	0.07	0.25	0.03	0.16	0.05	0.25	0.24	0.01
TP7	0.12	0.18	0.18	0.01	0.14	0.18	0.14	0.09
TP8	0.08	0.02	0.33	0.01	0.02	0.00	1.22	0.41

B.3 Experiment 3b

B.3.1 Pitch statistics

Table B.3: T-*tests for pitch differences between single nouns (*SIN*) and compound constituents (*COM*) for successive 25 ms time windows (time slots). Any word is included in both prosodic conditions. Pitch values are in* Hz, p-*values are two-tailed. See also Fig. 8.5*

time slots	pitch–SIN (25 ms)	pitch–COM (25 ms)	*t*-value	*df*	*p*-value
1	250	249	-0.45	78	.66
2	244	245	0.46	96	.65
3	243	246	1.88	99	.06
4	247	251	2.51	123	**.01**
5	251	256	3.16	132	<**.01**
6	253	258	2.74	135	<**.01**
7	253	258	2.27	135	**.03**
8	253	258	2.44	126	**.02**
9	251	260	4.25	116	<**.01**
10	249	261	5.30	114	<**.01**
11	247	260	5.94	117	<**.01**
12	244	261	7.04	108	<**.01**
13	243	262	7.56	106	<**.01**
14	239	259	7.50	102	<**.01**
15	233	257	9.53	90	<**.01**
16	234	258	7.57	78	<**.01**
17	238	258	4.47	73	<**.01**
18	232	254	6.16	62	<**.01**
19	232	257	6.92	50	<**.01**
20	232	261	8.91	46	<**.01**
21	232	261	7.78	42	<**.01**
22	232	263	7.51	36	<**.01**
23	231	264	7.29	34	<**.01**
24	227	264	8.09	31	<**.01**

Table B.4: T-*tests for pitch differences between single nouns (*SIN*) and compound constituents (*COM*) for successive, equivalent time windows. Single nouns and compound constituents were segregated into the same number of time slots (*SIN *32.5 ms &* COM *25 ms). Pitch values are in* Hz, p-*values are two-tailed. See also Fig. 8.6*

time slots	pitch–SIN (32.5 ms)	pitch–COM (25 ms)	*t*-value	*df*	*p*-value
1	250	252	.64	43	.53
2	243	248	1.61	56	.11
3	248	248	-0.10	78	.92
4	253	253	-0.03	107	.98
5	252	255	1.23	117	.22
6	252	258	2.22	120	**.03**
7	248	257	3.04	119	<**.01**
8	245	258	4.01	102	<**.001**
9	243	260	4.39	93	<**.001**
10	243	260	4.00	87	<**.001**
11	238	259	5.38	96	<**.001**
12	230	260	9.39	91	<**.001**
13	225	262	10.71	80	<**.001**
14	224	260	7.17	69	<**.001**
15	213	262	11.98	59	<**.001**
16	212	261	10.58	44	<**.001**
17	214	258	9.70	44	<**.001**
18	208	251	7.04	38	<**.001**

B.3.2 ERP statistics

Table B.5: *Separate ANOVAs for single electrodes. The factor* number agreement *was tested for single nouns in successive 50 ms time windows between 200 and 600 ms. Listed are the* F*(1,19) values for each electrode and each time epoch. Note:* * p<*.05;* $^+$ p<*.10.*

Electrode	**time window/ms**							
	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600
AF3	2.78	0.04	0.09	0.35	0.22	2.05	0.10	2.71
AF4	0.45	1.49	1.52	0.06	0.00	1.38	0.03	0.86
AF7	1.55	0.49	0.34	1.19	0.56	1.48	0.01	1.25
AF8	1.52	0.42	1.20	0.05	0.62	0.01	0.89	0.00
AFZ	1.94	0.01	0.41	0.19	0.08	0.81	0.20	0.91
C3	0.65	0.11	0.02	0.07	0.11	2.46	0.39	2.72
C4	0.02	0.18	0.85	0.40	0.17	0.00	0.05	0.06
C5	1.27	0.27	0.37	0.05	0.04	0.75	0.19	2.17
C6	0.02	1.20	1.23	0.54	0.42	0.35	0.00	0.10
CP3	1.50	0.70	0.17	0.00	0.43	1.76	1.00	2.61
CP4	0.06	0.02	0.61	1.49	0.47	0.85	0.01	0.21
CP5	2.43	0.99	0.32	0.07	0.43	0.36	0.39	2.12
CP6	0.02	0.01	0.73	1.94	1.52	1.17	0.03	0.34
CPZ	0.41	0.11	0.20	0.00	0.16	0.57	0.44	0.36
CZ	0.11	0.04	0.31	0.25	0.01	2.66	0.52	1.26
F3	3.15$^+$	0.55	0.52	0.00	0.18	0.77	0.18	1.46
F4	1.88	0.00	0.04	0.19	0.68	0.01	0.60	0.11
F5	4.28$^+$	0.61	1.30	0.18	0.00	1.15	0.23	2.44
F6	1.41	0.01	0.06	0.26	0.64	0.00	0.67	0.01
F7	4.45*	0.55	1.78	0.15	0.01	0.00	0.95	0.21
F8	0.12	1.13	0.89	0.02	0.15	0.37	0.05	0.05
FC3	1.16	0.08	0.10	0.08	0.01	2.57	0.17	3.74$^+$
FC4	0.15	0.50	0.57	0.02	0.18	0.19	0.00	0.37
FC5	2.78	0.86	0.96	0.09	0.00	0.81	0.00	2.25
FC6	0.17	1.19	0.54	0.02	0.11	0.14	0.01	0.14
FCZ	0.41	0.20	0.40	0.59	0.01	4.65*	0.35	3.80$^+$
FP1	0.56	0.92	1.54	0.84	0.15	0.66	0.04	0.82
FP2	0.50	1.54	3.09$^+$	0.51	0.00	0.51	0.38	0.27
FPZ	2.04	0.42	1.16	0.34	0.01	0.44	0.33	0.33
FT7	2.42	1.33	3.34$^+$	0.05	0.00	0.01	0.59	0.31
FT8	0.03	1.93	1.56	0.24	0.44	0.04	0.02	0.18
FZ	1.47	0.01	0.17	0.14	0.06	1.80	0.00	1.86

Tab. B.5 cont.

Electrode	**time window/ms**							
	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600
O1	1.07	0.10	0.25	0.19	0.61	0.28	2.26	0.31
O2	0.13	0.05	0.40	0.30	1.37	0.04	1.54	0.07
OZ	0.19	0.03	0.41	0.02	0.45	0.12	2.58	0.04
P3	2.08	0.82	0.32	0.53	2.31	0.17	0.74	0.94
P4	0.01	0.00	0.53	1.62	0.64	0.43	0.85	0.03
P5	0.44	0.33	0.14	0.04	0.98	0.72	2.58	3.33^{+}
P6	0.13	0.01	1.41	1.50	0.87	0.64	0.19	0.08
P7	0.13	0.03	0.19	0.00	0.57	1.04	2.51	1.39
P8	0.64	0.00	2.20	1.34	0.53	0.51	1.09	0.07
PO3	1.52	0.21	0.03	0.51	2.18	0.56	3.07^{+}	1.33
PO4	0.00	0.00	0.96	0.94	0.55	0.29	1.00	0.00
PO7	1.72	0.38	0.05	0.57	3.30^{+}	0.21	0.83	0.34
PO8	0.03	0.00	0.99	0.73	0.53	0.42	0.88	0.00
POZ	0.88	0.18	0.00	0.43	1.81	0.13	1.45	0.33
PZ	1.09	0.44	0.04	0.29	1.23	0.11	0.76	0.15
T7	0.32	0.00	0.26	0.85	0.65	1.11	0.42	3.16^{+}
T8	0.00	0.12	0.42	1.18	2.26	1.68	0.19	2.20
TP7	0.74	0.03	0.00	0.31	0.01	0.68	0.38	1.63
TP8	0.11	0.01	0.87	1.41	1.22	0.92	0.08	0.80

Table B.6: *Separate ANOVAs for single electrodes. The factor* number agreement *was tested between 600 and 900 ms for the compound constituent condition. Note:* $^{+}$ p<*.10.*

time window 600-900 ms					
Electrode	*F*(1,19)	Electrode	*F*(1,19)	Electrode	*F*(1,19)
AF3	1.21	F5	0.02	OZ	0.64
AF4	2.49	F6	2.42	P3	0.45
AF7	0.97	F7	2.53	P4	0.05
AF8	1.66	F8	3.54^{+}	P5	0.21
AFZ	0.26	FC3	0.01	P6	0.09
C3	0.01	FC4	0.06	P7	0.53
C4	0.02	FC5	0.11	P8	0.11
C5	0.10	FC6	0.34	PO3	0.34
C6	0.16	FCZ	0.03	PO4	0.08
CP3	0.14	FP1	1.28	PO7	0.15
CP4	0.00	FP2	1.48	PO8	0.03
CP5	0.24	FPZ	2.06	POZ	0.50
CP6	0.00	FT7	1.20	PZ	0.01
CPZ	0.08	FT8	0.02	T7	0.47
CZ	0.09	FZ	0.23	T8	0.50
F3	0.18	O1	0.47	TP7	0.26
F4	2.17	O2	0.00	TP8	0.01

Table B.7: *Separate ANOVAs for single electrodes. The factor* number agreement *was tested between 1,100 and 1,200 ms for the single noun condition (beginning slope). Note:* $^{+}$ p<*.10.*

time window 1,100-1,200 ms					
Electrode	*F*(1,19)	Electrode	*F*(1,19)	Electrode	*F*(1,19)
AF3	0.31	F5	1.16	OZ	2.65
AF4	0.13	F6	0.26	P3	2.37
AF7	0.42	F7	0.01	P4	2.64
AF8	0.18	F8	0.00	P5	0.79
AFZ	0.07	FC3	1.60	P6	1.89
C3	1.01	FC4	0.02	P7	0.78
C4	0.91	FC5	0.60	P8	0.94
C5	0.61	FC6	0.00	PO3	1.84
C6	0.44	FCZ	0.20	PO4	1.50
CP3	1.28	FP1	0.25	PO7	2.46
CP4	2.65	FP2	0.00	PO8	1.78
CP5	0.91	FPZ	0.09	POZ	2.51
CP6	2.30	FT7	0.12	PZ	3.95^{+}
CPZ	2.16	FT8	0.36	T7	0.17
CZ	0.49	FZ	0.03	T8	1.43
F3	0.66	O1	2.51	TP7	0.00
F4	0.02	O2	3.83^{+}	TP8	0.72

Table B.8: *Separate ANOVAs for single electrodes. The factor* number agreement *was tested between 1,200 and 1,700 ms for the single noun condition. Note:* $^{+}$ p<*.10.*

time window 1,200-1,700 ms					
Electrode	*F*(1,19)	Electrode	*F*(1,19)	Electrode	*F*(1,19)
AF3	0.10	F5	0.01	OZ	1.89
AF4	1.04	F6	0.76	P3	0.75
AF7	0.77	F7	0.61	P4	0.12
AF8	0.04	F8	1.24	P5	0.02
AFZ	0.01	FC3	0.06	P6	0.05
C3	0.13	FC4	2.66	P7	0.01
C4	1.51	FC5	0.54	P8	0.19
C5	1.01	FC6	3.90^{+}	PO3	1.16
C6	1.63	FCZ	3.22^{+}	PO4	0.80
CP3	0.02	FP1	0.12	PO7	2.14
CP4	0.00	FP2	0.37	PO8	1.06
CP5	0.04	FPZ	0.02	POZ	1.29
CP6	0.03	FT7	1.67	PZ	0.81
CPZ	0.03	FT8	0.91	T7	4.21^{+}
CZ	0.54	FZ	0.26	T8	0.48
F3	0.02	O1	1.41	TP7	1.57
F4	0.71	O2	2.77	TP8	0.86

Appendix C

Materials

C.1 Experiment 1

Novel compounds with three masculine constituents (M-M-M)

Stahlhakenpreis (steel hook price), Hundezüchterwitz (dog breeder joke), Hafenrandlotse (harbour edge pilot), Todesschusskandidat (death shot candidate), Lärmschutzwall (noise protection dam), Arbeitergesangsverein (worker canto club), Mörderromancharakter (murderer novel character), Teezuckeranteil (tea sugar share), Männervereinspräsident (men club president), Monatseinkaufsverbund (month purchase combine), Druckknaufverschluss (push knob latch), Wegezollantrag (way duty application), Schnabelwalangler (beak whale angler), Hobelspanofen (wood shaving kiln), Topfladenverkäufer (pot shop seller), Baupreisentwurf (construction price draft), Bärenführerschutz (bear guide protection), Wurmschlammhaufen (worm mud heap), Rocksaumfaden (skirt hem thread), Försterhuthaken (forester hat peg)

Novel compounds (masculine neuter masculine, M-N-M)

Fußgelenkbruch (foot joint fracture), Stromkabelschacht (current cable duct), Bauchfellschmerz (stomach fur [peritoneal] pain), Briefpapierstapel (letter paper pile), Schuhpaarriemen (shoe pair lace), Rhythmusgefügewechsel (rhythm structure change), Motorenbenzinvertrieb (engine fuel distribution), Ofenfeuerqualm (kiln fire smoke), Kastenhausbau (box house building), Kartonmaterialhersteller (cardboard material manufacturer), Keksrezeptbedarf (biscuit recipe demand), Fischskelettkarton (fish skeleton cardbox), Hammerklavierkalender (hammer piano calendar), Fleckfiebertod (stain fever death) Anglermehlwurm (angler flour worm), Waldmoosberg (wood moss mountain), Urwaldreptilfang (jungle reptile catch), Offiziersgefechtsstand (officer fight stand), Sängergehörmeister (singer hearing master), Tresorenwortverrat (safe word betrayal), Tischporzellanmaler (table china painter)

Novel compounds, M-M-N

Strandgrillfest (beach barbecue party), Dornenstrauchbeet (thorn shrub bed), Malerbetriebsauto (painter company car), Kampfhundegesetz (fight dog law), Lehrermonatsgefecht (teacher month fight), Planmordbuch (plan murder script), Pokalgastfinale (cup guest final), Sonntagsausflugsziel (Sunday trip destination), Rebellensprecherzitat (rebel spokesman quotation), Kaffeeanbaufeld (coffee cultivation field), Tagesschlusspalaver (day closing palaver), Käseexportland (cheese export country), Blitzangriffsverfahren (lightning attack [to blitz] procedure), Berichtsentwurfformat (report outline format), Menschenaffenhaus (human ape house), Muskelaufbaupräparat (muscle regenerative preparation), Besitzanspruchsrecht (possession claim right), Flugfuchsgehege (flight fox pen), Doktorfischessen (doctor fish meal), Kuchentellerporzellan (cake plate china)

Novel compounds, M-N-N

Kochfachgeschäft (cooking specialist shop), Schmutzwasserbecken (dirt water basin), Schutzgeldgebiet (protection money area), Schreckenserlebnistrauma (horror experience trauma), Strumpfbandmedaillon (stocking string medallion), Luxusregalbrett (luxury rack board), Fingerzeichensymbol (finger sign symbol), Heldenvolksdenkmal (hero ethnic memorial), Himmelslichtspiel (sky light play), Knotennetzmuster (knot net pattern), Frühlingsrätselfoto (spring riddle photo), Sommerprogrammkonzert (summer programme concert), Würfeleisgetränk (cube ice drink), Magneteisengitter (magnet iron grating), Kuriereierpaket (courier egg parcel), Quirlgehäusemetall (beater cabinet metal), Kranzgebindehaar (chaplet bundle hair), Namenssiegelkuvert (name seal envelope), Filtergewindegeschäft (filter winding shop) Spatzennestmaterial (sparrow nest material)

Novel compounds, N-N-N

Kabinettsgebäudedach (cabinet building roof), Lammaromagewürz (lamb flavour spice), Autodachfenster (car roof window), Seilradgetriebe (rope wheel gear), Häuserfestheft (house party book), Pferdequartierheu (horse accommodation hay), Insektenwunderjournal (insect miracle journal), Festkonzertkomitee (party concert committee), Kalbsfleischgefäß (calf meat container), Wattengebietsheim (mudflat area home), Schnitzelfettdepot (cutlet fat depot), Segeltuchfett (sail cloth grease), Granulatgerüstgestell (resin scaffold rack), Kasinopersonalgebäude (casino staff building), Rindsaugenpaar (cow eye pair), Wunderbadmodul (miracle bath module), Papiersegelgeld (paper sail money), Strohkostümregiment (straw costume regiment), Internatszimmeretikett ([boarding school] room label) Schweinebeinfleisch (pork leg meat)

Novel compounds, N-M-N

Konzertstreitgespräch (concert argument disputation), Radunfallprotokoll (bicycle accident protocol), Konzeptrahmenschild (concept frame label), Bluttestergebnis (blood test result), Kapitalprofitverbrechen (capital profit crime), Biergartengras (beer garden grass), Eisverwertersystem (ice utiliser system), Wortbestandslabor (word inventory laboratory), Schiffsmotorentalent (ship engine talent), Hemdenknopfgarn (shirt button thread), Militärmarschkommando (military march command), Rechtemarktmonopol (right market monopole), Bretterastloch (plank branch hole [knothole]), Gebetssaalgeflüster (prayer hall whisper), Gedichtekalenderangebot (poem calendar offer), Ferkelbratenaroma (piglet roast flavour), Haarrissstadium (hair crack stadium), Ritualteilnehmerzentrum (ritual participant centre), Gewächskübelkonzept (plant tub concept) Lichtschattenphänomen (light shadow phenomenon)

Novel compounds, N-N-M

Ruderbootfahrer (oar [row]boat driver), Gesetzbuchverlag (statue book publisher), Geldschicksalsschlag (money fate stroke), Mofaledersitz (moped leather seat), Sofakissenbezug (sofa pillow cover), Theaterprojektplan (theatre project plan), Wachsbildkleber (wax picture glue), Heeresgewehrparagraph (army rifle paragraph), Liederheftautor (song booklet author), Gehirngewebeforscher (brain tissue researcher), Wissenspensumsleser (knowledge pensum reader), Gerüstlagerwald (scaffold store wood), Regalsystemerfinder (rack system inventor), Talentplakatleim (talent poster glue), Projektbüroetat (project office budget), Institutsgeländeteich (institute area pond), Bankettmenüteller (banquet menu plate), Besteckritualmord (cutlery ritual murder), Opfergrabkranz (victim grave wreath)

Novel compounds, N-M-M

Ballettkurslehrer (ballet course teacher), Feuerschutzhelm (fire protection helmet), Telefonschrankzettel (telephone cabinet slip [of paper]), Papierkorbmarder (paper basket marten), Augenarztbesuch (eye specialist visit), Dachraumausbau (roof room extension), Videofilmabend (video film night), Finalenebelgeruch (final fog smell), Mopedspiegelhalter (moped mirror retainer), Zeltplatzzaun (tent area fence), Jahresplanertrag (year plan benefit), Benzintankbagger (fuel tank digger) Geschäftsabschlußtermin (business transaction deadline), Dorfkonsumchef (village shop boss), Instrumentenhebelgriff (instrument lever handle), Wasserdampfbehälter (water steam container), Kinderschlafraum (child sleep room), Wortbestandteil (word integral part), Paketbotenvertrag (parcel carrier contract), Schafshirtenhund (sheep shepherd dog), Goldpokalgewinner (gold cup winner)

C.2 Experiment 2a

Semantically transparent compounds with gender identical constituents

N-N Gleissignal (rail signal), Porzellanbecken (china basin), Schilfrohr (reed pipe [cane]), Steuerruder (steering-wheel rudder [helm]), Kükennest (chick nest), Feuerpotential (fire potential), Gummiband (rubber string), Farnkraut (fern herb), Idealbild (ideal image)

M-M Kastenwagen (coffer vehicular), Atlantikwall (Atlantic rampart), Oberlehrer (chief teacher), Schäferkarren (shepherd cart), Seesand (sea sand), Tankwagen (tank car), Bartwuchs (beard growth), Staubmantel (dust cloak), Hufschlag (hoof beat), Regentag (rain day), Sandhaufen (sand heap)

F-F Kontrollampe (control light), Luftdichte (air density), Stirnfalte (forehead wrinkle), Kunstkritik (art critique), Weltmarke (world mark), Luftflotte (air armada), Milchkanne (milk jug), Provinzstadt (province town), Existenzangst (existence angst), Ferienreise (holidays travel)

Semantically transparent compounds with gender diverging constituents

M-N Saftkonzentrat (juice concentrate), Likörglas (liquor glass), Abendmagazin (evening magazine), Pfirsichgesicht (peach face), Streikrecht (strike right), Reisfeld (rice field), Balkendiagramm (bar diagram), Pfeilgift (arrow poison), Transistorgerät (transistor device)

F-N Schwesterschiff (sister ship), Presseamt (press office), Karteiblatt (file sheet), Nadelholz (softwood), Paradestück (parade piece), Nachtgewand (night gown)

N-M Obstsaft (fruit juice), Klosterbruder (monastery brother), Wilddieb (wild thieve [poacher]), Opferwille (victim will)

F-M Bahnbrecher (trailblazer), Nussbaum (nut tree), Federstrich (feather stroke), Eckpfeiler (corner pillar), Waffelbruch (waffle break), Stadtdirektor (town director), Machthunger (power hunger)

N-F Teerpappe (tar paper), Glastür (glass door), Puderdose (powder box), Grasfläche (grass area), Nestwärme (nest warmness), Silbermünze (silver coin), Landschule (hedge-school), Fleischbrühe (beef-broth), Tuchfabrik (cloth mill), Tiergestalt (animal shape)

M-F Zanksucht (quarrel addiction [termagancy]), Rauchbombe (smoke bomb), Manteltasche (cloak pocket), Tonerde (clay earth), Kompassnadel (compass needle), Schlussrunde (end round), Senfsoße (mustard sauce), Bergkette (mountain), Kopfarbeit (mental work), Sternfahrt (star travel), Steinbank (stone bench), Ringstraße (ring street), Rasenfläche (meadow area), Ladenkasse (shop cashier)

Semantically opaque compounds with gender identical constituents

N-N Hühnerauge (chicken eye; corn), Herzstück (heart piece; core), Fettnäpfchen (fat bowl; to put one's foot in it), Eisbein (ice leg; pickled knuckle of pork), Meerschwein (sea pig; guinea pig)

M-M Schneebesen (snow broom; egg whisk), Sattelschlepper (saddle carrier; articulated lorry), Laufpass (run pass; quietus), Kohldampf (cabbage steam; hunger), Stuhlgang (chair aisle; defecation), Waldmeister (wood master; woodruff), Löwenzahn (lion tooth; dandelion), Bärlauch (bear leek; bear's garlic), Negerkuss (Negro kiss; chocolate marshmallow), Windbeutel (wind bag; cream puff), Himmelschlüssel (heaven key; cow-slip), Zaunkönig (fence king; wren), Kotflügel (dung wing; mudguard), Hasenfuß (rabbit foot; coward), Saftladen (juice shop; dump), Köhlerglaube (charburner believe; superstition), Donnerkeil (thunder wedge; kind of stone), Halsabschneider (throat cutter; cutthroat), Drahtesel (wire donkey; bicycle)

F-F Pusteblumen (breath flower; dandelion), Seifenoper (soap opera), Jungfernfahrt (spinster ride; maiden trip), Seifenkiste (soap box)

Semantically opaque compounds with gender diverging constituents

M-N Walross (whale steed; walrus), Schäferstündchen (shepherd hour; nap), Nagelbett (nail bed), Donnerwetter (thunder weather; blowup), Nilpferd (Nile horse; hippopotamus), Schlitzohr (slit ear; chiseller), Schlüsselbein (key leg; wishbone)

F-N Lampenfieber (lamp fever; stage-fright), Muffensausen (muffle sough; panic), Eichhörnchen (oak croissant; squirrel), Trommelfell (drum fur; ear-drum), Ammenmärchen (fairy tale; cock-and-bull story), Stillleben (calmness life; still life), Luftschloss (air castle; daydream), Mutterkorn (mother corn; ergot)

N-M Maulwurf (mouth chuck; mole), Dachstuhl (roof chair; truss), Goldregen (gold rain; laburnum), Ohrwurm (ear worm; catchy tune), Feldstecher (field picker; field glasses), Bildschirm (picture umbrella; screen), Haarspalter (hair splitter; pettifogger), Wasserhahn (water cockerel; water tap), Pferdeapfel (horse apple; horse dung), Strohwitwer (straw widower; grass widower)

F-M Spitzenreiter (pinnacle rider; front-runner), Ellenbogen (ell bow; elbow), Düsenjäger (nozzle hunter; jet fighter), Hexenschuss (witch shot; lumbago), Gassenhauer (lane tusk; popular song), Kunstgriff (art grasp; artifice), Flaschenzug (bottle train; block and tackle), Pustekuchen (breath cake; no way/no such luck), Seitensprung (side jump; side leap), Klammeraffe (peg monkey; spider monkey)

N-F Festplatte (party disc; hard disc), Schafgarbe (sheep sheaf; yarrow), Wasserhose (water trousers; waterspout), Maultaschen (mouth bag; Swabian ravioli), Hochburg (high castle; stronghold)

M-F Sommersprossen (summer step; freckle), Käseglocke (cheese bell; cheese cover), Standpauke (standing bass drum; telling-off), Schreckschraube (fright screw; virago), Nervensäge (nerve saw; to be a pain in the neck), Zuckertüte (sugar bag; a gift for kids at their first day at school), Gottesanbeterin (god adorer; mantis), Eselsbrücke (donkey bridge; memory hook), Kammscheibe (comb slice; steak from the neck), Wallfahrt (wall trip; pilgrimage), Flügelmutter (wing mother; butterfly nut), Wirbelsäule (swirl pillar; backbone)

C.3 Experiment 2b

Note that the stimuli used in Experiment 2b are a subset of the stimuli from Experiment 2a.

Semantically transparent compounds with gender identical constituents

Idealbild, Gummiband, Seesand, Schäferkarren, Regentag, Oberlehrer, Atlantikwall, Tankwagen, Bartwuchs, Hufschlag, Kastenwagen, Luftdichte, Existenzangst, Milchkanne, Luftflotte, Stirnfalte, Ferienreise

Semantically transparent compounds with gender diverging constituents

Schwesterschiff, Presseamt, Paradestück, Streikrecht, Likörglas, Klosterbruder, Opferwille, Nussbaum, Eckpfeiler, Federstrich, Stadtdirektor, Silbermünze, Glastür, Ladenkasse, Tonerde, Ringstraße, Rasenfläche, Manteltasche, Schlussrunde

Semantically opaque compounds with gender identical constituents

Hühnerauge, Saftladen, Schneebesen, Windbeutel, Zaunkönig, Stuhlgang, Waldmeister, Löwenzahn, Laufpass, Kohldampf, Kotflügel, Halsabschneider, Donnerkeil, Negerkuss, Jungfernfahrt, Pusteblumen

Semantically opaque compounds with gender diverging constituents

Walross, Schlitzohr, Schlüsselbein, Lampenfieber, Kanonenfutter, Luftschloss, Stillleben, Ammenmärchen, Kerbholz, Bildschirm, Maulwurf, Wasserhahn, Buchhalter, Ellenbogen, Spitzenreiter, Kunstgriff, Seitensprung, Wirbelsäule, Nervensäge, Standpauke

C.4 Experiment 3a

Note that the stimuli used in Experiment 3a are included in the stimulus set of Experiment 3b.

Compounds with both constituents in the singular form (S-S)

Tierversuch (animal experiment), Akkusativobjekt (accusative object), Altarsakrament (altar sacrament), Kursanstieg (rate rise), Rindvieh (cow cattle), Dienstgeheimnis (office secret), Kreistag (district day), Detektivroman (detective novel), Öldruck (oil pressure), Ritualmord (ritual murder), Kamelfell (camel fur), Abendkleid (evening dress), Anteilschein (share certificate), Gasherd (gas stove), Zeltmast (tent mast), Haarschnitt (hair cut), Honigwein (honey wine), Idealbild (ideal image), Preisschild (price tag), Fischgeschäft (fish shop), Netzgerät (net device), Gleisdreieck (rail triangle)

Compounds with singular-plural form constituents (S-P)

Bergkristalle (mountain crystals), Feldwege (field paths), Giftgase (poison gases), Zinstermine (interest deadlines), Mineralöle (mineral oils), Pfeilgifte (arrow poisons), Atomblitze (atom lightnings), Photoalben (photo albums), Gewinnanteile (benefit shares), Rehkitze (deer fawn), Systemfeinde (system enemies), Mondberge (moon hills), Brotlaibe (bread loafs), Paketdienste (parcel services), Schiffsmotoren (ship motors), Eidgenossen (oath companions), Knalleffekte (bang effects), Rohrnetze (pipe nets), Brettspiele (board games), Kniegelenke (knee joints), Kostümfeste (costume parties), Metallbleche (metal steelplate)

Compounds with P-S constituents

Motorengeräusch (engines sound), Eierlikör (eggs liqueur), Geschlechterstreit (sexes argument), Ohrenzeuge (ears witness), Seniorenkonvent (seniors convent), Senatorenzelt (senators tent), Mythenlexikon (myths lexicon), Themenbereich (topics domain), Pfauenauge (peacocks eye), Diktatorenabbild (dictators image), Direktorenkollektiv (directors collective), Tagedieb (days thieve), Interessengebiet (interests field), Augenlicht (eyes light), Gespensterauftritt (phantoms entry), Faktorenkatalog (factors catalogue), Professorenkollegium (professors college), Reaktorenkern (reactors core), Bilderalbum (pictures album), Traktorenventil (tractors valve), Wegegeld (paths money), Paragraphenkrieg (paragraphs war)

Compounds with P-P constituents

Liederabende (songs nights), Autorenrechte (authors rights), Insektenstiche (insects stings), Juwelenringe (jewels rings), Schmerzensschreie (pains cries), Konditorengeschäfte ([pastry cooks] companies), Kinderheime (children homes), Gespensterschiffe (ghosts ships), Staatenapparate (nations instruments), Schweineexporte (pigs exports), Geisterschiffe (spirits ships), Gedichtethemen (poems topics), Investorenwettbewerbe (investors contests), Hundejahre (dogs years), Mitgliederprotokolle (members protocols), Nervensysteme (nerves systems), Hemdenstoffe (shirts cloths), Pferdebisse (horses bites), Mysterienkulte (myths cults), Lichterphänomene (lights phenomena), Gladiatorenfilme (gladiators films), Doktorenvereine (doctors clubs)

C.5 Experiment 3b

The initial constituents of these compounds were produced either as single nouns or as compound constituents. Compound constituent were extracted from compounds which are presented here. Note that the second constituents were not presented to subjects.

Initial compound constituents in the singular form

Abendkleid (evening dress), Feldwege (field paths), Fischgericht (fish dish), Tischbein (table leg), Briefpapier (letter paper), Salatdressing (salad dressing), Taktgefühl (tact sense), Transistorradio (transistor radio), Festbericht (party report), Herbsttag (autumn day), Haarschnitt (hair cut), Öldruck (oil pressure), Tierversuch (animal experiment), Altarsakrament (altar sacrament), Dienstgeheimnis (office secret), Protestlied (protest song), Labortest (laboratory test), Lidstrich (lid line), Meerblick (sea view), Konzertzyklus (concert cycle), Videoclub (video club), Projektbeginn (project start), Zeltmast (tent mast), Detektivroman (detective novel), Honigwein (honey vine), Kreisabschnitt (circle section), Kursanstieg (rate rise), Knalleffekt (bang effect), Gleisdreieck (rail triangle), Idealbild (ideal image), Kamelfell (camel fur), Rindvieh (cow cattle), Transportgeld (transport money), Ballettstudio (ballet studio), Dialogstil (dialog style), Filmpreis (film award), Rekordwert (record value), Restgewinn (rest benefit), Zoobesuch (zoo visit), Gefängnistor (jail gate), Klavierkonzert (piano concert), Modellprojekt (model project), Problemfeld (problem field), Plakatdesign (poster design), Radioprogramm (radio programme), Pfeilgifte (arrow poison), Schuhpaar (shoe pair), Keksrezept (cookie recipe), Kreditinstitut (credit institute), Steingefäß (stone container), Preisschilder (price tags), Ritualmord (ritual murder), Systemfeinde (system enemies), Paketdienste (parcel services), Atomblitze (atom lightning), Textelemente (text elements), Mordmotive (murder motif), Druckformate (print formats), Zwergponys (dwarf pony), Gewinnpotential (benefit potential), Dokumenttypen (document types), Kinofreunde (cinema friends), Schafpelz (sheep fur), Phantomschmerzen (phantom pains), Revierbeamten (estuary officer), Originaltexte (original texts), Bergkristalle (mountain crystals), Eidgenossen (oath companion), Mondberge (moon hills), Zinstermine (interest deadline), Muskelrisse (muscle rupture), Metallbleche (metal steelplate), Mineralöle (mineral oils), Giftgase (poison gases), Hormonpräparate (hormone supplement), Brettspiele (board games), Netzgeräte (net devices), Romanautoren (novel authors), Teilaspekte (fraction aspects), Testkandidaten (test candidates), Stoffreste (cloth remainder), Zweigbetriebe (subsidiary business), Telefongespräche (telephone conversations), Regalgestell (rack frame), Rehkitze (deer fawn), Rohrnetze (pipe nets), Kniegelenke (knee joints), Kostümfeste (costume parties)

Initial compound constituents in the plural form

Motorengeräusch (engines sound), Lotsenboot (pilots boat), Pfauenauge (peacocks eye), Professorenkollegium (professors college), Traktorenventil (tractors valve), Tagegeld (days money), Senatorenzelt (senators tent), Produktevertrieb (products distribution), Geschlechterkonflikt (sexes conflict), Affenskelett (monkeys skeleton), Ahnenerbe (ancestors heir), Gespensterauftritt (phantoms entry), Aztekenreich (Aztecs realm), Felsenlabyrinth (crags maze), Gedankenexperiment (thoughts experiment), Heldenepos (heroes epic), Ohrenzeuge (ears witness), Diktatorenabbild (dictators copy), Eierlikör (eggs liquor), Falkennest (hawks nest), Reaktorenkern (reactors core), Paragraphenkrieg (clauses war), Bärenpark (bears path), Botenjunge (messengers boy), Mythenlexikon (myths lexicon), Direktorenkollektiv (directors collective), Absolventenkolleg (alumni colleague), Hirtenbrief (shepherds letter), Indizienbeweis (signs proof), Bilderalbum (pictures album), Augenlicht (eyes-sight), Spieleangebot (games offer), Juristenberuf (lawyers occupation), Themenbereich (topics area), Schützenkönig (marksmen kings), Untertanengeist (subjects spirit), Zeugeneid (witnesses testimony), Invalidendom (invalids cathedral), Kundenkreis (customers circle), Matrosenlehrling (sailors apprentice), Narrenstreich (fools coup), Interessengebiet (interests area), Dramenfragment (dramas fragment), Kleiderdepot (dresses repository), Diamantencolliers (diamonds colliers), Autorenrechte (authors rights), Geisterschiffe (spirits ships), Hundejahre (dogs years), Konditorengeschäfte ([pastry cooks] shops), Nervensysteme (nerves systems), Bauernbrote (farmers breads), Pferdebisse (horses bites), Schweineexporte (pigs exports), Mysterienkulte (myths cults), Kinderarme (children arms), Gesellenstücke (assistants pieces), Menschenkinder (people children), Namenverzeichnisse (names catalogue), Patengeschenke (godfathers gift), Sklavenquartiere (slaves accommodation), Hasenohren (rabbits ear), Insektenstiche (insects stings), Liederabende (songs nights), Hemdenstoffe (shirts cloth), Seniorentickets (seniors tickets), Investorenkonferenzen (investors conferences), Juwelenringe (jewels rings), Studentenjobs (students jobs), Partisanengefecht (partisans fight), Touristenbusse (tourists coaches), Löwenkäfige (lions cages), Nomadenhirten (nomads shepherds), Planetenmonde (planets moons), Riesenschritte (giants steps), Gedichtethemen (poems topics), Lichterphänomene (lights phenomena), Geräteteile (devices parts), Satellitenstaaten (satellites nations), Soldatenhelme (soldiers helmets), Herrensalons (men saloons), Elefantenbullen (elephants bulls), Agentenkrimis (agents [crime thrillers]), Faktorenkataloge (factors catalogues), Staatenapparate (nations apparatus’), Gladiatorenfilme (gladiators films), Doktorenvereine (doctors societies), Mitgliederprotokolle (members protocols), Virengene (viruses genes)

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Curriculum Vitae

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Morphology and Spoken Word Comprehension: Electrophysiological Investigations of Internal Compound Structure
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Paper The present work investigated morphosyntactic and lexical-semantic aspects of German compounds in auditory word comprehension. Previous studies were conducted in the visual modality or else concentrated exclusively on semantic aspects. The question of whether and how compound constituents are accessed from the mental lexicon during auditory comprehension was addressed in five experiments using the method of recording event-related potentials. In order to see whether compounds are decomposed, the availability of morphosyntactic gender information of initial and last constituents was determined whereby the last constituent determines all (morpho)syntactic features of a compound in German. In a next step, the processing of linking elements, which are often identical with plural morphemes, was explored. The relevant question here was whether or not initial constituents marked with a linking elements might be processed as plural forms. In addition, the comparison of easy vs. difficult to integrate novel compounds, and semantically transparent vs. opaque compounds provides evidence concerning the temporal dimension of lexical-semantic integration of compound constituents. The first experiment established the left-anterior negativity (LAN) as a reliable marker for the decomposition in novel compounds. A LAN was observed in response to initial and last constituents if they were gender incongruent. A second experiment replicated this effect for low-frequency transparent and opaque compounds, and a control experiment suggests that the effects are not due to the experimental set-up. While these gender effects suggest morphosyntactic decomposition, an N400 effect of number incongruity could be observed only for the last constituents. That is, linking elements do not function as plural morphemes. In a follow-up experiment the null effect in response to linking elements was shown to be due to prosodic cues that differentiate compounds from single nouns. The lexical-semantic integration of constituents is suggested to begin during the final constituent, which mostly determines the semantic category of the compound. Difficult and transparent compounds elicited a negativity with an N400-like scalp distribution in comparison to easy and opaque compounds, respectively. It is suggested that prosodic cues are used to initiate the morphosyntactic decomposition of compounds. However, morphosyntactic representations are not specified for number by linking elements, and the lexical-semantic integration begins during the last constituent.

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