On the Representation and Processing of Phonological Stem Variants of Complex Words

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Presented by
Natalia Bekemeier

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Faculty of Humanities
Department of Linguistics

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First referee: Prof. Dr. Carsten Eulitz
Second referee: Prof. Dr. Aditi Lahiri
Third referee: Prof. Dr. Martina Penke

In loving memory of

Nikolai Zhivolozhnov

(1955-2011)

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Abstract

In the present thesis we explored regular and irregular phonological stem variants with respect to their representation and processing. We analyzed (i) derivation involving regular stem alternations in English (trisyllabic shortening – TSS) and German (umlaut) and (ii) past tense formation of German strong verbs involving irregular stem alternation (ablaut). The first chapter provides a short discussion of morphological complexity, the existing models of perception and processing of complex words and of the ERP technique employed in the reported experiments. The hypotheses and objectives of the present thesis are also laid out in the first chapter. The second chapter introduces the methods used in the following experiments.

The third chapter investigates the representation and processing of regular stem allomorphy. We hypothesized that regular stem vowel alternations, such as umlaut and TSS, should be captured within a single underlying stem morpheme with a set of morphophonological and morphosyntactic rules defining its surface phonetic form. To test this hypothesis, we examined violation related brain responses triggered by allomorph misapplication, viz. **ser[i:]nity/*Starkung* (Related Derived), and purely phonological violations, viz. **ser[aɪ]nity/*Sturkung* (Unrelated Derived), and **seromity/*Stögung* (Nonce Complete), in a series of experiments with gradually modified experimental settings (lexical decision and memory task in word list or sentence context experiments). We argued that if regular stem allomorphs have a mental representation, the reparable pseudowords should elicit error-detection responses different from those evoked by irreparable pseudowords depending on the experimental task and design. The first two experiments explored the processing of English trisyllabic shortened deadjectival nouns (*serenity*) presented in isolation with a superimposed lexical decision task (Experiment 1) or a memory task (Experiment 2). Experiments 3-4 investigated the processing of German deverbal nouns derived from deadjectival umlauted verbs (*Stärkung*) in similar experimental settings. Throughout all word list experiments, reparable (RD) and irreparable (UD and NC) pseudowords elicited differential error-detection brain responses. RD but not UD or NC pseudowords were treated as items violating morphophonological rules. We considered this response pattern as supporting our hypothesis that regular stem allomorphs share a single underlying stem morpheme.

The sentence context experiments (5 & 6) that assessed the processing of deviant stimuli (RD &UD) in a biasing context showed that repair process could be triggered by the contextual effects independent of the violation type. We also report a pilot study (Experiment 7) conducted with low-proficiency L2 learners of German that investigated the acquisition of a morphosyntactic rule in the L2. We conclude the third chapter with a detailed discussion of the results of the first part of the thesis and put forth a highly speculative model of a unified mental lexicon entry for regular stem allomorphs.

The focus of the fourth chapter is the representation and processing of irregular stem allomorphs of German strong verbs. We hypothesized that irregular stem allomorphs of strong verbs should be represented separately within a unified lexical entry in an underspecified manner. Thus, past tense allomorphs and not the basic stems should be marked for tense. To investigate this topic, we compared normal processing of strong verbs with deviant processing of incorrectly inflected strong verbs: *geh-t/ging* (C) vs. *ging-t/ging-te* (EI) and *geh* (BaS irregular), in the present (Experiment 9) and past (Experiment 8) tense contexts. Additionally, we compared the strong verb conditions with the processing of correctly and incorrectly inflected weak verbs: *schenk-t/schenk-te* (C regular) vs. *schenk* (BaS regular). The BaS irregular (*geh*) condition, being a bare basic stem, systematically elicited a semantic conflict, as reflected in the N400 amplitude. We attributed this effect to the underspecification of the present tense/basic allomorph for the tense feature. Therefore, the results of the second part of the thesis provided evidence for the separate representation of irregular stem allomorphs of strong verbs within a hierarchical lexical entry based on the underspecification of morphological features. We conclude the chapter with the discussion of results of the second part of the thesis and put forth a tentative model of the mental representation of irregular stem allomorphs of strong verbs.

The fifth chapter provides the general discussion of the results in the framework of the existing models of perception and processing of complex words in line with the key questions presented in the first chapter. We also address the issues that could be relevant for future research.

Zusammenfassung

Die vorliegende Dissertation erforschte die Repräsentation und Verarbeitung regulärer und irregulärer phonologischer Stammvarianten. Wir analysieren die folgenden Phänomene: (i) Derivation, die reguläre Stammalternation involviert, in Englisch (trisyllabic shortening – TSS) und Deutsch (Umlaut) und (ii) die Generierung der Präteritum Formen der Deutschen starken Verben, die irreguläre Stammalternation (Ablaut) involviert. Das erste Kapitel liefert eine kurze Diskussion der morphologischen Komplexität, der Modelle zur Wahrnehmung und Verarbeitung komplexer Wörter, sowie eine Übersicht der EKP (Ereignis Korrelierte Potentiale) Technik, die wir in den Experimenten angewendet haben. Die Hypothesen und Ziele der Doktorarbeit sind im ersten Kapitel dargelegt. Das zweite Kapitel präsentiert die Methoden, die für alle vorliegenden Experimente relevant sind.

Im dritten Kapitel wird die Repräsentation und Verarbeitung der regulären Stammallomorphie untersucht. Wir stellen eine Hypothese auf, dass die regulären Stammalternationen, wie Umlaut und TSS, unter einem lexikalischen Eintrag im Mentalen Lexikon gespeichert werden sollen. Außerdem sollte dieser Eintrag auch eine Reihe morphophonologischer und morphosyntaktischer Regeln, die die phonetische Form des Stammes bedingen, beinhalten. Um unsere Hypothese zu testen haben wir die Hirnreaktionen auf den Fehlgebrauch der Allomorphe, z.B. **ser[i:]nity/*Starkung* (Related Derived), und auf rein phonologische Verletzungen, z.B. **ser[aɪ]nity/*Sturkung* (Unrelated Derived), und **seromity/*Stögung* (Nonce Complete), analysiert. Dies haben wir in einer Reihe von Experimenten mit graduell veränderten Experimentalbedingungen (lexikalische Entscheidungsaufgabe und Gedächtnisaufgabe in einer Wortlistenstudie oder in Satzkontext Experimenten) gemacht. Wir argumentierten, dass, sollten die regulären Stammallomorphe einen Eintrag teilen, würden sich die von reparierbaren Nichtwörtern (RD) evozierte Hirnreaktionen von denen unterschieden, die von irreparierbaren Nichtwörtern (UD und NC) evoziert wurden. Jedoch sollte dieses Reaktionsmuster vom experimentellen Design und von den Experimentalbedingungen abhängig sein. Die ersten zwei Experimente untersuchen die Verarbeitung der Englischen TSS Nomen (*serenity*), die einzeln präsentiert wurden, mit der lexikalischen Entscheidung (Experiment 1) oder mit einer Gedächtnisaufgabe (Experiment 2). Experimente 3-4 erforschen die Verarbeitung Deutscher Nomen, die von

Adjektiven mithilfe des Umlauts und des Suffixes {-ung} abgeleitet wurden (*Stärkung*), in ähnlichen experimentellen Bedingungen. In den Wortlistenexperimenten unterschied sich die Verarbeitung der reparablen Nichtwörter (RD) systematisch von der der irreparablen Nichtwörter (DU und NC). RD (aber nicht UD und NC) Nichtwörter wurden als Verletzung morphophonologischer Regeln behandelt. Dieses Reaktionsmuster wurde von uns als unsere Hypothese, dass reguläre Stammallomorphe einen Eintrag teilen sollten, unterstützend betrachtet.

Die Satzexperimente, die die Verarbeitung der devianten Stimuli (RD und UD) im Kontext untersuchten, haben gezeigt, dass beide Verletzungsarten durch kontextuelle Effekte reparierbar sind. Experiment 5 demonstriert die Ergebnisse der Deutschen Gruppe. Experiment 6 berichtet diese der Britischen Gruppe. Nach den Satzexperimenten präsentieren wir die Daten unserer Pilotstudie (Experiment 7), die wir mit den Deutschstudenten (B1 Niveau) durchgeführt haben. Das Ziel der Pilotstudie war die Untersuchung des Erwerbs einer morphosyntaktischen Regel in der Zweitsprache. Wir schließen das dritte Kapitel mit der Diskussion der Ergebnisse des ersten Teils der Dissertation. Darüber hinaus schlagen wir ein spekulatives Modell eines Einheitseintrages für die regulären Stammallomorphe vor.

Das vierte Kapitel ist auf der Repräsentation und Verarbeitung irregulärer Stammallomorphie der Deutschen starken Verben konzentriert. Wir stellen eine Hypothese auf, dass die irregulären Stammallomorphe starker Verben separate Repräsentationen in einem Eintrag haben, der auf dem Prinzip der Unterspezifikation organisiert ist. Demnach, sollte nur die Präteritum Form für Tempus markiert werden. Die Basisform wird somit in der morphologisch unterspezifizierten Form gespeichert. Wir erforschen dieses Thema, indem wir die Verarbeitung normal flektierter starker Verben mit der devianten Verarbeitung falsch flektierter starker Verben vergleichen: *geh-t/ging* (C) vs. *ging-t/ging-te* (EI) und *geh* (BaS irregular), im Präsent (Experiment 9) und Präteritum (Experiment 8). Zusätzlich vergleichen wir die normale und deviante Verarbeitung der starken Verben mit der Verarbeitung normal und falsch flektierter schwacher Verben: *schenk-t/schenk-te* (C regular) vs. *schenk* (BaS regular). Die BaS irregular (*geh*) Bedingung, die einen unflektierten Basisstamm darstellt, hat systematisch einen semantischen Konflikt, den die Amplitude der N400 Komponente reflektierte, evoziert. Wir führten diesen Effekt auf die Unterspezifikation der Basisstämme für Tempus Merkmal zurück. Die Ergebnisse des zweiten Teils der vorliegenden Dissertation haben deshalb unsere Hypothese unterstützt, dass die irregulären

Stammallomorphe starker Verben separate Repräsentationen in einem Eintrag haben, der auf dem Prinzip der Unterspezifikation organisiert ist. Wir beenden das Kapitel mit der Diskussion der Ergebnisse des zweiten Teils der Arbeit und schlagen ein Model zur Repräsentation der irregulären Stammallomorphie vor.

Das fünfte Kapitel bespricht die Ergebnisse beider Teile der Arbeit im Rahmen der Modelle zur Wahrnehmung und Verarbeitung komplexer Wörter. Diese Diskussion folgt den im ersten Kapitel dargelegten Arbeitsfragen. Darüber hinaus sprechen wir die für die zukünftige Arbeit relevanten Probleme an.

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Glossary

µV	Microvolt
Adj.	adjective
Adv.	Adverb
ANOVA	analysis of variance
BaS	bare stem condition
C	consonant (in Chapter 3)
C	correctly inflected verb condition (in Chapters 4-5)
dB	decibel
DP	determiner phrase
EEG	electroencephalography
EI	excessive inflection condition
ELAN	early left anterior negativity
EOG	electrooculogram
ERP	event-related potential
ERP	event-related potentials
fMRI	functional magnetic resonance imaging
Hz	Hertz
ISI	interstimulus interval
kHz	kilohertz
L1	first language
L2	second language
LAN	left anterior negativity
LPN	late posterior negativity
MEG	magnetoencephalography
MHG	Middle High German
MMN	mismatch negativity
msec	milliseconds
n.	noun
NC	nonce complete condition

OHG	Old High German
PDP	parallel-distributed processing
Pers.	person
PET	positron emission tomography
Pl.	plural
PMN	phonological mapping negativity
RD	related derived condition
RP	received pronunciation
Sg.	singular
SPS	syntactic positive shift
TSS	trisyllabic shortening
UD	unrelated derived condition
V	vowel
v.	verb
W	real word condition

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1 General Introduction

The word recognition process does not take a second, but still requires different amounts of time and effort depending on a word's structure. Consider these pairs of words: *dog*/*doggish*, *sane/sanity, dance/danced* and *catch*/*caught*. The relation between the words in the first to the third word pairs is semantically and morphologically transparent, whereas the relation between the words in the last word pair is arbitrary. The question is how the relation between a stem and a word form contributes to the word recognition process. If a word form is accessed directly, the word form and its base have separate lexical entries in the mental lexicon (Butterworth, 1983; Rumelhart, McClelland, & Group, 1986; Seidenberg & Gonnerman, 2000). This account implies a huge number of lexical entries comprising all possible inflectional and derivational word forms. Such a storage method is not really efficient, considering the cost of maintenance of the numerous low-frequent word forms, e.g. *beauty*/*beautify*. If a word form is accessed via its stem, the word form and its base are represented by a single underlying stem morpheme (W.D. Marslen-Wilson, Tyler, Waksler, & Older, 1994; Scharinger, Lahiri, & Eulitz, 2010). In this case the question is which types of stem variants/ allomorphs should share the lexical entry. The phonological structure of the stem allomorphs in the *dog*/*doggish* and *dance/danced* examples is basically identical, while the example *sane/sanity* involves a vowel alternation, the last example – *catch*/*caught* – demonstrates only a shared onset and no morphological overlap whatsoever. The examples *sane/sanity* and *catch*/*caught* represent the cases of regular and irregular stem allomorphy respectively. The representation of the regular and irregular stem allomorphy still remains an open question. The present thesis will try to provide an answer to this question.

The theoretical accounts of the representation of regular and irregular forms are considered in terms of morphology. The regularity of the phonological processes involved in the generation of morphological constructs is only considered in the domain of inflectional morphology. Dual-Mechanism models (Clahsen, 1999; W.D. Marslen-Wilson & Tyler, 1997, 1998, 2003; Pinker, 1999; Pinker & Ullman, 2002; Ullman, 2001a) suggest that only *regular inflectional* forms should share a lexical entry, while the rest should be memorized and stored separately. Some derivational cases, however, also employ regular stem allomorphy: the suffix {-*ish*} does not involve any stem alternations, whereas the suffixes {-*ic*} and {-*ity*} induce a regular stem vowel alternation. The question is how these regular stem allomorphy cases should be treated. The reports in the literature so far have only proposed to store all products of derivation separately. Considering examples as *dog*/*doggish*, *tone/tonic* vs. *author*/*authorize,* this storage proposal also seems to strain the maintenance cost. The *author*/*authorize* example demonstrates a word pair with an opaque semantic relation, as the meaning of *authorize* cannot be deduced from the combined meanings of its constituents. Therefore, each word in this word pair needs a separate lexical entry. The meaning of *doggish* or *tonic*, on the other hand, can be easily deduced from the combined meanings of the morpheme constituents. Thus, despite a huge amount of research on the structure of mental lexicon, the manner of representation of regular stem allomorphy still remains an open question.

The present dissertation focuses on the mental representation and processing of phonological stem variants of morphologically complex words. To investigate this topic, we chose two word formation processes that are generally considered to be irregular: derivation, involving regular stem allomorphy, and past tense formation of irregular verbs. The comparison of these processes will shed light onto the manner of representation of regular vs. irregular stem allomorphy, thereby clarifying the issue addressed in the previous paragraph. To track the processing stages with high temporal resolution, we will employ the Event-Related brain Potentials (ERP) technique. Should there be a difference in the processing stages, this would be indexed by topographically and/or functionally distinct brain responses.

The first part of the General Introduction provides a short discussion of morphological complexity, followed by an overview of the existing models of perception and processing of complex words. The second part addresses the ERP technique and the ERP components that can be used to study the retrieval and processing of complex words. The structure of the present thesis, the research questions and the hypotheses are discussed in the Outline section. Taking into account our objective to differentiate the representation of regular vs. irregular stem allomorphy, we dwell upon the possible ERP patterns supporting or falsifying our hypotheses in the end of this chapter.

1.1 Complex words

1.1.1 Morphological complexity

A morpheme is the smallest unit of a language that has its own meaning (Lieber, 2010). Complex words are made up of more than one morpheme. According to their ability to function as individual words, morphemes are classified into *free* and *bound* morphemes. Free morphemes, also known as *stems* (stem morphemes), are simple or simplex words, such as *dog* and *tone*. Bound morphemes cannot function as words and thus have to be attached to a stem. For example, the English morpheme {-s} contributes the meaning of plurality: *dog* (sg.) + {-*s*} = *dogs* (pl.). With regard to the present investigation, the object of study is a stem morpheme acting as a base in a complex word.

Complex words are built by means of three types of word formation: inflection, derivation and compounding. All of them are closely connected to the term *lexeme* described by Lieber (2010:5) “as a family of words that differ only in their grammatical endings or grammatical forms”. The singular and plural forms of a noun, different forms of a pronoun, and tense and aspect forms of verbs are “families” of the respective items or lexemes. According to this definition, *inflection* applies within a grammatical paradigm of a lexeme, generating word forms that can be used in various grammatical contexts. Thus, changing number, person, case, tense or inflection does not change the meaning of a word, nor its grammatical category. In accord with Dual-Mechanism models (Clahsen, 1999; W.D. Marslen-Wilson & Tyler, 1997, 1998, 2003; Pinker, 1999; Pinker & Ullman, 2002; Ullman, 2001a), the inflected words whose stem morpheme does not undergo a qualitative change during word formation should share a lexical entry. Some words, however, have to undergo qualitative changes within their inflectional paradigm. Thus, the past tense and past participle formation of German strong verbs involves the application of ablaut patterns: *gehen* (to go) – *ging* (went) – *gegangen* (gone). The ablaut patterns do not follow a single phonological rule. Furthermore, they are unpredictable and unproductive. The stem variants of German strong verbs cannot be regarded as regular and, therefore, should be stored separately.

In contrast to inflection, derivation and compounding participate in lexeme formation. Derivation employs affixation, i.e. attachment of prefixes or/and suffixes, to make up new words. A word’s category can be changed via attachment of a suffix, i.e. *divine* (adj.) + {-ity} = *divinity* (n.), or via zero derivation/ conversion, i.e. *to read* (v.) – *a read* (n.)[1]. A word's meaning can be changed by attachment of a prefix/suffix to the stem: *legal* (adj.) – *illegal* (negative adj.), *to read* (v.) – *to reread* (repeat v.), *mile* (n.) – *mileage* (containing, measured in n.). A number of affixes can change both the meaning and the category of a word, such as *a code* (n.) – *to decode* (v., to translate from n.), *able* (adj.) – to *enable* (v., to make adj.), *to breathe* (v.) – *breathable* (adj., able to v.). There are also cases where the meaning of a derived word cannot be obtained by combining the meaning of its morphemes: *depart* + {-ment} = *department* (n.). Such words are called "semantically opaque", compared to the semantically transparent words, of which the meaning is retrievable through the combined meanings of their components. Considering the fact that derivation generates new lexemes, the products of derivation should be stored separately. This point of view is supported by the advocates of both storage hypotheses, i.e. all words and word forms are listed separately (Butterworth, 1983; Rumelhart et al., 1986; Seidenberg & Gonnerman, 2000) and regular inflection forms share a lexical entry, while the rest is stored separately (Clahsen, 1999; W.D. Marslen-Wilson & Tyler, 1997, 1998, 2003; Pinker, 1999; Pinker & Ullman, 2002; Ullman, 2001a).

While derivation requires the basic word to undergo manipulations via conversion or attachment of affixes, compounding can form lexemes out of several words, therefore allowing for unlimited combinability options. Apart from the ability to combine different word classes to produce new lexemes, compounding may also create semantically transparent words, e.g. *a truck driver* (n.) – *a driver who drives trucks*, and semantically opaque words: *a tallboy* (n.) – *a high chest of drawers*. The products of this type of word formation are also regarded by the above-mentioned models as subject to separate mental representation.

The reported accounts of mental lexicon organization regard the products of derivation as *irregular*. This term, however, does not consider the regularity of the phonological, morphological and semantic structure involved in the derivational process. In contrast to the reported accounts, we are concerned with the regularity of phonological alternations involved in derivation. We are also interested in how irregular alternations employed in the grammatical paradigm are represented in the mental lexicon. If the regularity of a stem alternation is

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[1]Cases of conversion involving a phonological rule, such as umlaut in German (*kurz* (adj.) (short) – *kürz*{-en} (v.) (shorten)) or stress shift in English (*to conduct* [kən'dʌkt] (v.) – *conduct* ['kɔndʌkt] (n.)), will be discussed in the next section.

productive and predictable, it should be generalized into a morphophonological/ morphosyntactic rule for the sake of economy of the cognitive resources. This rule must be integrated into the lexical entry shared by the regular allomorphs of the same stem. If the stem alternations cannot be generalized into a single rule, such allomorphs should be represented separately.

1.1.2 Representation of complex words in the mental lexicon

The investigation of the mental representation of complex words is essential to the study of the mental lexicon structure. Simplex words, such as *dog* or *smart,* map directly onto their mental representations. But how should the following words be represented: e.g. *dogs* or *smarter*, or even more difficult – *a dirty dog* or *a smarty-pants*? The first ones have a clear-cut morphological and semantic structure stemming from the base morpheme, i.e. *dogs* means "more than one *dog*" and *smarter* means "a greater degree of *smart*". The last ones look like determiner phrases (DPs) due to the syntactic structure made up of a determiner (*a*), an adjective (*dirty*/*smarty*), and a noun (*dog*/*pants*). Yet here they are semantically opaque compound nouns. A *dirty dog* is a despicable or contemptible person, while a *smarty-pants* is a person who talks and behaves as if he knows everything. The discrepancy between the clear-cut DP structure and the actual nominal grammatical category of these lexemes, combined with their singular idiomatic meanings, diminishes the possibility for such compound nouns to be represented in the same manner as simplex or semantically transparent derived words.

The definition of morphological complexity is that a lexeme can be broken down into its constituent parts, such as a stem morpheme (or morphemes) and affixes. The words sharing a stem morpheme, such as *smart* and *smarter,* demonstrate a relationship between the form and the meaning, established by means of morphology. How this relationship is listed in the mental lexicon still remains an open question. There are three major approaches to the structure of the mental lexicon: (i) all known word forms are stored without decomposition; (ii) all complex words are stored in a decomposed form; (iii) some word forms are stored in a decomposed form, while the others are fully listed.

The existing models of perception and processing of complex words are generally divided into two major classes: the single-route and the dual-route models. The approaches (i) and (ii), mentioned above, can act as a basis for the single-route models, as they implicate a single storage method (fully listed or fully decomposed). Approach (iii) offers a morphological decomposition for some word forms, while the others have to be stored in a non-decomposed form. This dichotomy is the foundation of the dual-route models.

The prerequisite of the single-route models is that all words are recognized by means of the same spread activation association-based mechanism, regardless of the regularity of the inflectional form and/or the semantic transparency of the complex words. The advocates of the **Full Listing Hypothesis** (Butterworth, 1983) claim that all words and word forms are stored in the mental lexicon, and there is no morphological decomposition prior to the lexical access. Morphological information is not stored, and the lexical retrieval occurs due to the fast associative network containing orthographic and semantic relations between word forms. **Parallel-distributed processing** (PDP) models (Rumelhart & McClelland, 1986; Seidenberg & Gonnerman, 2000) assume that decomposition does take place before the lexical retrieval, but the relationship between morphemes does not influence further processing steps, i.e. regular (e.g. *play-played*) and irregular forms (e.g. *catch-caught*) are accessed in the same way by means of phonological and semantic associations.

Contrary to the Full Listing Hypothesis and the PDP, the single-route model by Taft and Forster (1975, 1976), known as the **Affix Stripping Hypothesis**, requires prelexical decomposition of all morphologically complex words, regardless of their frequency, inflection or derivation forms. According to this hypothesis, the detection of an affix in an affixed word helps to identify the stem morpheme. The basis of the early affix recognition and isolation mechanism would make a clear prediction. Since affixes are isolated early in the visual word recognition and are treated as separate units, early affix recognition would contribute considerably to the fluency of the lexical retrieval process. The model by Taft and Forster has been recently revised and tested by means of electrophysiological techniques, and found many followers (Frost, Deutsch, & Forster, 2000; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000; Lewis, Solomyak, & Marantz, 2011; W.D. Marslen-Wilson, Bozic, & Randall, 2008; Meunier & Longtin, 2007; Morris & Stockall, 2012; Smolka, Komlosi, & Rosler, 2009; Solomyak & Marantz, 2009; Stockall & Marantz, 2006).

The prerequisite of the dual-route models is that some words are accessed in a different way than others. According to the **Parallel Dual-Route** model by Schreuder and Baayen (1995), some words can be accessed directly as whole units if these are high-frequency words. If a word has a low frequency of occurrence, it is recognized via its constituent parts. The authors claim that lexical retrieval by means of morphological decomposition is slower than that by means of whole word entries in the lexicon, thus, it is resorted to only in case of novel or unknown words. **Dual-Mechanism models** (Pinker, 1999; Clahsen, 1999; Friederici et al, 1993; Marslen-Wilson & Tyler, 1997, 1998, 2003, Ullman, 2001, Pinker and Ullman, 2002) get away from the frequency effects on morphological decomposition, and posit that the mechanism of lexical access depends on the type of morphological compositions. Regular inflection forms are subject to morphological decomposition, and they undergo the full parsing procedure. Irregular inflection forms and derived words are, on the contrary, stored as full units, and therefore they are subject to full listing.

While inflectional morphology is treated in different ways by almost all models, there seems to be more homogeneity about derivational morphology, probably due to the fact that there is considerably less work done in this field than there is on inflection. According to the majority of the models, derived words should be treated as entities. Connectionist single-route models presuppose that there is a whole word entry for a derived word in the mental lexicon that gets activated (along with its predecessors, successors and semantic relatives) as soon as phonological/orthographic and semantic conditions are fulfilled. The dual-route models posit that a) there is a whole word entry, and b) if a word is a low-frequency word, it can be morphologically decomposed to obtain the meaning from the semantics of its constituent parts (at least, for semantically transparent words). The single-route model by Taft and Forster (1975), however, maintains that all complex words should be decomposed.

In this thesis, we adopt the point of view that all complex words are decomposed prelexically (Taft & Forster, 1975). Only after the decomposition into constituent morphemes, does it become possible to assess the processing and, by implication, the storage of the stem allomorphs. Taking into account the speed at which such processing proceeds, we needed to find a technique that could provide a millisecond precision in the information transfer. For this purpose, we decided to employ a neurophysiological technique that has a very good time resolution, viz. electroencephalography (EEG).

The investigation of the representation of complex words in the mental lexicon requires a high time precision in order to trace back the phonological and morphological processing involved in the retrieval of these words. The techniques that meet these requirements are EEG and MEG (magnetoencephalography). MEG is not only capable of tracking the online brain activity with a millisecond precision; it also provides an excellent topographic resolution. The drawback of this technique is that, whilst extremely precise in its temporal and topographic resolution, MEG requires considerable operating cost. EEG, on the other hand, is less costly and fairly low-maintenance which makes it more wide-spread and accessible than MEG. The following section provides a short survey of electroencephalography and the ERP technique, and discusses the ERP components that could be observed in the planned experiments.

1.2 Electroencephalography and Event-Related Potentials

Electroencephalography (EEG) is a non-invasive technique used to study the electrical activity of the brain. EEG plots the neural activity that is measured by electrodes attached to the scalp (Berger, 1929). The physical obstructions (the meninges, the skull, etc.) between the source of the current flow and an EEG electrode weaken and distort the electric field until it reaches the surface of the head. Therefore only the currents produced by large populations of vertically oriented pyramidal cells firing synchronously can be recorded by the EEG. Although the EEG delivers information about the online brain activity with a high time precision, it has its limitations. A spontaneous EEG recording represents a mixture of processes running simultaneously in numerous cortical regions as well as a lot of noise and artifacts, such as muscular and eye movements, and electrocardiogram. Therefore, a raw EEG recording provides very general information about the online brain activity such as information about the present state of a person, i.e. if the person is awake, sleepy, having a seizure, etc.

The activity related to higher order cognitive processes that are of interest for linguistic research is embedded within the general brain activity. In order to investigate a certain cognitive process, the neural responses to the stimulation (auditory, visual, tactile, etc.) associated with this cognitive process must be isolated. If every instance of the stimulation (an event) is encoded and time-locked, it is possible to average all of them into the average waveform of the whole sample reducing the noise and singling out the brain activity associated with this particular type of event. Thus, the neural responses related to specific events are called *event-related potentials* (ERP) (Luck, 2005).

The classification and, therefore, labeling of the ERP components is based on four characteristics with which an averaged waveform can be described: topography (the surface distribution across the scalp), the amplitude of an effect (peak or mean voltage across the body of a component relative to a baseline), polarity (positivity or negativity of the waveform relative to a baseline), and the latency, i.e. the time scope of an effect in milliseconds. Figure 1 exemplifies the classification of ERP components by demonstrating the detection of an N400 effect (Kutas & Hillyard, 1983; M. Kutas & S.A. Hillyard, 1984; M. Kutas & S. A. Hillyard, 1984). After the visual observation of the topography and grand average waveforms, the peak activity is found in the centro-parietal area (A), around 400 msec post-stimulus. The subsequent observation of the grand average waveform (B) at the Pz electrode site demonstrates an ERP component that reaches its peak amplitude at around 400 msec in the negative polarity; hence this ERP component should be N400.

The polarity of an effect is not exclusively determined by the position of the peak amplitude in the negative or positive scope of a plot. It is rather the position of the peak amplitude of the violation condition relative to the baseline condition, i.e. more positive/negative than the baseline condition, that determines the polarity of an effect.

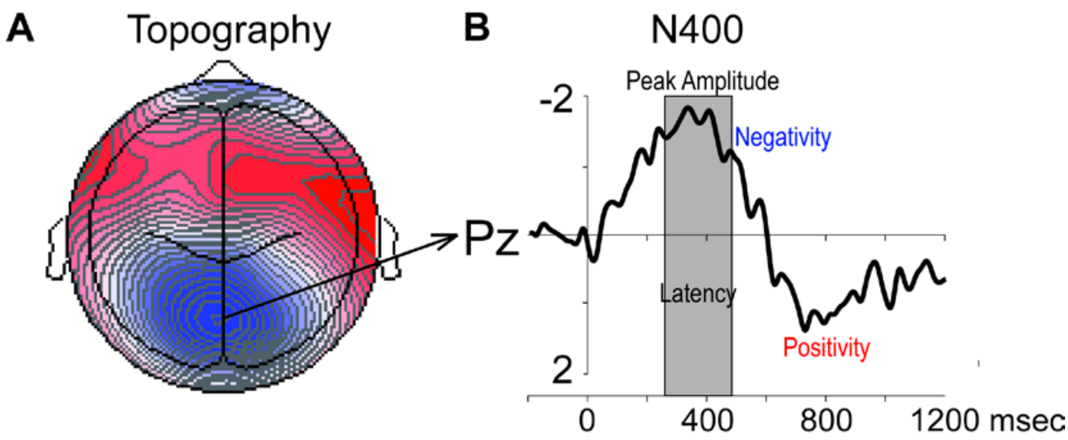

Figure 1. The detection of the N400 effect

The left part of the plot (A) shows the mean topography of a violation condition in the time window of 250-500 msec. The negative amplitude reaches its peak in the centro-parietal area. The right part of the plot (B) demonstrates a grand average waveform at the electrode site Pz. Negativity is plotted upwards. The effect reaches its peak amplitude around 400 msec in the negative polarity. A grey bar represents the latency of the effect.

In its early stages, the processing of linguistic input is modality dependent, i.e. according to the presentation of the material, a certain physiological pathway and, therefore, a certain set of actions is used to perceive and decode the incoming information. Due to the linear character of the auditory input, the lexical retrieval process is set into motion as soon as an acoustic signal is recognized as a speech signal. The process is completed as soon as there is only one possible word candidate left (W. D. Marslen-Wilson, 1987; W.D. Marslen-Wilson & Zwitserlood, 1989). However, the preceding context can also preactivate certain word candidates that are then matched to the incoming input. The process of word recognition can be easily traced with the ERP technique by means of certain ERP components. The ERP components have separate cognitive bases and different timing, according to the modality and the type of processing they reflect. The present thesis investigates the process of word recognition of complex words and nonwords in isolation and in sentence context, therefore, the ERP components that reflect the processing in question are the endogenous components starting to peak at late 200 msec latency range.

The following section provides a detailed account of the ERP components that we expected to observe in the experiments. We shall discuss these ERP components in order of their appearance in an ERP waveform (Friederici, 2002). The decision to describe them in this particular order was based on the linear character of the auditory input. Thus, the early ERP components reflect such processing stages as the phonological mapping, the fulfillment of phonological expectations, the mapping mismatch, etc. The semi-automatic procedures related to the morphosyntactic and semantic processing are observed later at around 300-500 msec post-stimulus. The higher order cognitive processes are reflected in the ERP components peaking after 500 msec post-stimulus. Although the ERP components observed between 300 and 800 msec post-stimulus are the most popular and well-known, the chronological order of description offers not only a coherent account on the ERP components but also a certain hierarchy in the processing of auditory input.

1.2.1 ERP Components Relevant to the Present Study

During auditory speech perception, information becomes available with the unfolding acoustic signal. Without the possibility of perceiving an entire word at once, as is the case during reading, the listener has to map the signal onto phonological representations in his/ her mental lexicon. Therefore, the initial processing of a spoken word always starts with phonology. In the following processing stages the decision should be made as to what word class a word candidate belongs to, what a word candidate might mean and after a certain stage, how this word is relevant for the context at hand. The present section discusses the ERP components relative to the processes they index. We start with the initial phonological processing. After the phonology, we continue with the semi-automatic semantic processing. The timing of the semi-automatic morphosyntactic and semantic processing overlaps and is followed by a higher order syntactic processing (Friederici, 2002). Therefore, we decided to discuss the morphosyntax after the semantics in order to group the syntactic ERP components together. The juxtaposition of the syntactic components offers better comparability and functional differentiation. The last ERP component in this section indexes the post-retrieval processing connected to the episodic memory. Though not directly related to linguistics, the LPN reflects the memory cost required for the maintenance of a word/ morphological construct.

1.2.1.1 Phonological Mapping Negativity

The first ERP component that is of interest for the present series of studies is known as PMN –phonological mapping negativity. Though this is now a generally accepted definition of the component, it was formerly described as the phonological mismatch negativity. We start this subchapter using the old definition of the PMN (phonological mismatch negativity) and we finish it with the introduction of the new terminology by Steinhauer & Connolly (2008).

The PMN is normally observed around 200 msec post stimulus onset and is sensitive to the violation of contextually driven phonological expectations. The discovery of this component took much time and effort as it was believed to be part of higher order cognitive/linguistic processing. Connolly et al. (1992) designed a study to tease apart what they thought at that time to be the N200 component from the N400 (see 2.2.2 Lexical Access: N400) in processing of terminal words in high and low constraint sentences. The authors used the high and low constraint sentences in four conditions: the Control condition with attention paid to the terminal words, the Semantic condition with a semantic judgment task following the terminal words, and the masked variation of the first two conditions. The auditory mask they employed was the babble mask, i.e. a background babble of twelve voices, which was reported to interfere with the lexical retrieval process due the presence of false speech cues. Therefore, the initial phonetic processing should not have been affected by the masking procedure, whereas higher order cognitive processes such as lexical retrieval should have been influenced by it. The goal of the masking procedure was to trigger a delayed onset of the N400 component thus functionally separating the two components. The results of the experiment supported the authors' hypothesis about functional differentiation of the N200 and N400 as, although both of them were sensitive to the contextual constraints, only the N400 was delayed by the masking procedure. The authors argued that the processing of an unexpected word elicited both the N200 and the N400 effects. However, the N200 was induced by a word with an unexpected initial phoneme, while the N400 was evoked by a semantically unexpected word. Connolly et al. (1992) put forward a model where the co-occurrence of the N200 and the N400 reflected the interaction of the independent acoustic-phonetic and contextual-semantic processing.

For the purpose of disambiguation of this phonologically driven effect from other negativity effects happening in this latency, Connolly and Phillips (1994) labeled this response the phonological mismatch negativity (PMN). To show the independence of the PMN from the N400 effect, the authors designed an experiment with manipulated sentences that ended in words with either phonemic or semantic violations, or both of them. This time the authors gave up the masking procedure, as the timing of the effects was no longer an issue. Instead, they created four conditions: (i) the Control condition – the highest Cloze probability word; (ii) the Phoneme Match – Semantic Mismatch condition – a semantically anomalous word that had the same initial phoneme as the highest Cloze probability word; (iii) the Phoneme Mismatch – Semantic Match condition – a semantically appropriate word that had a different initial phoneme as the highest Cloze probability word; (iv) the Phoneme Mismatch – Semantic Mismatch condition – a completely phonologically unexpected semantically anomalous word. A delayed N400 effect was observed in the Phoneme Match – Semantic Mismatch condition, while only a PMN was elicited in the Phoneme Mismatch – Semantic Match condition. Both effects were evoked in the Phoneme Mismatch – Semantic Mismatch violation condition. The results of this experiment provided further evidence for the previous research (Connolly et al., 1992), confirming the authors' hypothesis about the functional separation of the PMN and the N400 effect.

Connolly and Philips (1994) interpreted the occurrence of the PMN in terms of the Cohort model (W.D. Marslen-Wilson, 1984; W.D. Marslen-Wilson & Tyler, 1980; W.D. Marslen-Wilson & Zwitserlood, 1989; Zwitserlood, 1989). The core of this model is represented by the term *cohort*. The cohort refers to a group of words and word forms that share initial segments, such as CONVICT and CONCERT. A cohort is activated during lexical access, while the selection and integration of a word candidate depend on the interaction of the sensory input with the contextual information. Connolly and Philips (1994) argued that the perception of terminal words in their study started with the simultaneous activation of several word cohorts. These cohorts contained the words semantically matching the contextually driven expectations with various degrees of probability. Thus, a sentence *"He put a book on the…"* would activate the cohorts containing the words TABLE and SHELF. As soon as a sufficient amount of sensory input was received, only the cohort of the terminal word with the highest cloze probability remained activated. At this point, a PMN could be elicited by the presentation of a word belonging to a different cohort, which was demonstrated by the results from the Phoneme Mismatch – Semantic Mismatch and the Phoneme Mismatch – Semantic Mismatch conditions. The Phoneme Match – Semantic Mismatch condition elicited only the N400 effect, demonstrating the selection and integration processes driven by the competing word candidates belonging to the same cohort. The authors argued that the occurrence of the PMN reflected a mismatch between an expected word cohort and the acoustic-phonological features of the actual word-initial sensory input.

The co-occurrence of an early negativity and the N400 effect was observed in a number of other studies (Hagoort & Brown, 2000; van den Brink, Brown, & Hagoort, 2006; van den Brink & Hagoort, 2004; Van Petten, Coulson, Rubin, Plante, & Parks, 1999). However, the interpretation of the early negativity did not coincide with that by Connolly and Phillips (1994). Van Petten et al. (1999) used gated words as terminal words and then compared their isolation points with the time course of semantic integration on the ERP waveforms. The authors hypothesized that contextually driven semantic processing should be evident even before the isolation point if semantic integration can operate with partial acoustic information about word identity. The results supported the authors' hypothesis, demonstrating differential N400 responses to congruent and incongruent terminal words starting at about 200 ms before the isolation point. Although an early negativity was observed in the cohort incongruent condition (the word-initial phonemes could not form a congruous completion), Van Petten et al. interpreted it as a latency shift of the N400 effect. The statistical analyses as well as the observation of the grand average and single-subject ERP waveforms failed to display a biphasic negativity that could be indicative of two separate ERP components. The authors considered the possibility of form-based phonological expectations but excluded this possibility in favor of context-based semantic expectations. According to Van Petten et al., the listeners developed a contextually driven expectation about the meaning of a terminal word and compared it to the meaning of the incoming acoustic information. The latency of the N400 reflected the semantic compatibility between the expected and the actual auditory information, hence the early onset latencies of the congruity effects.

In the replication of the Connolly and Phillips (1994) study by van den Brink et al. (2001), the subjects were presented with spoken sentences that ended in (i) a fully (phonologically and semantically) congruent word – *FC*; (ii) an initially congruent (the same initial phoneme as in FC condition but semantically anomalous) word – *IC*, and (iii) a fully (phonologically and semantically) incongruent word – *FI*. In contrast to Connolly and Phillips (1994), they observed an early negativity in all conditions. The amplitude of the early negativity or, as van den Brink et al. (2001) labeled it, the N200 effect, was most pronounced in the FI condition, while the magnitude of the N200 effect was similarly small in FC and IC conditions. The authors argued that the N200 effect cannot be elicited by a phonological mismatch, but rather reflects a separate semantic process in word recognition, viz. lexical selection, that precedes the integration of a word into the sentence context. They claimed that small amplitude of the N200 effect was indicative of the presence of the semantic features required by the sentence context, whereas large amplitude of the N200 effect was indicative of the lack thereof. The authors also found that the observed N200 effect, although most prominent over the frontal sites, was equally distributed across the scalp, whereas the N400 effect was concentrated in the centro-parietal area.

The amplitude differences of the N200 effect found by van den Brink et al. (2001) were replicated by van den Brink et al. (2004). However, the authors failed to replicate the differential spatial distribution of the N200 and the N400 effects. The results revealed that both effects were largest over the centro-parietal sites indicating similar neuronal populations involved in the process of speech comprehension. In line with Van Petten (1999), the authors hypothesized that the N200 effect was identical to the N400 effect.

D’Arcy et al. (2004) ran a cross-modal study on phonological and semantic processing using the high-resolution event-related brain potentials (ERPs) technique. The goal of the study was the investigation of the spatial distribution of the PMN and the N400 effect. The hypothesis was that the two effects have differential spatial distribution and, therefore, they are functionally separate components. The results provided evidence in favor of functional distinction between the PMN and the N400. The authors found that incongruent words elicited both the PMN and the N400 effect in the high and low probability conditions. The low probability congruent words elicited only a small PMN, partly replicating the results from the van den Brink et al. (2001) study. However, neither a PMN nor an N400 was observed in the high probability condition. In addition, separate sources of neuronal activity were localized for the PMN and the N400. While the primary sources of the PMN were observed in left inferior frontal and inferior parietal lobes, the primary N400 source was observed along the left perisylvian cortex. The authors argued that the PMN response was sensitive to the size of a phonological set of word candidates kept in the working memory.

Diaz and Swaab (2007) conducted a study where they manipulated the phonological and semantic congruency of critical words in a word list experiment and of the terminal words in a sentence context experiment. The goal of the study was to determine the electrophysiological signature of early context effects on the lexical retrieval process in speech comprehension. The phonological and semantic conditions in the word list experiment were designed in such a way that there was no overlap in these conditions. In the phonological condition – the Alliterative Lists – the critical word had either the same initial phoneme as the preceding seven words (phonologically congruent), or had a different initial phoneme (phonologically incongruent). In the semantic condition – the Category Lists – the critical word either fitted the semantic category of the preceding seven words (semantically congruent), or it did not (semantically incongruent). Therefore, the experimental design made it possible to tease apart the form-based phonological effects from the context effects caused by the semantic constraints. The phonologically incongruent critical words elicited an early negativity in the time window of 200–300 msec that was most pronounced over the occipital sites. The phonologically congruent critical words evoked a frontal negativity in the 300–600 msec time window. However, neither of these conditions elicited an N400 effect, suggesting the absence of influence of the phonological congruity on the semantic processing of the spoken words. The results of the Category Lists were completely dissociable from those of the Alliterative Lists. The semantically incongruent critical words elicited a robust N400 effect with the canonical centro-parietal distribution, albeit no early negativity was observed in both of the semantic conditions. The results of the sentence context experiment were consistent with the results of the van den Brink et al. (2001, 2006) studies. All conditions evoked an early negativity, but this effect was significantly reduced by the High Congruent terminal words. The N400 was most pronounced in the Incongruent and Phonologically Congruent conditions. However, a significant N400 effect was also elicited by the Low Congruent condition. These N400 effects had the classic topographic distribution with the maximum over the centro-parietal sites.

Steinhauer and Connolly (2008) introduced a new terminology for the PMN. They claimed that the effect was sensitive to the violation of contextually driven phonological expectations and, therefore, had nothing in common with the mismatch negativity (MMN), which is a pre-attentive response to deviant auditory features after a series of standard ones (see Table 1 for the characteristics of the PMN). To avoid a misconception between the PMN and the MMN, the authors offered a new description of the PMN – the phonological *mapping* negativity. According to Steinhauer and Connolly, the PMN is a prelexical response that reflects phoneme awareness, triggered by top-down phonological expectations, and the consequent mapping of the auditory signal onto the pre-activated phoneme. In contrast to the MMN, the PMN is not sensitive to the degree of deviation of the actual signal from the expected one. This effect has a binary value, i.e. no PMN is observed in High Congruent condition, while all other violation conditions evoke similar PMN effects. Therefore, it is reasonable to employ the PMN as a tool in experiments with binary phonological conditions.

Table 1. Characteristics of the Phonological Mapping Negativity (PMN)

Characteristics	***PMN***
Latency	200-300 msec post stimulus
Topography	Centro-parietal sites
Stimulus type	A word with an unexpected initial phoneme (both modalities)
Sensitivity	Violation of contextually driven phonological expectations
Functionality	A prelexical response reflecting phoneme awareness
Suitable for	Experimental designs with binary phonological conditions
Unsuitable for	Experiments investigating the degree of deviation from the expected signal
Open questions	- Is it only possible to evoke the PMN by the initial segment of a word? - Does the gravity of violation influence the (co)occurrence of the PMN?
Relevance to the present thesis	The presentation of a wrong allomorph in a restricting morphosyntactic context could induce PMN

PMN is an automatic prelexical response, which makes this component not directly related to the interface of phonology and morphology. However, this effect can act as an index of the automatic error-detection. In relation to the objective of the present thesis, the PMN effect may index the detection of a wrong allomorph.

1.2.1.2 Lexical Access: N400

The next ERP component is the best investigated ERP component known, inter alia, to reflect the difficulties in the semantic processing, such as the lexical retrieval process, the semantic composition, etc. The peak amplitude of this component is usually observed around 200-600 msec post stimulus at centro-parietal electrode sites, which was pivotal for the labeling of the component as the N400 effect (Kutas & Federmeier, 2011).

The N400 effect was first reported by Kutas and Hillyard (1980), who ran a reading study with inappropriate final words embedded in sentence frames. The authors observed different types of ERP components that were elicited by different types of anomalous words. The physically deviant but semantically correct words elicited a late positivity around 560 msec post stimulus. The semantically incongruent words were subdivided into the “moderate” condition (for instance, *He took a sip from the waterfall*. p.203) and the “strong” condition (*He took a sip from the transmitter*. p.203). Both semantic conditions evoked a negativity that was most pronounced at 400 msec post stimulus over the centro-parietal electrode sites. The N400 amplitude was consistently larger in the strong incongruent condition than it was in the moderate condition. The authors argued that the N400 reflected the cost of the processing of semantically anomalous words, or as they put it “the interruption of ongoing sentence processing by a semantically inappropriate word and the ‘reprocessing’ or ‘second look’ that occurs when people seek to extract meaning from senseless sentences (p.207).”

In the follow-up study, Kutas and Hillyard (1983) presented the subjects with semantic anomalies and grammatical errors inserted into varied positions within a sentence context. The results of this study provided further evidence for the nature of the N400 effect as being specifically sensitive to the semantic anomalies. The amplitude of the N400 component elicited by the semantic anomalies in the intermediate position was similar to that evoked by the terminal inappropriate words. This result proved the hypothesis that the incoming input is immediately integrated into the preceding context (Just & Carpenter, 1980) and are not held in the short term memory for the parsing at the end of the sentence. Another goal of the Kutas & Hillyard (1983) study was the disambiguation of the N400 from the slow potential shifts. Such ERP responses had been reported to develop over the course of a sentence and reflected an anticipation of a word that could be more appropriate for the context. If the N400 belonged to the same ERP component family, the brain response to the terminal anomalous words would have been cardinally different from that elicited by the intermediate anomalous words. The results of the study refuted this hypothesis and thus discarded the possibility of the interpretation of the N400 effects as having the same neural generator as the slow potential shifts.

Since the discovery of the N400 effect, extensive research has been done on this component in a variety of languages and violation paradigms. The N400 was reported to be sensitive to such factors as word frequency, priming (M. Kutas & S.A. Hillyard, 1984; Kutas, Van Petten, & Besson, 1988; Neville, Kutas, Chesney, & Schmidt, 1986), word repetition (Besson, Kutas, & Van Petten, 1992; Rugg, 1990), content words as compared to the function words (Münte et al., 2001), the degree of fit of the content words into the preceding context (Besson, Faita, Czternasty, & Kutas, 1997; Brown, van Berkum, & Hagoort, 2000; Connolly & Phillips, 1994; Connolly et al., 1992; Connolly, Stewart, & Phillips, 1990), etc. The establishment of the N400 as a linguistic ERP component that reflects the lexical access and is very stable in its characteristics made it possible to employ this effect as a tool for further linguistic research.

McKinnon et al. (2003) ran a visual study on the decomposition of morphologically complex words, employing the amplitude of the N400 component as an indicator of the decomposition process. They compared the N400 effects elicited by complex words, made up of non-productive morphemes (e.g. *retain*, *intrude* (p.883)) – bound-stem words, and by bound-stem nonwords, made up of the same morphemes (e.g. **intain*, **retrude* (p.883)). The authors argued that if the bound-stem words are decomposed online and their semantics is accessed via their constituent morphemes, then the bound-stem nonwords could be treated as low-frequency words due to the existing representations of the morphemes. If, however, there is no morphological decomposition of complex words, the bound-stem nonwords used in this study should elicit larger N400 effects than the low-frequency words do. Therefore, the authors introduced a nonword control condition consisting of no morphemes (e.g. *flermuf*) by permuting the letters of the bound-stem words. The results of the study provided evidence for the decomposition of complex words, revealing the following pattern: the N400 effect elicited by the bound-stem nonwords was similar to that evoked by the bound-stem words; the N400 effect elicited by the control nonwords was significantly larger than the N400 effects evoked by both bound-stem conditions.

The morphological decomposition and semantic composition of German compounds were investigated in the study by Koester et al. (2007). The authors conducted two experiments with auditorily presented compound nouns made up of either three stems (e.g. "*der Stahlhakenpreis*" - the$_{masc}$ steel$_{masc}$-hook$_{masc}$-price$_{masc}$ (p.65)) in the first experiment or two stems (e.g. "*Schneebesen*" – egg whisk) in the second experiment. The first experiment used a gender agreement violation to study the morphosyntactic decomposition. The second experiment contrasted the processing of semantically transparent and semantically opaque compounds to investigate the semantic composition. The results of the first experiment provided evidence for the morphological decomposition revealing LAN effects for the gender agreement with both the initial stem and the head stem of the compound. The authors also observed a slow negative shift in the centro-parietal area in the time window of 1200-1600 msec after the stimulus onset. Koester et al. (2007) argued that this component reflected the integration process of the semantics of the morpheme constituents into the single compound, i.e. the process of semantic composition. Besides, the timing of the slow negative shift, relative to the beginning of the head of the compound, as well as the topography of this component were very similar to that of the N400, suggesting that this negativity was at least related to the N400 component. The second experiment provided evidence for the semantic composition process as only the low-frequency semantically transparent compounds elicited the slow negative shift, reminiscent of the N400. The authors argued that the only difference between the transparent and opaque compounds was the degree of semantic complexity, with both type of compounds being morphologically complex. Therefore, the only plausible interpretation for the occurrence of this late N400-like component would be the process of semantic composition.

Considering the discrepancies between the results obtained by McKinnon et al. (2003) and Koester et al. (2007), it seemed necessary to clarify which processes exactly – the morphological decomposition or the semantic composition – are directly indexed in the amplitude of the N400. The research groups resorted to different types of morphologically complex words: McKinnon et al. (2003) employed pseudo derived words and nonwords with bound morphemes, while Koester et al. (2007) used existing and novel compounds. An experimental design with a unified approach to the morphological complexity, i.e. using both derived and compound words/ nonwords, should be able to tease apart the morphological decomposition and semantic composition. Coch, Bares and Landers (2013) recorded the ERPs to the visually presented words and nonwords made up of bound morphemes (e.g. *discern*, *predict* – **disject*, **percern*), free stems (*cobweb*, *earring*; **cobline*, **bobweb*) and simplex words and nonwords (*garlic*, *minnow*; **gartus*, **buzlic* (p.355)) with a lexical decision task. All types of nonwords elicited N400 effects that were larger in the amplitude than those elicited by their real word counterparts, thus producing only the main effect of lexicality. There was no interaction with or the main effect of the morphological type (free vs. bound morphemes). Coch et al. (2013) interpreted the absence of morphological effects reflected in the amplitude of the N400 component as an indication that the N400 could not be used as a direct index of the morphological decomposition. Instead, the authors claimed that their pattern of results provided evidence for the N400 as an index of the semantic composition process. They suggested the syntactic ERP components, such as the LAN and the P600, should be employed as a reliable indicator of the morphological decomposition process.

Apart from being used in the studies on the processing of words and nonwords in isolation and in context, the N400 can serve as an indicator of the learning effects. In a recent study by Borovsky, Elman and Kutas (2012), the N400 effect was used as an index of the semantic integration of the meanings of novel words from a single exposure in a context. The authors employed a set of high and low constraint sentence pairs and a consequent priming procedure. The combined context of these sentence pairs built up an expectation of a certain meaning of the terminal word of the second sentence. The terminal word of the second sentence was either an existing English word or a novel word. This latter word was then employed as a prime to a target that was semantically related/ unrelated or had a synonymous/ identical meaning. The novel words elicited a larger N400 effect than the known words did at the end of the second sentence regardless of the contextual constraint. The results of the priming part revealed a considerable reduction in the amplitude of the N400 effect for semantically related targets after both known and novel word primes immediately following a high constraint context. The results of Borovsky et al.'s (2012) study provided evidence for the influence of a word's initial learning context onto the subsequent access to the word's mental representation. Thus, the novel words acquired via a highly constraining context were immediately built into the network of semantically related known words, as reflected in the reduction of the N400 amplitude of the corresponding prime-target pairs. The novel words whose meanings were rendered by the weakly constraining contexts failed to be immediately acquired after the single exposure. This study showed that the N400 component could be sensitive to the acquisition of word meanings as well as their grammatical characteristics after only a single exposure in a highly constraining context.

In sum, the previous body of research on the N400 effect demonstrated that this ERP component can be employed in various experimental designs and paradigms as a reliable index of the semantic association, the semantic composition, the semantic integration and the lexical access processes (Table 2). Although frequently observed in the studies on morphological decomposition, the N400 cannot be used as a direct indicator of the morphological processing. It rather reflects the semantic composition or the lexical access that takes place after or based on the primary morpho-orthographic (morphophonological) segmentation (Beyersmann, Iakimova, Ziegler, & Colé, 2014; Morris, Grainger, & Holcomb, 2013).

Table 2. Characteristics of the N400 effect

Characteristics	***N400***
Latency	200-600 msec post stimulus
Topography	Centro-parietal sites
Stimulus type	Auditorily and visually presented words, signs, images, events; also smells and sounds
Sensitivity	Word frequency, congruity, neighborhood size, priming
Functionality	Reflects difficulties driven by a context to connect the sensory input with the representations in the semantic memory
Suitable for	Studies exploring semantic association, semantic composition, semantic integration and lexical access processes
Unsuitable for	Application as a direct index of morphological processing. It rather reflects the semantic composition or the lexical access based on the primary morpho-orthographic (morphophono-logical) segmentation
Open questions	Can the N400 be employed for the studies on the allomorph representation?
Relevance to the present thesis	The application of a wrong allomorph in a certain environment could result in a nonword. The nonword status should be indexed by the prominence of N400

1.2.1.3 Left Anterior Negativity

The research on the syntactic ERP components started with the secondary findings of the Kutas and Hillyard (1983) study that was aimed at investigating the specificity of the N400 component. The authors were interested in the types of violations that could elicit the N400, viz. only semantic anomalies or a broader class of unexpected words, e.g. grammatically violated words. Alongside semantically inappropriate words, number (singular vs. plural) violation and tense (past vs. present) violations were used in connected prose passages that were visually presented to the subjects word after word. Kutas and Hillyard hypothesized that if the N400 was associated with a wide range of higher order linguistic processes, all violation types should evoke an N400 effect. On the other hand, if the N400 was specific to semantic anomalies, it should not be elicited by grammatically violated words. The results showed a distinct N400 effect elicited by semantic anomalies, while grammatical errors evoked a less pronounced late negativity in frontal and anterior temporal areas. Apart from being less pronounced, the ERPs evoked by grammatical violations were also inconsistent, viz. some of them were observed at 200-300 msec, while the others peaked at about 400-500 msec. The authors argued that the violation types were not homogeneous or salient enough to elicit a distinct ERP component. The most important finding of this study was the dissociation of semantic and syntactic processing by means of differential scalp distribution of the effects evoked by the above mentioned violation types.

The grammatical violation paradigm was elaborated in Friederici et al.'s (1993) study, separating morphological violations from the syntactic ones. The authors were interested in different aspects of auditory speech processing including semantic and grammatical (morphological and syntactic) processing. For this purpose, they developed a violation paradigm including a selectional restriction semantic error, viz. a mismatch between the sentence-final verb and the preceding noun; a morphological error, i.e. a mismatch between the passive voice auxiliary and the sentence-final verb; and a syntactic error caused by a mismatch between the sentence-final word and the head of the phrase preceding this word. The subjects listened to sentences that were either correct or incorrect containing one of the above-mentioned violations. The participants were instructed to react to a probe word that appeared 800 msec after the sentence presentation. All three types of violations elicited distinct ERP effects differing from each other in timing and scalp distribution. The semantic violation (selection restriction error) evoked a prominent N400 effect; the syntactic violation (phrase structure error) elicited an early negativity peaking at 180 msec at frontal and anterior electrode sites followed by a less pronounced negativity at about 400 msec with the same topographic distribution. The morphological violation (verb inflection error) elicited a late negativity peaking at 400 msec with anterior distribution followed by a weak late positivity with its maximum at parietal sites.

The late left anterior negativity caused by syntactic violations was also observed in Rösler et al.'s (1993) study that was designed to find ERP correlates of the semantic and syntactic processing. The subjects were visually presented with sentences (word by word) and had to make a lexical decision to the sentence-final string of letters. This last segment could be either a German word or a pseudoword. As a word it could be a semantically and syntactically correct completion to the preceding sentence fragment or it could function as a semantic or a syntactic violation of the preceding context. The syntactic violation consisted of (i) the passive voice error, viz. the passive voice auxiliary *wurde* (was) + the past participle of a verb that can be passivized/ cannot be passivized, and (ii) the past perfect error, i.e. the present perfect auxiliary *hat* (has) + a past participle of a correct verb (requires *hat*)/ an incorrect verb (requires *ist* – is – as an auxiliary). The semantic violation was realized via lexical selection errors with respect to animacy/ inanimacy of the subject as restricted by the verb, e.g. *Der Honig wurde ermordet.* (The honey was murdered.) and *Der Ball hat geträumt*. (The ball has dreamed.) (Rösler et al., 1993:348). The syntactic violations elicited a negativity peaking between 400 and 700 msec after target onset with left anterior distribution – LAN – followed by a late posterior positivity peaking between 700 and 1200 msec (P600 component) after the target onset. The semantic violations evoked a classical N400 effect at parietal electrode sites.

In a series of word-by-word reading experiments, Gunter et al. (1997) investigated the processing of syntactic and semantic violations. The authors developed three experiments to explore different aspects of the semantic (N400) and syntactic (the left anterior negativity – LAN and P600) ERP components. The first experiment was designed to look into the interaction of semantics and syntax. The subjects read 8-word sentences with the final word being either congruent or incongruent past participle completions or infinitive forms of these completions. The results showed a major effect of congruency as reflected in the amplitude of the N400 component followed by a very pronounced effect of syntax (P600). No LAN effect was observed in this experiment.

The second experiment employed complexity of the sentences as an additional syntactic factor. The objective of this experiment was to determine whether any of the above mentioned ERP components is automatic or if it is dependent on the working memory load. The main clause and its final word were disrupted by a subordinated clause in the *high complexity* sentences, while the *low complexity* sentences consisted of a subordinate clause followed by the main clause. The results of the second experiment demonstrated a semantic congruity effect that was similar to that reported in the first experiment, as reflected in the amplitude of the N400 component. Contrary to the results of the first experiment, a distinct LAN component was observed and it was independent of both complexity and congruity. In addition, the authors also observed a syntax-related early negativity in the latency of the N1 component that was also complexity and congruity independent. The P600 effect turned to be more pronounced in the sentences with congruent endings. These findings suggested that P600 should be sensitive to the working memory load - indicating a broad and general nature of this component - while LAN should not be influenced by it.

The third experiment employing probability of occurrence of syntactic violations (75% in one block and 25% in the other) demonstrated a LAN effect that was independent of the probability manipulations. Gunter et al. (1997) argued that syntactic processes reflected in the amplitude of the LAN component were autonomous and ran parallel in time to the semantic processes reflected in the N400.

The proposition that syntactic and semantic processes, reflected in the LAN and the N400 components, are autonomous at an early processing stage was also confirmed in a visual study by Gunter et al. (2000). The authors recorded brain responses to nouns embedded in sentence frames. These nouns were direct objects of the given verbs and had either high or low semantic expectancy. In addition, they were manipulated syntactically, i.e. the article preceding the noun had either congruent or incongruent gender. The results of the experiment revealed the following pattern: (i) grammatical gender violations evoked a LAN effect that was independent of the semantic probability effect; (ii) the N400 was elicited only by the semantic probability (low cloze nouns) effect; (iii) the effects of both grammatical gender violation and cloze probability interacted in the latency range of the P600, i.e. gender disagreement elicited a P600 only in case of high cloze probability nouns. The results of this study proved LAN as a purely syntactic component. Furthermore, they provided evidence for functional separation and autonomy of the neuronal mechanisms underlying early processing stages ("a first phase", Gunter, et al. 2000:564).

The LAN effect was observed in a number of studies in connection with morphosyntactic violations, such as subject-verb agreement violation (Coulson, King, & Kutas, 1998; Friederici, Hahne, & Mecklinger, 1996; Mancini, Molinaro, Rizzi, & Carreiras, 2011; Münte, Matzke, & Johannes, 1997; Roll, Gosselke, Lindgren, & Horne, 2013; Shen, Staub, & Sanders, 2012), over-regularization of the default formation rule, viz. addition of a regular inflectional suffix to an irregular verb (Penke et al., 1997; Rodriguez-Fornells, Clahsen, Lleo, Zaake, & Münte, 2001; Weyerts, Penke, Dohrn, Clahsen, & Munte, 1997) and pronoun case violation (Coulson et al., 1998). Lück et al. (2006) replicated the results of the visual studies, especially that by Weyerts et al (1997), for the auditory modality. The authors used similar materials and the same conditions as Weyerts et al. (1997), i.e. the misapplication of the German default plural suffix {-*s*} in words that require plural suffix {-*n*} and the misapplication of the non-default plural suffix {-*n*} in words that require default plural formation. Apart from finding the LAN/ P600 pattern in case of the misapplication of the default rule, the authors also found that this pattern is more prominent in the auditory modality than it is in the visual modality. Lück et al. claimed that the amplitude effects of the LAN/ P600 pattern in the auditory modality were due to the increased sensitivity of the perceptual system to the internal morphological structure.

Rodriguez-Fornells et al. (2001) observed LAN effects for the violation of stem formation rules in Catalan. The authors considered the first conjugation as default rule, while the second and the third conjugations were considered as lexicalized patterns. Therefore, the misapplication of the 1st conjugation default rule in case of 2nd and 3rd conjugation verbs should trigger a LAN effect, while the misapplication of the non-default pattern should not evoke a LAN. The results of the study were completely in line with the predictions, as only the excessive application of the default rule evoked a LAN effect. Thus, the results for, at least, Catalan showed that LAN is not restricted to inflectional affixation but also to the violation of regular stem vowel alternation, as employed in the verb conjugation paradigm. The authors claimed that, considering the results, LAN should not be interpreted only within the framework of inflectional morphology; it should rather receive a broader interpretation involving the implementation of the default stem formation rules.

LAN effects were reported to be more pronounced if the incorrect inflectional forms were presented within sentence frames, as compared to the single-word presentation. Morris and Holcomb (2005) designed a series of reading experiments employing violated regular and irregular English verbs. The verbs were placed in a sentence or in a word list (with a sentence/word acceptability judgment task). The authors predicted a LAN/P600 pattern only for the incorrect irregulars in the sentence context experiment (in line with Penke et al., 1997; Rodriguez-Fornells et al., 2001; Weyerts et al., 1997; Lück et al., 2006). Yet the results demonstrated a distinct LAN/P600 pattern for all incorrect verb forms, the LAN effect being most pronounced for the incorrect irregulars. In the single-word presentation, however, all violation conditions failed to elicit a LAN effect, while N400-like negativities were observed. Morris and Holcomb maintained that the LAN component reflected difficulties in syntactic rather than morphological processing. This finding provided the explanation for the occurrence of LAN within a longer context, such as a sentence. On the other hand, the participants were instructed to listen to the stimuli and to perform an acceptability judgment task. The strategy employed by the participants to improve the task performance depended on the experimental context. The sentence context required a check-up of the syntactic structure, while the single-word presentation demanded a lexical check-up. Therefore, the task superimposed a certain type of processing, viz. syntactic and lexical respectively. This resulted in a (morpho-) syntactic LAN/P600 pattern in the sentence context experiment and in N400-like negativities followed by P600 in the word list experiment.

Apart from inflectional morphology, LAN was also observed in the studies on derivation. Thus, LAN was reported for illegal adjective formations in German (Bölte, Jansma, Zilverstand, & Zwitserlood, 2009). Bölte et al. (2009) conducted a study on the processing of derived German adjectives (*freundlich* – "*friendly*"). The authors employed two types of pseudowords that were (i) structurally anomalous but semantically interpretable (**freundhaft*) or (ii) both structurally and semantically anomalous (**freundbar*). Bölte et al. (2009) observed a LAN-like ERP effect that had its maximum around 450-500 msec post stimulus over the left-frontal electrode sites, which was elicited by both types of pseudowords. Considering the similarity of the LAN effect for both violation types, the authors argued that the LAN component reflected the morphological parsing process aggravated by the deficient morphological structure. In addition to this finding, the results also showed that the processing of the morphological structure overrode the semantic interpretation, for even the semantically anomalous condition failed to elicit the N400 effect.

Table 3. Characteristics of the Left Anterior Negativity (LAN)

Characteristics	***LAN***
Latency	300-500 msec post stimulus
Topography	Left anterior sites
Stimulus type	Morphosyntactic structures
Sensitivity	Violations of the subject-verb/case/number agreement, violation of the morphological structure of complex words, over-regularization of default rules, etc.
Functionality	Reflects semi-automatic syntactic processing, such as agreement in the local syntactic relations
Suitable for	Studies on the morphosyntax
Unsuitable for	Studies on the long distance syntactic relations, semantic studies
Open questions	Can a LAN effect be observed if the internal/phonological structure of a word is violated?
Relevance to the present thesis	The misapplication of an allomorph could result in the violation of the morphosyntactic structure or in the violation of the local syntactic relations, inducing a LAN effect

Taken together, the reported studies demonstrated the LAN effect as a reliable index of the morphosyntactic rule violation and/or of the over-regularization of the default formation rules (Table 3). The present thesis explores the rule-driven stem alternations, on the one hand, and the rule-based paradigmatic structures, on the other. Therefore, the LAN component can be employed as an index of the regularity of a complex morphological construct in the first part of this thesis and as an index of the misapplication of the default inflectional rules in the second part.

1.2.1.4 Parsing: P600

The second syntactic ERP component, the P600, is a positive-going wave observed at centro-parietal sites starting at about 500 msec post stimulus (Kuperberg, 2007; Osterhout & Holcomb, 1992, 1995). The P600 has been reported to reflect a wide range of higher order cognitive processes, such as parsing and repair. This component can last several hundreds of milliseconds depending on the complexity of the syntactic structure, the type and/or the gravity of a syntactic or semantic violation. The P600 effect can follow an N400 or a LAN effect, reflecting the combinatorial or integrative costs elicited by the semantic or morphosyntactic violations, but it can also occur by itself.

The P600 component was first reported in 1992 by Osterhout and Holcomb in a word-by-word reading study employing a garden path effect, e.g. (a) *The broker persuaded* ***the man*** *to sell the stock.* and (b) *The broker persuaded* ***to sell*** *the stock was sent to jail*. The garden path effect is usually observed when a preferred syntactic analysis employing the least effort proves to be inappropriate (Frazier & Fodor, 1978). The example (a) demonstrates the preferred syntactic analysis, i.e. the parsing of the structure involving the minimum number of syntactic nodes. Osterhout and Holcomb argued that a word marking the violation of the preferred syntactic structure (the infinitival marker ***to*** from the example (b)) would require a structural reanalysis of the previous string of words. The parsing caused by the failure to perform a computed syntactic analysis should be reflected in the brain responses. Therefore, the first goal of the study was to find an electrophysiological marker of the garden path effect. The second goal was to find out whether the ERP component evoked by a syntactic violation, i.e. by the garden path effect, was distinct from the semantic ERP component, the N400. The results of the study met the authors' expectations: first, the words marking the inconsistency with the computed syntactic structure evoked a widely distributed positive-going wave (the P600 effect); second, the P600 effect was distinctive from the N400 effect. Despite the unambiguous results, Osterhout and Holcomb argued that the P600 effect observed in this study could be elicited due to the use of the infinitival markers and auxiliary verbs, the N400 effect being more prominent for the content words (Münte et al., 2001).

In a follow-up study, Osterhout and Holcomb (1993) resorted to a more natural presentation style than they did in the previous study. Thus, the subjects now listened to the sentences containing garden path effects. Although the sentences were read by a native speaker, they were recorded, then processed and cross-spliced to dispose of the confounds concerning the sentence prosody and coarticulation effects. The results of this auditory study replicated the previous results, revealing a similar P600 effect evoked by the words that were inconsistent with the preferred syntactic analysis of the sentences. The authors confirmed the syntactic nature of the P600 effect for both the visual and auditory modality.

Hagoort, Brown and Groothusen (1993) extended the investigation of the syntactic ERP components by employing three different types of syntactic violations in Dutch. The authors instructed the subjects to silently read the sentences for comprehension without any other additional task. By rejecting the experimental task, Hagoort et al. (1993) intended to assess the mechanisms involved in the processing of syntactic violations. The syntactic violations used in this study included (i) the violation of the subject-NP and the finite verb number agreement, (ii) the violation of a verb’s intransitivity subcategorisation, and (iii) the violation of the word order constraint on a phrase structure. The results of the study demonstrated a set of robust positivity effects for the subject-verb number agreement violation and for the word order constraint violation. Hagoort et al. labeled this effect Syntactic Positive Shift (SPS), rather than the P600, as they were not convinced that the processes underlying these two effects were similar or homogeneous. Thus, the SPS in the present study was elicited by the content words (verbs) and by the words with close-class/function word characteristics (adverbs), while the P600 in the Osterhout & Holcomb (1992) study was evoked by function words (infinitival markers and auxiliaries). The brain responses recorded to the words following the violation that evoked the late positivity – the penultimate and the terminal words of the sentences – demonstrated a pronounced N400 effect that reflected the difficulties in the semantic integration based on the deficient syntactic processing (Hagoort et al., 1993; Osterhout & Holcomb, 1992; Osterhout & Holcomb, 1993).

Taken together, the three reported studies provided solid evidence for the characteristics of the late positivity as a syntactic component sensitive to the violations of a syntactic structure or to the discrepancies between the preferred/ computed syntactic structure and the actual linguistic input. This late positive component was also classified as independent of modality and the word-class (content vs. function). Considering the different approaches that Osterhout & Holcomb (1992, 1993) and Hagoort et al. (1993) took to the investigation of the syntactic ERP components, there was no homogeneity in the labeling and the nature of the late positivity. The task and the design of Osterhout & Holcomb's studies suggested that the P600 was the member of the P3 family, i.e. an ERP component elicited by an unexpected but task-relevant event. At the same time, the design employed in the study by Hagoort et al. (1993) did not involve any kind of task apart from reading for comprehension, implying that the late positivity was a purely linguistic component. Thus, the exact nature of the late positivity still needed a definition. Furthermore, the connection between both syntactic components – the LAN and the late positivity – had to be established.

Gunter et al. (1997) intended to determine the semantic and syntactic ERP components and the time course of the processes that they reflect. The authors addressed three questions: (i) if the LAN and the late positivity were affected by the semantic processing; (ii) if syntactic complexity affected the LAN and the late positivity; and (iii) if the frequency of occurrence of a syntactic violation modulated the LAN and the late positivity. Gunter et al. (1997) hypothesized that the late positivity should index a number of higher order cognitive processes if this late component turned out to be sensitive to the manipulations of syntactic complexity. The higher order processes would include the reanalysis of the structure, the parsing of the semantic structure, the processing of the pragmatic information and the costs of the working memory load. Such a result would provide support for the hypothesis that the late positivity belonged to the P3 effect family and should thus be labeled P600. Another factor in favor of the label "P600" would be the sensitivity to the probability of occurrence of a syntactic violation. The results of the experiments provided evidence for the P600 to reflect controlled stages of the reanalysis involving multiple levels of higher order cognitive processing. The sensitivity to the probability of occurrence also indicated that the P600 could belong to the P3 family.

A Dutch study by Kolk et al. (2003) also employed syntactic complexity to assess the processes that trigger the occurrence of the P600 and the N400 components. Kolk et al. (2003) manipulated subject-verb agreement (syntactic anomaly) and plausibility of events (semantic anomaly) in the mid-sentence subject/ object relative clauses in two ERP experiments. The experiments differed in the task: Experiment 1 required an acceptability judgment; in Experiment 2, the subjects were instructed to read for comprehension. In both experiments the semantic anomalies failed to elicit an N400, while both types of anomalies evoked P600 effects. The amplitude of the P600 effect interacted with the syntactic complexity: both anomalies in the object relative clause either elicited a reduced P600 effect (Experiment 1) or failed to elicit one altogether (Experiment 2). The authors claimed that the P600 could reflect the semantic bias even in the syntactically well-formed sentences. The failure to map the input onto the expected syntactic form (syntactic anomaly) or onto the truthfulness of an event that was part of the general knowledge (semantic anomaly) triggered the language monitoring (Hartsuiker & Kolk, 2001; Levelt, 1983) as reflected in the amplitude of the P600 effect. The authors further argued that if the language monitoring was triggered, the semantic integration of an event could not be carried out; hence the absence of the N400.

The findings of Gunter et al.'s (1997) and Kolk et al.'s (2003) studies demonstrated the P600 effect as an index of higher order cognitive processing that can be elicited by growing processing demands. The still-remaining question was whether the P600 could be observed during a single word presentation or in a phrasal context. Morris and Holcomb (2005) ran a series of experiments, presenting their subjects with correct and incorrect regular and irregular past tense verb forms in a sentence context and a word list experiments. The authors observed the P600 in the sentence context experiments for the morphological violations and the semantic anomalies. This result confirmed the authors' hypothesis that the P600 effect reflected more than one (syntactic) underlying cognitive process. In a single word presentation, only the morphological violation elicited the P600 effect, the semantic anomalies having evoked an effect reminiscent of the P3. The absence of the P600 in the semantic condition during a single word presentation provided a solid explanation for the results of the sentence context experiment. Thus, the P600 effect in the first experiment was triggered by the difficulties of integrating a non-existing item into the sentence context. The reported pattern of results contributed to the interpretation of the P600 as an index of combinatorial processes at both morphological and syntactic levels.

Van de Meerendonk et al. (van de Meerendonk, Kolk, Vissers, & Chwilla, 2008) hypothesized that the reanalysis as indexed by the P600 could be triggered only by a strong conflict between the expected input and the actual one.

The authors manipulated the plausibility of a critical noun within a given context in Dutch, varying the contextual constraint from mild to strong. The violation of both plausibility constraints (mild and strong) elicited a broadly distributed N400 effect. The findings concerning the P600 supported the authors' hypothesis: only the violation of the strong plausibility constraint elicited a P600 effect. In line with the monitoring theory of language perception (Kolk et al., 2003), Van de Meerendonk et al. (2008) argued that the occurrence of the P600 should be determined by the gravity of a conflict. The authors claimed that the monitoring process could not be launched by every conflict as it was not efficient to doubt the truthfulness of every seemingly implausible event. Therefore, mildly implausible sentences triggered semantic integration, as reflected in the amplitude of the N400, but were not conflicting enough to activate the monitoring process.

Considering the influence of the syntactic complexity and the working memory load on the amplitude of the P600 effect in a sentence context, similar interactions should be observed within a phrase context. O'Rourke & Van Petten (2011) developed an experimental design that investigated the possibility of occurrence of the P600 in a morphological agreement violation in a Spanish noun phrase when the distance between the (dis)agreeing constituents was varied. The main finding of this study was that the increasing distance between the (dis)agreeing words of a noun phrase reduced the P600 response to the gender agreement violations, while the LAN effect remained constant. The secondary finding was that the LAN and P600 responses elicited by the number agreement violation were weak even in the adjacent position of the agreeing words, entirely disappearing with the distance. The authors argued that the P600 effect reflected the computation of the resources required for the sentence reanalysis. If the revision of the ambiguous structure was not efficient or if the conflict was not grave enough, an event or a structure was immediately integrated into the sentence context even after the initial automatic error detection. The P600 amplitude could therefore be modified by the sentence structure, the task requirements, and the gravity of a morphological violation for a correct structural analysis (Alemán Bañón, Fiorentino, & Gabriele, 2012; O'Rourke & Van Petten, 2011; Van Petten & Luka, 2012).

The characteristics of the P600 component (Table 4) demonstrate it as a valuable tool for the assessment of the (morpho)syntactic processing. With respect to the objective of the present thesis, the P600 effect can be employed in a sentence context experiment. A shared lexical entry for the regular stem allomorphs could enable structural repair process indexed by P600. A misapplication or an omission of inflectional morphosyntactic rule can also trigger parsing and structural repair. Therefore, the P600 effect can be observed in both parts of the present thesis.

Table 4. Characteristics of the P600 component

Characteristics	***P600***
Latency	From 500 to 700 msec post stimulus and sometimes until the end of an epoch
Topography	Centro-parietal
Stimulus type	Auditory and visual sentences, images, events
Sensitivity	Garden path effects, grammatical errors, complexity, etc.
Functionality	Reflects higher order cognitive processing, such as parsing
Suitable for	Studies on syntax, long distance syntactic relations, complexity
Unsuitable for	Phonological and semantic studies
Open questions	Can a P600 effect be observed if a morphophonological/ morphosyntactic rule is violated?
Relevance to the present thesis	The misapplication of an allomorph could result in the violation of the syntactic structure of a sentence triggering parsing, indexed by P600

1.2.1.5 Late Posterior Negativity

Late posterior negativity has been observed in the research on action monitoring, contextual retrieval, and recognition memory. Recognized or "old" items, as compared to the new items, are reported to elicit a sustained posterior negativity, starting at around 600 msec and lasting for almost a second, hence the label of this component is late posterior negativity (LPN). According to Johansson and Mecklinger (2003), the functional characteristics of the LPN are heterogeneous being associated with two distinct components. The first component is action monitoring evoked by a strong response conflict. The second component is associated with the source monitoring, i.e. with the retrieval of contextual information related to the study event.

In an attempt to dissociate the two components of the LPN, Jane Herron (2007) designed a study with a source memory paradigm repeated across four blocks. During the first two blocks, the motoric and task fluency had to increase due to the familiarity with the task and practice. However, in the following two blocks the participants were instructed to reverse the responses. This design was employed to reduce the motoric fluency, while keeping the task fluency intact. The author hypothesized that (i) LPN would be influenced by the block order (i.e. the first two blocks compared to the last two blocks) if it is sensitive to the task fluency and motoric fluency; (ii) LPN would be unaffected by the block order if it indexes the retrieval of attribute conjunctions, whose demands always remained invariant. The results of the study revealed two distinct LPN components. The first LPN was observed in the 600-1200 msec time window and it was affected by the block order, being attenuated by the growing task fluency. This LPN component was argued to reflect the search for episodic information. The second LPN, observed between 1200-1900 msec, remained invariant across all four blocks, indexing the maintenance of contextual information. In addition to the stimulus-locked LPNs, the author also observed a response-locked LPN between 50 and 300 msec that was sensitive to the response fluency and was thus indicative of the action monitoring function.

Leynes and Phillips (2008) used LPN as an indicator of varied recollection during the source monitoring task. They presented the subjects with two hundred words, produced by a male and a female speaker, in the study phase. In the test phase, a hundred "new" words were added to the already heard set of words. These items were presented visually with the instruction to press the corresponding key if the word was (i) spoken by a male, (ii) by a female, or (iii) was not heard during the study phase, viz. was "new". After the correct source judgments, the participants had to perform a "remember/ know" task, i.e. if they could remember the context of hearing a word, or they just knew that they heard it. The LPN effect was more robust and had an earlier onset time for the "remember" responses that it was for the "know" responses. The results were consistent with the hypothesis that the accurate source monitoring was supported by varying degrees of recollection. These data also provided support for the previous findings by Herron (2007) that the LPN observed at around 1200 msec indexed the maintenance of contextual information, which was directly related to the degree of recollection.

The recollection is the retrieval of the qualitative information about a previous event from the episodic memory, and it is therefore directly associated with the accurate source memory. In order to recover a specific event out of a number of very similar episodes, there should be a cognitive mechanism that provides control of the recollection, i.e. ensures the retrieval of the appropriate contextual information. Evans et al. (2010) ran a study that assessed the control that the subjects exerted over memory retrieval. Upon the presentation of a concrete noun, the participants had to indicate whether the object was (i) pleasant/ unpleasant, (ii) was larger/ smaller than a shoebox, and (ii) was easy/ difficult to draw. In the retrieval task, the subjects had to press one key for the words that were presented in the "easy/ difficult to draw" task (target words) and another key for all other words, i.e. the rest of the presented set (non-target) and new words. The old/new effect was reliable for the target words only. The LPN effects were larger for the non-targets than for the targets, also supporting the accounts by Johansson & Mecklinger (2003) and Herron (2007) that suggested that the LPN was related to the retrieval of the attribute conjunctions. The ability to bind an object or an event with its context in the exclusion task was lower for the non-targets than it was for the targets, which consequently increased the context retrieval demands.

Regarding the present series of studies, the LPN effect could be observed when the retrieval of contextual information is hindered by a deviating form, i.e. by the application of a wrong allomorph (Table 5). However, the distance between the standard and the deviant form should not be long in terms of phonology and morphology, as the retrieval of contextual information would no longer be possible without a structural repair process. A short distance relationship between allomorphs is instantiated in the one-step derivation (morphology) and/or a similar place of articulation (phonology). As the LPN component is an index of the recollection process, it might be encountered in the word list experiments employing a memory task.

Table 5. Characteristics of the LPN (Late Posterior Negativity) component

Characteristics	*LPN*
Latency	600-1200 and 1200-1900 msec post stimulus
Topography	Centro-parietal electrode sites
Stimulus type	Words, images, events
Sensitivity	A strong response conflict, retrieval of contextual information
Functionality	Reflects action monitoring, source monitoring
Suitable for	Studies on action monitoring, contextual retrieval, and recognition memory
Unsuitable for	Studies employing linguistic tasks, i.e. grammaticality judgment, etc.
Open questions	Can LPN be used in linguistic studies?
Relevance to the present thesis	LPN could be observed when the retrieval of contextual information is hindered by the application of a wrong allomorph

1.2.2 The ERP components within the framework of the current experiments

The ERP experiments that will be discussed in the following chapters investigate the interface of phonology and morphology in the representation and processing of phonological stem variants, i.e. regular and irregular stem allomorphs. These experiments assess the processing of deviant morphological constructs in isolation or within a sentence context in comparison with the normal processing of correct word forms. Considering the nature of experimental stimuli, we expect to observe morphosyntactic ERP components – LAN and P600 – as an index of allomorph misapplication. On the other hand, if stem allomorphs are stored separately, the structural repair process of a wrong allomorph is impossible. In this case, the deviant structure may be processed as a semantic anomaly triggering an N400 component.

The task requirements and experimental design may influence the processing of experimental items in order to improve or accelerate the task performance. Thus, a lexical decision task must trigger semantic processing indexed by N400. During the presentation of morphologically deviant word forms in isolation, we may observe a PMN effect reflecting a deviant phonological structure. The PMN effect may be followed by an N400, indexing a semantically anomalous structure, or by an LPN effect reflecting a problematic retrieval of contextual information.

Summarized, if (i) a phonological alternation can be generalized into a morphophonological rule this rule can be listed in the mental lexicon. In this case the manner of representation of regular vs. irregular stem allomorphs should differ. If (ii) a phonological alternation must be memorized regardless of its regularity or productivity, regular and irregular stem allomorphs must be stored in a similar manner. For the validation of (i) we expect to observe differential violation-related brain responses elicited by the misapplication of regular vs. irregular stem allomorphs. Conversely, for the validation of (ii) similar error-detection mechanisms should be observed.

1.3 Outline

The present thesis is focused on two morphological processes, viz. derivation and past tense formation of irregular verbs, and is therefore subdivided into two major parts. The *first* part of the thesis investigates the derivation involving an obligatory regular alternation of the stressed stem vowel. Here we apply a cross-linguistic approach using two Germanic languages – English and German. These Germanic languages differ in inflectional morphology and compounding, German being richer in these terms than English. However, in terms of derivational morphology, these languages are based on similar structural principles. Both English and German have derivational paradigms involving an obligatory stressed stem vowel alternation, e.g. *tone* [əʊ] – *tonic* [ɔ] or *divine* [aɪ] – *divinity* [ɪ] in English, and *lang* [a] (long) – *Länge* [æ] (length) in German, that could be used for cross-linguistic generalizations. If the results obtained for one language could be replicated for the other belonging to the same language family (in this case, the West Germanic family), it could suggest a similar organization of the structure of lexical entries in the mental lexicons of these languages.

The *second* part of the thesis investigates the past tense formation of the German strong (irregular) verbs. The goal of this series of studies is to establish the structure of the mental lexicon entry with respect to irregular stem allomorphy. The secondary goal is to find out whether there is a hierarchy in the processing of the irregular stem allomorphs, i.e. a prioritization of one tense form over the other. The decision to use the German strong verbs as an object of the study was determined by a number of reasons. Both English and German irregular verbs use a stem vowel alternation, known as ablaut, to generate a past tense form. Ablaut is qualitatively different from the stem alternations employed in the derivational patterns discussed in the first part of this thesis. While the derivational patterns under discussion make use of the regular stem allomorphy, ablaut patterns are irregular (although they can still be classified) and unproductive. Whilst English only employs ablaut to generate a past tense or a past participle form of an irregular verb, German makes use of both ablaut and inflectional affixes to generate past tense forms for certain persons and numbers (e.g. ablaut+{- *st*} in the 2nd pers., sg.). Thus, the first reason to choose German over English was the possibility of studying ablaut in combination with inflection, which is impossible with the English irregular verbs.

The second reason for choosing German was determined by the necessity to investigate the processing of violated and non-violated verbs in a sentence context. With the exception of emphatic constructions that allow inversion, English is an SVO language, i.e. a finite verb follows its subject and precedes its object: $\textit{Martha}_{\textit{subject}}$ $\textit{loves}_{\textit{verb}}$ $\textit{dogs}_{\textit{object}}$. The obligatory feature of the German sentences (main clauses) is that a finite verb be in the second position either preceded or followed by the subject. Compare the following sentences: (1)

Martha$_{subject}$ *isst*$_{verb}$ *Müsli*$_{object}$ *zum Frühstück*$_{adv}$ (Martha eats muesli for breakfast). (2) *Zum Frühstück isst*$_{verb}$ *Martha*$_{subject}$ *Müsli*$_{object}$ (For breakfast eats Martha muesli). The structure of the first German sentence corresponds to the canonical word order of an English sentence, i.e. the verb follows its subject. The second German sentence, however, demonstrates a legal German structure that cannot be encountered in a non-emphatic construction in English. The possibility of introducing the adverbial modifier of time prior to the predicate allows us to establish a temporal context. The temporal context, in its turn, exerts restrictions upon the tense form of a strong verb including the set of the person and number suffixes. Differential error-sensitivity to the misapplication of a strong verb's tense form and to the violation of the subject-verb agreement could be indicative of the organization of the mental lexicon with respect to the irregular stem allomorphy.

Taken together, the results of the experiments reported in the first and second parts of the present thesis should provide answers to the following questions:

1) How is regular stem allomorphy represented in the mental lexicon? Does each regular stem allomorph have a separate entry or do they share a lexical entry?
2) Does the storage manner of regular stem allomorphs in the English mental lexicon differ from that in the German mental lexicon?
3) How are irregular stem allomorphs of strong verbs stored in the German mental lexicon? Is there a hierarchy in the representation and/ or processing of different tense forms?

2 General Methods

The present chapter describes the methods common to the studies reported in this thesis. The general methods chapter comprises the information about the selection process of the subjects, the recording and auditory processing of the stimuli, the general set up and procedure of the experiments and the EEG recording and, finally, the statistical analyses employed in the data processing. The specific information concerning each study will be discussed in the corresponding chapters.

2.1 Experiments on Stem Allomorphy

The reported series of experiments were designed to investigate the structure of the mental lexicon with respect to the representation of regular and irregular stem allomorphy. The first part of the present thesis investigates the regular allomorphy in German and English for the purpose of cross-linguistic generalization. We also added a pilot study with Italian/Spanish L2 learners of German to study the acquisition of the morphosyntactic rules employed in the regular stem allomorphy. Considering a very small sample size, we decided not to include the L2 speakers into the General Methods chapter. The second part of the thesis explores the irregular stem allomorphy in the German mental lexicon only. Therefore, the proportion of the nationality samples, i.e. British vs. German, is three to five.

A detailed account of the composition of the stimulus materials will be presented in the following chapters. The present chapter simply provides the information about the physical processing of the stimuli.

2.2 Methods

2.2.1 Participants

All subjects were native speakers of British English or Standard German (no other language learned before the age of five) and were assessed right-handed (i.e. with the lateralization quotient of over 81%) by the Edinburgh Handedness test (Oldfield, 1971). They had normal or corrected-to-normal vision, no hearing impairments, as tested by the standard audiometry procedure (DIN EN ISO 8253. Audiometrische Prüfverfahren. Berlin: Beuth-Verlag), were not taking any psychoactive medication, and reported no psychological or neurological disorders. The subjects gave written informed consent and were paid for participation. Each subject participated only once in the reported series of studies.

2.2.2 Materials

A native speaker of either British English or Standard German was trained to pronounce all experimental items naturally with a similar speed but with a variable prosodic contour. The stimuli were recorded and digitized with 16 bits precision and 44.1 kHz sampling rate using Tascam HD-P2 portable stereo audio recorder. During the consecutive processing with the software *Adobe Audition 2.0* the RMS amplitude of the stimuli was normalized to 70%, the onsets and offsets (30 msec) of the samples were smoothly faded. To avoid a jitter of approx. 230 msec from the begging of the critical word to its vowel, the trigger was set on the third glottis wave of the stem vowel. This wave is the first point on the spectrogram where the first and the second formants of the vowel are visible.

2.2.3 Procedure

The subjects were tested individually in a dimly illuminated sound-attenuating booth. Before the experiment, the EOG was recorded. The participants were seated in a comfortable EASY chair 1.5 meters away from a computer monitor. The stimuli were presented binaurally through headphones with the interstimulus interval (ISI) of 2 seconds. During the stimulus presentation the computer screen was black with a white fixation cross in the middle; the fixation cross appeared 200 msec before the stimulus presentation and disappeared at the onset of the ISI. The subjects were instructed to avoid any body or eye movements, to fixate on the cross, but were free to blink when the cross was not displayed during the ISI. Before the experiment, the participants had a short practice block. The whole procedure took approximately 2 hours, including the set-up and three 5-minute breaks between the runs.

2.2.4 EEG Recording

Electroencephalogram (EEG; BrainAmp amplifier; Brain Products GmbH) was recorded using 64 sintered Ag/AgCl electrodes placed in an elastic electrode cap (EasyCap 64 channels, equidistant) with respect to a vertex reference (Cz). The EEG data underwent an average-reference transformation off-line. The electrooculogram (EOG) was recorded bipolarly using two electrodes positioned near the outer canthi of the eyes (LO1, LO2) for horizontal eye movements (HEOG). Vertical eye movements (VEOG) were monitored with electrodes placed below (IO1 and IO2) and between the eyes (Nz). The ground electrode was affixed to the right cheek. The impedances were kept below 5 kΩ at the scalp sites and below 10 kΩ for EOG. The EEG was recorded continuously with a sampling rate of 500 Hz using a time constant of 10 s up a cut-off frequency of 250 Hz.

2.2.5 Data Analysis

The EEG data were filtered offline with a low cutoff filter at 0.01 Hz and with a high cutoff filter at 30 Hz and corrected for eye artifacts using BESA 5 (Berg & Scherg, 1994). Event-related brain potentials (ERPs) were created by averaging all acceptable trials in each condition type for each participant. The duration of epochs was 1200 msec, from a 200-msec pre-stimulus onset baseline to 1000 msec post stimulus. Trials with gradient amplitude of over 75 µV were automatically discarded from the analysis; the remaining trials underwent visual inspection for artifacts. In total, approximately 10% of the data were rejected. The epochs were baseline corrected relative to the mean voltage of the 200-msec pre-stimulus interval.

All statistical analyses were performed with R 2.7.2 (The R Foundation for Statistical Computing), and SPSS (IBM SPSS Statistics 21, Inc.) software. The data matrices used in the repeated-measures analysis of variance (ANOVA) first underwent Mauchly’s sphericity test. If sphericity was not violated, the uncorrected results were reported. Conversely, if sphericity was violated, the Greenhouse-Geisser correction was employed, and the corrected results were reported. Post-hoc pairwise comparisons underwent Bonferroni α-correction. The α-corrected results are reported here.

The electrode sites used in the repeated-measures ANOVAs for the calculation of clusters of the factors *Anteriority* (Anterior, Central, Posterior) and *Laterality* (Left, Middle, Right) were selected as follows: F5, AF7, AF3, FP1, F1 – anterior left; Fz, FCz, FC1, FC2 – fronto-central; F6, AF8, AF4, FP2, F2 – anterior right; FT7, FC5, T7, C5, FC3 – medial left; Cz, CPz, CP1, CP2, – central; FT8, FC6, T8, C6, FC4 – medial right; CP5, TP7, P7, PO9, P3 – posterior left; Pz, P1, P2, – centro-parietal; CP6, TP8, P8, PO10, P4 – posterior right.

3 Regular Stem Allomorphy

3.1 Overview

3.1.1 Trisyllabic shortening

The most common examples of phonologically predictable allomorphy in English are those of the regular past tense, viz. the suffix {-ed}, and the negative prefix {in-}. In these examples the surface form of the morpheme is determined by its phonological environment. However, there are also cases of allomorphy that require some morphological information in order for a phonological rule to apply. For instance, final voicing of fricatives mark a noun-verb alternation such that the verb has the voiced obstruent while the noun surfaces with a voiceless one (*to advise* [z] (verb) – *advice* [s] (noun)). The cause is diachronic where the voiced fricative had undergone medial voicing. Another instance of moprho-phonological alternation is or trisyllabic shortening in derivation, where a long stressed vowel (or a diphthong) becomes lax and open: e.g. *serene* [i:] (adj.) – *serenity* [ɛ] (noun). In order to apply, both rules require morphological information about the stem morpheme and the target word. According to Mohanan (1986), "a rule application requiring morphological information must take place in the lexicon" (Mohanan, 1986:9). Nevertheless, the conditioning is phonological - that is, the window where the shortening takes place is a three-syllable window. The present series of ERP studies is focused on the investigation of the latter set of phonological alternations, i.e. when a derivational process involves a regular phonological alternation of a stem vowel. We hypothesize that such regular phonological stem variants, or allomorphs, should be represented by a single underlying morpheme with a set of morphophonological and morphosyntactic rules that determine the surface form of such an allomorph, rather than each allomorph having a separate lexical entry.

For the series of experiments reported in this subchapter, we chose a derivational phenomenon that involves both affixation (suffix {-ity}) and a phonological alternation of the stem vowel in the immediate derivation process (i.e. one-step derivation from an adjective to a noun), generally referred to as trisyllabic shortening. A group of words that underwent the process of trisyllabic shortening was used as a control condition. The experimental items were obtained by manipulating the stem vowel of the control words. They were subsequently used in word list experiments with a lexical decision task and a memory task. The main research objective of the present study was to determine the error detection mechanisms involved in the word recognition process when the phonological structure of words is violated. Particularly, it aimed to establish whether there is a correlation between the types of stem violation (a stem allomorph in the wrong morphological environment vs. a non-existing stem) and the violation responses.

The process of trisyllabic shortening is featured in the derivation of a noun from an adjective containing a long vowel or a diphthong in a stressed syllable. Its derivational paradigm consists of the attachment of the suffix {-ity} to the right boundary of an adjectival stem and a simultaneous shortening of the stem vowel: *serene* [səˈriːn] (adj.) + {-ity} & trisyllabic shortening > *serenity* [səˈrɛnəti] (n.). The resulting vowel is then lax and open, i.e. [aː] > [æ], [eɪ] > [ɛ], [iː] > [ɛ], etc.

In Modern English, trisyllabic shortening (TSS) is associated with derived environments, particularly those involving non-native (Romance) suffixes. Indeed, the majority of vowel alternations are found in the Romance loans. Lahiri and Fikkert (1999) argued that cases of TSS, like *sincere* – *sincerity*, appeared due to the difference in the time of borrowing (see Table 6). However, such a rule was present in the synchronic phonology of the late Old English and it was extended to the long nouns from Romance. The words were borrowed independently from each other, derived words often appearing earlier than their bases. Due to the difference in the time of borrowing and to the fact that these words were sometimes semantically unrelated, they were not considered as morphologically/derivationally related till later. The authors maintained that these words were borrowed with the preferred prosodic structure at the time of borrowing (a resolved moraic trochee), which included the constraint of TSS. In the seventeenth century, the derivational relation between *–ity*-words and their bases was established and the suffix {-ity} finally became productive. During this period, the TSS constraint came to ensure that the stressed vowel was lax, again following the prosodic system of that stage – a moraic trochee (Hayes, 1995). Therefore, at each stage of the diachronic development of the English vocabulary, TSS served the purpose of optimizing the prosodic structure.

Table 6. Romance loans

The first and fourth columns show the base words and words ending in –ity with vowel alternation in the derivational paradigm. The second and fifth columns indicate the date of borrowing. The third and sixth columns represent the meaning of the words at the time of borrowing (taken in a shortened form from Lahiri and Fikkert, 1999, p.250).

Base	***Date of borrowing***	***Meaning***	***Derived word***	***Date of borrowing***	***Meaning***
divine	1374	pertaining to God	*divinity*	1305	the science of divine things
extreme	1460	existing in the utmost possible degree	*extremity*	1375	the extremes as opposed to the mean
grave	1541	weighty, important	*gravity*	1519	seriousness, dignity
hostile	1594	pertaining to the enemy	*hostility*	1531	the state or fact of being hostile
humane	1500	characterized by such a behavior towards others that befits a man	*humanity*	1382	the character of being humane
sane	1628	of sane memory	*sanity*	1432	bodily health
serene	1503	honorific	*serenity*	1450	title of honor
severe	1548	rigorous condemnation or punishment	*severity*	1481	strictness of life
sublime	1586	expressing lofty ideas in a grand and elevated manner	*sublimity*	1526	loftiness of nature
vain	1300	worthless; useless	*vanity*	1230	that which is worthless
able	1325	having sufficient power	*ability*	1380	sufficient power, ME ablete, abilite
austere	1330	harsh to the feelings	*austerity*	1340	harshness to the feelings
brief	1325	of short duration; late ME bref	*brevity*	1509	being short in speech or writing
clear	1297	free from obscurity	*clarity*	1340	glory, divine luster
obscene	1593	offensive to the senses or to taste or refinement	*obscenity*	1608	impurity, indecency, lewdness
opaque	1420	lying in shadow, not illuminated	*opacity*	1560	mental or intellectual dullness
profane	1483	not pertaining or devoted to what is sacred	*profanity*	1607	the quality of being profane
profound	1305	characterized by intellectual depth	*profundity*	1432	depth in a physical sense
senile	1661	peculiar to the aged	*senility*	1791	the condition of being senile
sincere	1533	genuine; pure; honest	*sincerity*	1546	purity

Chomsky and Halle analyzed the nonback vowel alternations in such word pairs as *divine – divinity*, *serene – serenity*, *profane – profanity*, where the first member of a pair serves as the adjectival base of the second member, which is a derived noun. The adjectival base should have a tense vowel in the final syllable so that it receives stress by the strong cluster rule (a heavy syllable receives stress). Therefore, these words should be listed in the lexicon with a tense vowel in the final syllable, viz. *div**I**n*, *ser**E**n*, *prof**A**n* (where [***I***], [***E***], [***A***] are phonologically tense vowels). To account for nonback vowel alternations in the derived environments, Chomsky and Halle put forward the following set of rules. The first rule defined the nonback alternation of the tense vowels in certain contexts (Chomsky & Halle, 1968:179). The second rule defined those contexts, i.e. an underlyingly tense vowel became lax in a stressed position before the suffix {-*ic*}, {-*id*}, or {-*ish*} and before an unstressed nonfinal syllable, e.g. *tone/tonic*. In accordance with this rule, the disyllabic suffix {-*ity*} should have an immediate laxing effect on the preceding vowel.

The reported diachronic account (Lahiri & Fikkert, 1999) demonstrated that due to different times of borrowing of the adjectival bases and the nouns derived from those, these words were initially treated as morphologically unrelated. Therefore, it is reasonable to assume that, at least, at the time of borrowing the word pairs of the type *divine – divinity* were stored separately. According to the reported synchronic (Chomsky & Halle, 1968) account, the alternating stem vowel should be represented as a tense/long vowel in the mental lexicon. The stem vowel should be shortened due to the optimization of the prosodic structure, or in accordance with the laxing rule respectively. However, it was not established how the surface (phonetic) form of the alternating stem vowel should be generated in the derived environments, i.e. [aɪ]→[ɪ], [i:]→[ɛ], etc. Chomsky and Halle considered the possibility of representing the phonetic form of alternating stem vowels in terms of features. Such representation could render the changes that a tense vowel has to undergo to become lax. Such manner of representation would imply a separate list of alternating features for each case of laxing. Thus, the above mentioned laxing examples, viz. [aɪ]→[ɪ], [i:]→[ɛ], would require the alternating feature [BACK] in the first case that would be missing in the second one. This manner of representation was rejected by the authors as they thought it would unnecessarily complicate the rule, making the underlying generalization impossible.

Marslen-Wilson et al. (1994) investigated the structure of the English mental lexicon with respect to the modality (visual vs. auditory) of the mental representation. They explored the interface of morphology and semantics also considering the phonological structure of the morpheme constituents. The authors were especially interested in finding out whether priming could be triggered by phonologically opaque morphological pairs. In a series of cross-modal priming experiments with auditorily presented primes and visually presented targets, the authors examined the lexical retrieval process when one of the linguistic structures – phonological, morphological, or semantic – was opaque. Thus, they compared semantically related derivational pairs (a suffixed word as a prime and a stem as a target) whose stem vowel or a consonant was modified via the derivation procedure (*ser***e***nity - ser***e***ne* or *elu***s***ive - elu***d***e*). Despite the phonological opacity, the amount of priming in this condition did not significantly differ from the phonologically transparent and semantically related derivational pairs (*friendly - friend*). The follow-up experiments with derivational pairs, where free stems were used as primes and suffixed words as targets and vice versa, also showed a significant amount of priming. Priming however was blocked when two suffixed forms were used as prime-target pairs. The authors put forward the assumption that the mental lexicon was modality free and should be organized on a morphological basis in an abstract phonological form. The orthographic form as well as the surface phonetic form had to be derived from the abstract representation.

Taking into account different accounts of trisyllabic shortening in English (Chomsky & Halle, 1968; Lahiri & Fikkert, 1999) and the empirical evidence provided by Marslen-Wilson et al. (1994), we may conclude that allomorphs of stems with regular alternations should be represented by a common abstract stem morpheme. According to Chomsky and Halle, the stem vowel undergoing trisyllabic shortening should be represented in the lexicon as tense/long. Marslen-Wilson et al. (1994), however, argue that the alternating stem vowel should be unspecified for tenseness and height in the underlying representation. In order to define the surface form of this vowel, the lexical entry should contain the rules of possible phonological alternations within the stem. Furthermore, it should also contain combinatorial rules reflecting the stem's syntactic and phonological properties. Such a set of morphophonological and morphosyntactic rules can ascribe phonological changes within the stem to corresponding morphosyntactic processes. Thus, if the underlying morpheme with an unspecified vowel {serEn} is used in an underived environment, a tense/long vowel is used in the surface form, viz. the adjective *serene*. Also, if {-ity} is attached to the right boundary of the underlying morpheme with an unspecified vowel {serEn}, a lax and open vowel is used in the surface phonetic form {serɛn} of the resulting noun *serenity*. The application of the rule only takes place if stem vowel alternations are regular. The lexical entries of the morphemes capable of TSS should contain a morphophonological rule defining the surface form of the stem vowel in a certain derivational environment. The morphemes that are incapable of TSS – both stems and suffixes – are supposed to be stored without such a rule. The proposed structure of the lexical entry could account for the exceptions to the trisyllabic shortening rule, viz. *legal* – *legalize* [iː/iː], or *obese* – obesity [iː/iː].

The present series of experiments investigated the structure of the lexical entry for semantically transparent derivational pairs characterized by regular phonological alternations of the stem vowel caused by TSS. The objective of the study was to find out whether regular allomorphs of the same stem share an underlying representation in the English mental lexicon. The cases of TSS triggered by the suffix {-ity} are highly predictable and regular, and are therefore most suitable for the investigation of regular stem vowel alternations in derivation. We hypothesize here that regular stem allomorphs should be represented by a single lexical entry with a set of morphophonological and morphosyntactic rules that specify surface forms of a stem in combination with different affixes.

We developed a violation paradigm that included a non-application of the TSS rule in existing and non-existing stems. The resulting nonwords were either semantically repairable via the combined meanings of the constituent morphemes (the omission of the TSS rule in existing stems), or were irreparable nonwords containing non-existing stems. The omission of the TSS rule in non-existing stems was employed to ensure purely phonological violation. The degree of phonological distance – one phoneme or two phonemes – was varied in the non-existing stem conditions. Different types of nonwords were expected to elicit differential brain responses reflecting specific error-detection mechanisms, i.e. triggered by morphological relatedness in the existing stem condition or by purely phonological violation in the non-existing stem conditions. These error-detection mechanisms could be indicative of the processing stages required for the lexical retrieval of the violated as compared to the non-violated items. The degree of deviation from the standard lexical retrieval process could be indicative of the structure of the lexical entry. The online auditory speech processing can be investigated by means of the event related potentials (ERP) technique. The ERP technique provides an opportunity to attach a trigger to an event of interest, such as a phoneme/ a morpheme/ etc., and to observe the brain activity related to this event. The stimulus materials of the present study included nonwords made up by violating the TSS morphophonological rule on a par with completely irreparable nonwords. Therefore, the brain activity elicited by these stimuli could reflect a difficulty in the phonological mapping of the stem vowel, deviant morphological processing, or a failure in the lexical retrieval process. Hence, the expected ERP components could be phonological mapping negativity (PMN), the syntactic ERP component left anterior negativity (LAN), the semantic ERP component N400, and late posterior negativity (LPN) that is usually observed in the studies on the source memory (see Chapter 1 for a detailed account on ERP components). The occurrence and the prominence of the ERP components could reflect the error-detection mechanisms involved in the processing of different types of nonwords.

Table 7. Experimental conditions and predictions for the lexical decision task

*The names and composition of conditions are in the first row: bold italicized **V**s and $\boldsymbol{C_1}$ represent modified phonemes. The contrast of interest is that between **V** (a lax and open vowel) and a long vowel/diphthong $\boldsymbol{V_1}$. The composition example of an English word, "serenity", is given in the second row. The third row demonstrates a graded pattern of N400 effect if our hypothesis is valid, i.e. there is a single entry for all allomorphs. The fourth row represents similar responses for all violation conditions in case of invalidity of the hypothesis, i.e. separate entries for all allomorphs.*

Condition Composition	**W** – Word: Derived stem {C***V***C}+{-ity}	**RD** – related derived: Existing stem illegal in the combination {C$\boldsymbol{V_1}$C}+{-ity}	**UD** – unrelated derived: Non-existing stem {C$\boldsymbol{V_2}$C}+{-ity}	**NC** – nonce complete: Non-existing stem {C$\boldsymbol{V_3}$$\boldsymbol{C_1}$}+{-ity}
Example	serenity	*ser[i:]nity	*ser[aɪ]nity	*seromity
Single underlying stem morpheme	____________	small N400	large N400	large N400
Separate entries for allomorphs	____________	large N400	large N400	large N400

Tables 7 & 8 demonstrate the composition (first line) and the examples (second line) of the stimuli for all experimental conditions, and our predictions for the lexical decision task and the memory task experiments. The baseline *(W)ord* condition is exemplified in the second column of the tables. It is made up of a stem derived from an adjective, now containing a lax and open vowel, and a suffix {-ity}. An adjective *serene* has a long vowel [i:] in the stressed syllable, which is transformed into a lax and open vowel ***V*** [ɛ] via TSS during attachment of the nominalizing suffix {-ity}, viz. *serene* [səˈriːn] > *serenity* [səˈrɛnəti]. The first violation condition *(R)elated (D)erived* is demonstrated in the third column. These nonwords are made up by omitting the TSS procedure, i.e. the stimuli contain original adjectival stems with long vowels/ diphthongs $\boldsymbol{V_1}$ and the suffix {-ity}: e.g. **ser[i:]nity.* Although such nonwords have a faulty phonological structure and are non-existent in English, their meanings can still be retrieved by combining the meanings of their constituent morphemes. We consider these items reparable. The stems of the next two violation conditions are modified to such an extent that they are no longer found in the English vocabulary and are therefore irreparable. The *(U)nrelated (D)erived* items have a manipulated stem vowel $\boldsymbol{V_2}$ while the *(N)once (C)omplete* stimuli have a modified stem vowel $\boldsymbol{V_3}$ and a modified adjacent consonant $\boldsymbol{C_1}$. The NC condition was created to control for the degree of deviation from the stored standard. If the number of violated phonemes ($\boldsymbol{V_2}$ vs. $\boldsymbol{V_3}$+$\boldsymbol{C_1}$) plays a role during the word recognition process, the UD and NC conditions should elicit differential violation brain responses, and vice versa. Both tense and lax vowels were used to create the irreparable pseudowords so that the number of tense and lax vowels could be balanced across all experimental items.

Considering the structural homogeneity of the experimental items, viz. {-ity} nouns, we expected our subjects to develop a strategy related to the experimental task after hearing, at least, 10 items. In the lexical decision task experiment, such a strategy could be the stripping of the suffix {-ity} and mapping of the stems directly onto the stored stem variants. This lexical look-up could result in an N400 effect for the violated stimuli. The predictions for the amplitude of the N400 effect are given in Table 7 according to the validity or invalidity of our hypothesis. The third line demonstrates a differential N400 effect in case of validity of our hypothesis. If regular stem allomorphs have a single lexical entry, the semantics of RD items can be repaired online and the N400 effect, evoked by these stimuli, should be mild. The amplitude of the N400 evoked by the UD and NC items should be larger than that elicited by the RD items due to impossibility of retrieving the semantics of the pseudowords and structurally repairing them. Furthermore, based on equal irreparability of the UD and NC conditions, the N400 effect should be similar for both of these irreparable violation conditions.

If our hypothesis is invalid, i.e. regular stem allomorphs have separate entries, the morphosyntactic repair in case of the RD nonwords would be impossible because a long stressed vowel cannot be found next to the suffix {-ity}. The failure to map the RD stems directly onto the stored standards would result in a larger N400 effect than that described for this condition above. Therefore, all violation conditions would elicit similar large N400 effects. This pattern of results is demonstrated in the fourth row of Table 7.

Table 8. Experimental conditions and predictions for the memory task

The names and composition of conditions are given in the first row. The example of a graded violation pattern of an English word, "serenity", is in the second row. The third row shows predictions for a single entry with large PMN or large LAN for RD items, small PMN or large N400 for UD and NC items. The fourth row represents predictions for separate entries for all allomorphs with similar large N400 effects for all violation conditions.

Condition Composition	**W** – Word: Derived stem {C***V***C}+{-ity}	**RD** – related derived: Existing stem illegal in the combination {C$\boldsymbol{V_1}$C}+{-ity}	**UD** – unrelated derived: Non-existing stem {C$\boldsymbol{V_2}$C}+{-ity}	**NC** – nonce complete: Non-existing stem {C$\boldsymbol{V_3}$$\boldsymbol{C_1}$}+{-ity}
Example	serenity	*ser[i:]nity	*ser[aɪ]nity	*seromity
Single underlying stem morpheme	____________	large PMN/ large LAN large LPN	small PMN/ large N400	small PMN/ large N400
Separate entries for allomorphs	____________	large N400	large N400	large N400

The strategy the participants could develop for the memory task experiment was expected to be different from that used in the lexical decision task experiment. The subjects were instructed to listen to the stimuli and memorize them for a subsequent memory task which made the lexical retrieval a secondary process. Keeping the items in the short term memory should be the primary one. Therefore, several distinct components could be observed. If our hypothesis was valid, we predicted that the RD items would elicit a large PMN due to the incompatibility of the phonetic input with the expected morphophonological form or a large LAN effect due to the morphosyntactic processing (see Table 8). Considering the growing demand to maintain the contextual information attributed to the RD items, the increased task-related memory load could be reflected in the LPN effect. To sum it up, our hypothesis being valid, the RD items could elicit one or several of these components: a large PMN, a large LAN, and/ or a large LPN.

The PMN effect for the irreparable items – UD and NC – should be milder than that elicited by the RD items due to the fact that these violation conditions had an equal number of long and short vowels in the stressed position. We did not expect these items to evoke any LAN effects for the reason that the stems of these items were non-existent. Therefore, they should either be treated as irreparable nonwords evoking large N400 effects or be memorized as novel words eliciting no violation responses in the latency of the N400 component. Finally, as novel words do not carry any contextual information, we did not expect the irreparable nonwords to evoke any LPN effects.

All violation conditions should elicit either similar large N400 effects or no effects at all in line with the previous argumentation, if our hypothesis is invalid.

3.1.1.1 Experiment 1: Lexical Decision Task

3.1.1.1.1 Methods

Participants

Sixteen students of the University of Oxford (8 male, age range: 18-29 years, mean: 20.93) took part in this study. Three subjects had to be excluded from the analysis due to the muscular artifacts, alpha, and too many false responses in the behavioral task. All subjects were native speakers of British English (RP) and were born/brought up in the south-east area of England.

Materials

Five sets of tri- to five syllabic nouns were used in this study (see Table 7 and Appendix A for examples). The first four sets were made up of twenty-three items each. The control items (W condition) were relatively frequent (mean in Celex: 68.2, mean in Leipziger Corpus: 584.8) English nouns derived from mono- to trisyllabic adjectives with a tense vowel (diphthong) in the stressed final syllable by attaching the nominalizing suffix {-ity} to the right boundary of the stem. The suffix {-ity} triggers TSS, as a result of which the tense stressed vowel becomes open and lax: e.g. *ser**e**ne* [i:] (adj.) + {-ity} = *ser**e**nity* [ɛ] (noun).

In the related-derived condition (RD), the adjectival stem vowel was kept intact, so that the resulting nonword contained an existing stem in a morphophonologically illegal combination with the suffix {-ity}: viz. non-application of the TSS rule in the stem {*ser**e**n}* + suffix {-ity} = **ser[i:]nity*. The stem vowel in the unrelated-derived condition (UD) was changed to such an extent that the stem was no longer existent in the English language, e.g. **ser[aɪ]nity*. We balanced the number of trisyllabic shortened and non-shortened vowels in order to control for probable morphophonological confounds. If the morphophonological layer applies separately from the semantics, i.e. it is not part of the lexical entry, the cases of the non-application of the TSS rule should evoke a morphosyntactic component, such as P600. The last set of experimental stimuli, Nonce complete (NC), was introduced as a control condition for the nonword effects (such as zero frequency of occurrence, irreparability) as well as a control condition for purely morphophonological effects, with the same argumentation as that mentioned above. This condition was produced by manipulating two phonemes of the stem syllable adjacent to the suffix {-ity}, viz. the vowel and the coda consonant, in the stems of control words. This manipulation yielded a non-existent stem, e.g. **seromity*. The fifth set of stimuli was used as Fillers and was made up of forty-six existing nouns that were derived from adjectives by attaching the suffix {-ity} to the right boundary of the stem, however without the application of the TSS rule, viz. *capacity*, *majority*.

A native speaker of RP British English (male) was trained to pronounce all experimental items naturally with a similar speed but with a variable prosodic contour. For the recording, he pronounced each item thrice with different prosodic tunes, producing three tokens of each experimental item. We decided to employ variable prosodic tunes in order to avoid a listener's habituation to the listing intonation. With the intention of avoiding possible prosodic confounds, we controlled for the pitch contours so that they were completely randomized.

The total 414 experimental items were divided into three runs, 138 words each: the first run was made up of the RD items and the Fillers; the second run was made up of the UD items and the Fillers; the third run contained the W items and the NC nonwords. The pseudo-randomization procedure was run to ensure the appearance of each item in a unique context. We also rotated the experimental runs so that the order of these could not become a confound.

Procedure

The participants were tested individually in an electrically and acoustically shielded booth. They were instructed to listen to the presented words and to indicate an existing English word by pressing a corresponding button on the response box. The stimuli were presented binaurally through headphones. The fixation cross appeared 200 msec before the stimulus presentation and disappeared at the onset of the ISI. Different onsets of the visual and auditory events were chosen for the sake of the non-overlapping of the respective effects.

EEG Recording

The EEG recording proceeded as previously described in the General Methods section.

Data Analysis

The epochs of the correctly identified items within the amplitude range of 75 µV were averaged and baseline corrected for each condition and for each participant. The approximate rejection rate was 9%.

After the visual inspection of the grand averaged waveforms and the topographies, we set the time window for the parameterization of the data at 300 – 500 msec that corresponds to the latency range in which the N400 component had been reported in earlier studies (Kutas & Federmeier, 2011).

Repeated measures ANOVAs were run with three within-subject factors: Anteriority (anterior, central, posterior), Laterality (Left, Middle, Right), and Stem type (W, RD, UD, NC).

3.1.1.1.2 Results

Behavioral data showed that 2% of nonwords were falsely identified as words; however, the error rate did not differ between the experimental conditions. Repeated measures ANOVA with two within-subject factors (Presentation (first to third time) and Condition) revealed no main effects or interactions (all $p > 0.1$).

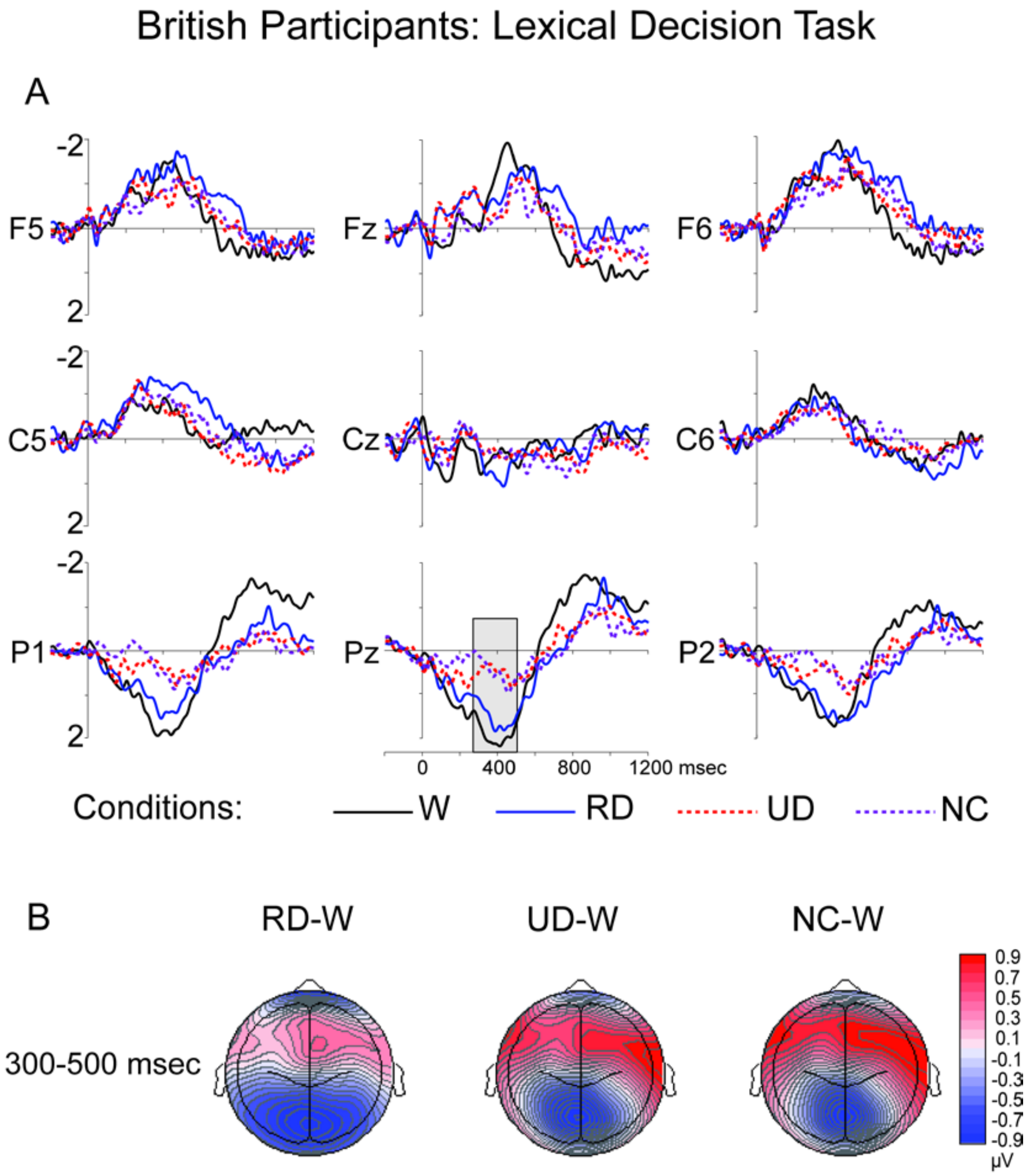

Figure 2. British Participants: Lexical Decision Task

Grand averages (A) and topographies (B) of the difference waveforms are shown for all experimental conditions in the lexical decision task experiment with the British participants. The N400 effect is highlighted at the Pz electrode. Note that the violation conditions demonstrate a graded pattern: the W (black solid line) condition is the most positive curve, followed by the RD (blue solid line) condition. The UD (red dashed line) condition is more negative than the RD curve and the (N)once (C)omplete (purple dashed line) patterns with the UD. The topographies (B) show a similar scalp distribution for all conditions.

Figure 2 displays the grand average waveforms and the topographies of the difference waveforms of the type Violation condition–W. The topographies are shown for the latency range of 300-500 msec. The graded pattern of the N400 effect is most pronounced at the Pz electrode: the W condition (a black solid line) has the most positive value, the RD condition (a blue solid line) is more negative than W but more positive than UD and NC; the UD (a red dashed line) and the NC conditions (a purple dashed line) pattern together and are most negative. The negativity triggered by the W condition at the frontal electrode sites as well as the general difference between this condition and the nonword conditions was most probably due to the motor-preparation.

The omnibus 3-way ANOVA revealed a significant interaction of the type Anteriority X Laterality X Stem type: F (5.42, 81.36) = 7.4, p < 0.001. We ran a series of one-way ANOVAs for each region that revealed a main effect of Stem type at the centro-parietal electrode sites (Pz, P1, P2): F (2.9,44.02) = 9.97; p<0.001. As the W condition was contaminated with the motor preparation we also ran a one-way ANOVA with the nonword conditions only: F(1.99,29.87) = 6.33, p<0.01. The mean amplitude values of the N400 component for all conditions are illustrated in Figure 3. The contrast analysis (RD vs UD&NC) revealed a significant difference of the reparable nonword condition (RD) from the irreparable ones: t(45) = 3.55, p=0.001.

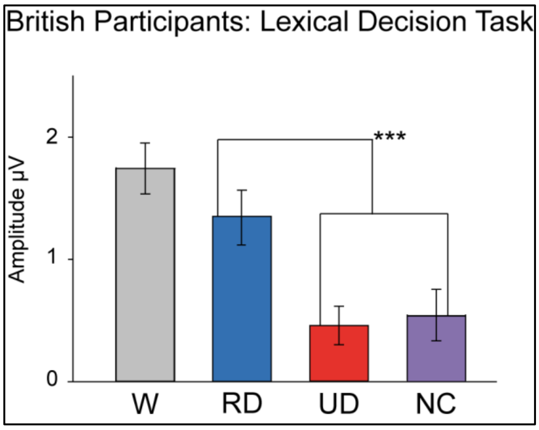

Figure 3. British Participants: the N400 Effect

*N400 amplitudes at the Pz electrode are shown for the lexical decision task experiment with the British participants. The significant difference between the RD and irreparable nonword conditions is marked with asterisks: *** = <0.001.*

3.1.1.1.3 Discussion

The brain activity during the lexical decision task revealed a graded ERP response pattern to the violated items. The RD items elicited a mild N400 effect, while the UD and the NC items evoked the most pronounced N400 effect that was similar for both of these conditions. No other violation effects were observed.

We hypothesized that regular stem allomorphs should share a lexical entry (Lahiri & Marslen-Wilson, 1991; W.D. Marslen-Wilson et al., 1994). For the validity of our hypothesis, we predicted a mild N400 effect for the RD items as these can be repaired via access to the semantics of the constituent morphemes McKinnon et al. (2003). Due to the impossibility of repairing the UD and the NC items, the N400 effect elicited by these conditions should be larger than that evoked by the RD items. Although the degree of deviation from the stored standard varied within these two conditions (stem vowel vs. stem vowel + coda consonant), we considered both conditions equally irreparable, and thus predicted a similar N400 for both of the irreparable violation conditions. The results of the experiment confirmed our predictions by demonstrating a graded N400 pattern, viz. W<RD<UD=NC.

We expected the participants to develop a strategy in the context of homogeneous experimental materials, i.e. nouns ending in the suffix {-ity}. The lexical decision task, i.e. a reaction to the existing words only, was also expected to trigger specific processing. The possible strategy was the suffix stripping and the mapping of the resulting stem onto the stored stem variant that is usually found in this morphophonological environment. The graded N400 effect, elicited by the nonwords, could be indicative of a differential goodness of fit for these items, or in other words, it could reflect the degree of deviation from the stored standard. The stem allomorph employed in the W condition always surfaces with a lax and open stem vowel, as required by the TSS rule. Despite the fact that the RD and the W conditions are derived from the same stem, the stems of the RD items containing a tense vowel are never found in the {-ity} environment. Therefore, an immediate reconstruction or a direct mapping onto the stored standard was not possible as reflected in the significant difference between the W and the RD conditions. At the same time, the possibility of formal repair via off-line application of the TSS rule attenuated the N400 effect elicited by the RD items.

The significant difference of the RD condition from the other two nonword conditions demonstrated differential mechanisms underlying the processing of these nonwords. Though formally/ morphophonologically deficient, the RD nonwords still had a rather transparent semantic structure via the access to the stem morpheme. Therefore, the RD violation was not severe enough for its items to be categorized as completely non-existent, as was the case with the UD and NC conditions (McKinnon et al., 2003). The UD and NC items elicited similar brain responses although they had variable degrees of deviation from the stored standard. While the UD items deviated in the stem vowel only, the NC items had a modified stem vowel and a modified adjacent consonant. Despite a differential distance to the standard, both irreparable conditions were processed in the same way, viz. as non-existent stems.

The difference of the RD items from all other conditions was in line with our hypothesis and predictions. Although the RD nonwords could not be found in the English vocabulary, they were semantically transparent and morphophonologically reparable due to the access to the basic stem. We argue that this stem has a vowel unspecified for tenseness, whose surface form is defined by the morphophonological and morphosyntactic rules (Marslen-Wilson et al. 1994). The possibility of the stem vowel surfacing as a tense vowel in one morphological context, or as a lax and open vowel in another, enables the formal repair process.

The error-detection mechanisms elicited by the violated stimuli in the present study were also highly influenced by the experimental design and the lexical decision task (Kutas & Federmeier, 2011). The items were presented in isolation without a semantic context that could bias the participants' attention towards a certain word candidate. At the same time, the homogeneity of the experimental stimuli created a formal morphosyntactic context – or structural priming – that required a certain type of stem morpheme, i.e. a stressed tense vowel of the adjectival stem must undergo the TSS in the environment of the {-ity} suffix (Ledoux, Traxler, & Swaab, 2007). Therefore, the morphosyntactic context necessitated a certain phonological structure upon the stem morphemes, while making no predictions about a certain word candidate per se. As for the task, the participants were instructed to react only to existing English words by pressing a corresponding key on the response box. On realizing that all stimuli were nouns derived by attaching the suffix {-ity}, the most reasonable strategy for the subjects to accelerate the task fluency would be to strip the suffix and to map the stem morpheme onto the form, preactivated by the morphosyntactic context. A nonword was recognized as such at the onset of the suffix, at the latest.

The implementation of the lexical decision task and the homogeneity of the stimulus materials inhibited the simultaneous activation of both regular stem allomorphs. The morphophonological context required stems, whose stressed vowel underwent TSS or was lax in the basic adjectival form. As the subjects were instructed to react to existing words, only the stem allomorphs that met the requirements of the morphophonological context were activated and retrieved. Although the RD items could be repaired online, such a procedure was unnecessary and 'costly' in light of the present experimental design. This resulted in the rejection of the RD items as real words. This rejection was not complete compared to the UD and NC items, as the constituent morphemes of the RD items exist in English.

The lexical decision task was specifically employed to investigate the processing of regular stem allomorphs from the point of view of lexical semantics. We were interested in the question of whether a structural repair mechanism could be activated regardless of the experimental task. The results of the present experiment revealed a distinct prioritization of one type of linguistic processing – the stem-mapping procedure – over the others, such as the structural repair or the retrieval of contextual information. Although the N400 effect demonstrated that the RD condition differed significantly from other conditions, it was still arguable whether this difference arose due the stem allomorphy or due to the stem frequency effects. To control for these confounds and for the already mentioned strategic effects, we designed an experiment that required memorization of all items as a whole, in order to perform a memory task.

3.1.1.2 Experiment 2: Memory Task

3.1.1.2.1 Methods

Participants

Sixteen subjects (8 male, age range: 19-30 years, mean: 21.31) participated in this experiment. Twelve of the participants were students of the University of Oxford and the other four participants were British exchange students recruited at the University of Konstanz.

Materials and Procedure

We used the same experimental stimuli as in the lexical decision task experiment. The randomization of the items and the rotation of the runs were also kept intact to ensure comparability of the two experiments. The task was, however, different: the participants were instructed to listen to the stimuli presented in blocks of 3-8 words. After each auditory block a word was presented on a computer screen. The subjects were asked to press a corresponding key if they heard this visually presented word in the last auditory block (Yes/No).

Data Analysis

Epochs of the same length as in the first experiment were averaged and analyzed in each condition type for each participant. The trials were baseline corrected and the epochs with amplitude of over 75 µV were automatically excluded from the further analysis. This resulted in the rejection of approximately 7% of the data.

The same statistical analyses as in the lexical decision task experiment were run in this study.

3.1.1.2.2 Results

A one-way ANOVA with the factor Stimulus type (W, RD, UD, NC) was run on the behavioral error data. The results revealed a similar recognition rate for all stimuli ($F(2.93,58.68) = 0.31$, $p > 0.05$).

Figure 4 displays grand averages and the topographies for the difference waveforms of the type Violation condition–W condition in two time windows: 80-180 msec, corresponding to the latency of the PMN component; and 900-1100 msec, corresponding to the time window of the LPN component.

The goal of the study was to determine whether the change of task could result in differential error-sensitivity. In order to assert the disparities between the experiments, we first ran an omnibus test in the time window of the N400 (300-500 msec) components with Task as a between factor. We didn't run the omnibus tests in the time windows of the other components as the Lexical Decision Task experiment data contained motor preparation artifacts. The results of the omnibus tests revealed a four-way interaction of the type Anteriority x Laterality x Stem type x Task: $F (7.07, 211.99) = 3.07$, $p < 0.01$. The within-group analyses were run on mean amplitudes at the centro-parietal electrode sites within the time windows, wherein the PMN and the LPN components have been observed.

The one-way ANOVA revealed a significant main effect of Stem type: $F(2.91,58.26)=4.57$, $p < 0.01$ in the latency range of the PMN component. Figure 5 illustrates the mean amplitude values for the PMN component. The post hoc paired t-tests revealed the following pattern: the W condition was significantly different from the RD ($t(15) = -3.76$, $p < 0.01$) and the UD ($t(15) = -2.26$, $p < 0.05$) conditions. The RD condition was significantly different from the NC ($t(15) = -4.77$, $p < 0.001$) condition.

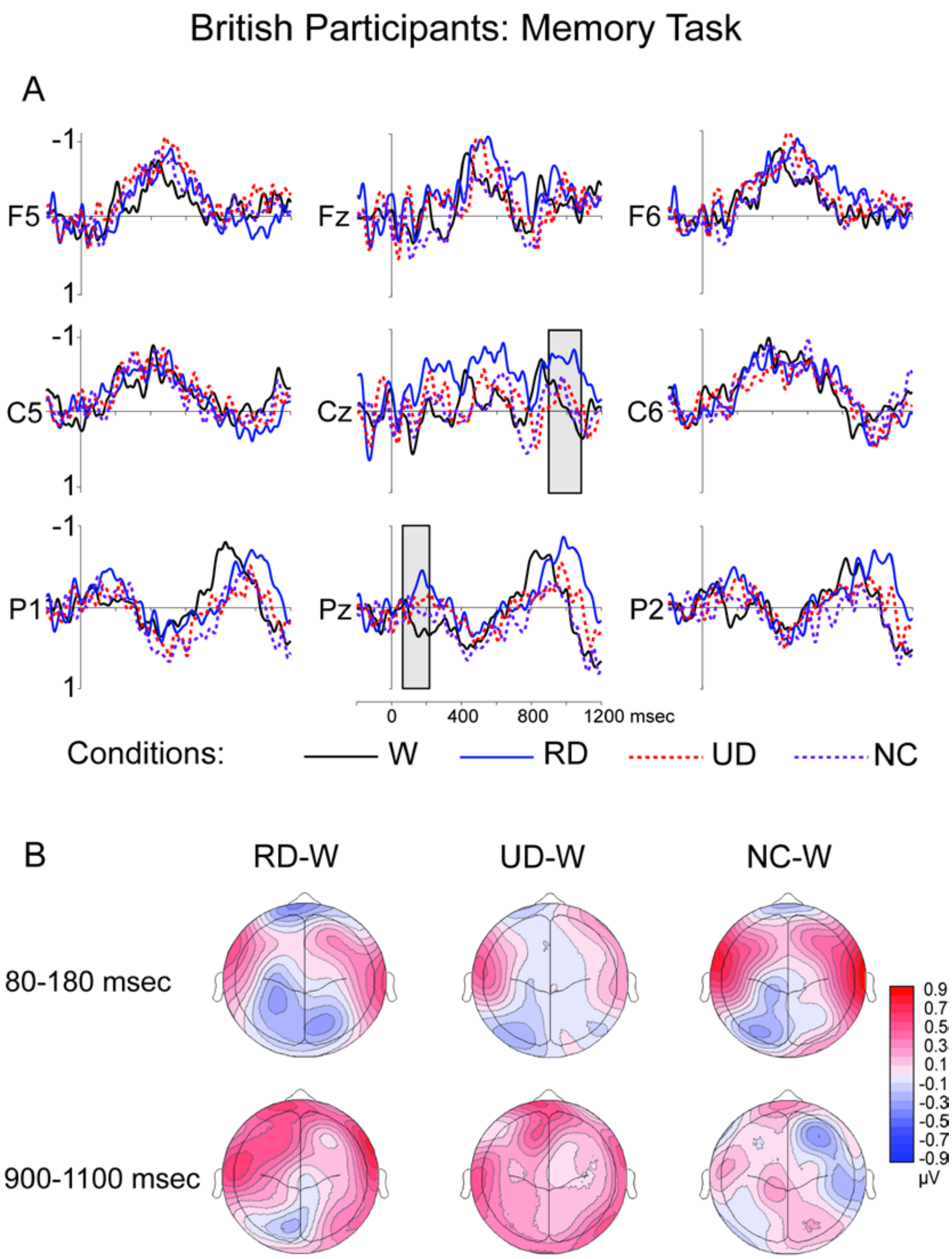

Figure 4. British Participants: Memory Task

Grand averages (A) and topographies (B) of the difference waveforms are shown for all experimental conditions in the memory task. The PMN effect is highlighted at the Pz electrode, with the W (black solid line) condition being the most positive curve, followed by the UD (red dashed line) and NC (purple dashed line) conditions that pattern together. The RD (blue solid line) condition is the most negative curve. The LPN effect is highlighted at the Cz electrode for the RD condition only. The topographies (B) show a similar scalp distribution for all conditions.

In order to study the violation effect without the interference of the standard processing, we also ran a series of paired t-tests on the difference mean amplitude values of the type Violation condition–W. The results showed a significant difference of the RD condition from the rest of the violation conditions: $t(15) = -2.15$, $p < 0.05$ for the UD condition and $t(15) = -6.12$, $p < 0.001$ for the NC condition. The difference between the UD and the NC conditions failed to reach significance both in the test on mean amplitudes and in the test on the difference mean amplitude values.

A significant main effect of the Stem type: $F(2.91, 58.26) = 3.8$, $p = 0.01$ was also revealed in the latency range of the LPN component. The mean amplitude values for LPN are demonstrated in Figure 6. The post hoc paired t-tests on mean amplitudes revealed a significant difference of the RD condition from all other conditions: $t(15) = -5.5$, $p < 0.001$ for the W condition, $t(15) = -2.77$, $p < 0.05$ for the UD condition, and $t(15) = -3.88$, $p = 0.01$ for the NC condition. There was no significant difference between the other experimental conditions.

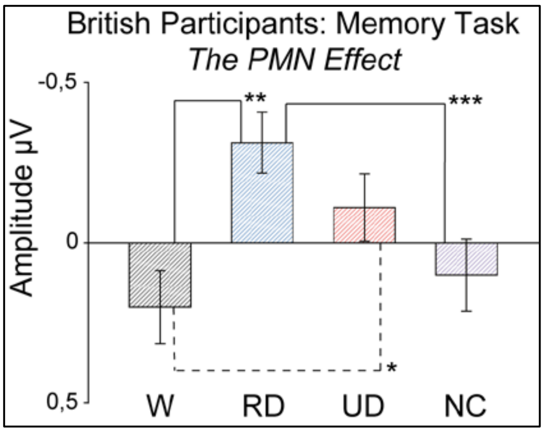

Figure 5. British Participants: the PMN Effect

The PMN effect at the Pz electrode is shown for the memory task. Note that the RD condition has the greatest negative value.

3.1.1.2.3 Discussion

The goal of the present study was to establish how the change of the experimental task modulated the error-sensitivity and the prioritization of the processing procedures. We hypothesized that the shift of focus from the lexical semantics to the memorization of the stimuli as a whole would reduce or eliminate the N400 effect. The results of the experiment supported our hypothesis. The memory task induced two separate ERP components: the PMN effect in the 80-180 msec time window and the LPN effect in the 900-1100 msec time window. The PMN effect was most pronounced for the RD condition, followed by the UD items, while the NC condition was not significantly different from the W items. The LPN effect was observed only for the RD items. As we predicted, the N400 effect was not elicited in this experiment.

We expected the change of the experimental task to induce the subjects to widen their attention scope. Without the need to perform a lexical look-up, the items were first analyzed in terms of the morphosyntactic context and later memorized for the task. The initial encounter with the nonwords resulted in a graded pattern of the PMN effect. The RD items evoked the largest PMN effect as their phonological structure was completely inappropriate in the present morphological context (Connolly & Phillips, 1994; Connolly, Phillips, & Forbes, 1995; Connolly et al., 1992; D'Arcy et al., 2004). The homogeneity of the stimulus material built up an expectation of a lax and open stem vowel in the stressed syllable. As the RD items contained only tense vowels in the stressed syllables, they elicited a phonological mismatch between the expected and the actual input. The completely irreparable items, though not significantly different from each other, revealed a distinct trend: the UD items were closer to the RD condition, while the NC items were closer to the W condition. We assume that the amount of the deviant input plays an important role in the initial phonological segmentation as reflected in the amplitude of the PMN component. Although both irreparable conditions were made up of non-existing stems, the UD items had only one abnormal phoneme, viz. the stem vowel. The NC items, on the other hand, deviated from the standard in two segments, which could result in a specific processing mechanism. Thus, the processing of the NC items did not significantly differ from processing of the real words, as these violated items could not be structurally associated with any existing words. The failure to find a comparable structure could yield an accommodation of the auditory input as a novel word with an exceptional phonological structure (such as *obesity* [i:]).

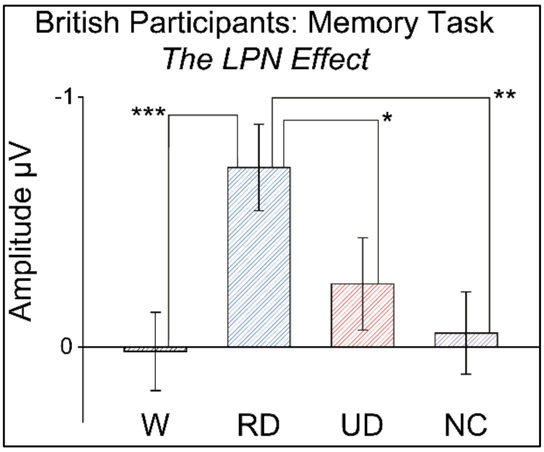

Figure 6. British Participants: the LPN Effect

The LPN effect at the Cz electrode is shown for the memory task. Note that the RD condition has the greatest negative value.

The more important difference, however, lies in the later time window, viz. in the latency range of the LPN component. The late LPN component was reported to reflect post-retrieval maintenance of the contextual information, reflecting the episodic memory processing (Herron, 2007). Considering the fact that only the RD items elicited the LPN effect, these items required more effort to maintain their contextual information than the rest of the conditions did. We assume that the high maintenance of the RD items was driven by their structural deficiency that could be repaired via access to the basic morpheme (Herron, 2007; Johansson & Mecklinger, 2003; Mecklinger, Johansson, Parra, & Hanslmayr, 2007). Thus, the memorization of the W and the irreparable items as a whole seemed not to demand any effort on the part of the episodic memory. As the W items were matched for the frequency of occurrence, they were equally easy to retrieve and to keep in the short term memory. As no additional task (e.g. a source judgment), except for the memory task, was imposed onto the participants, the involvement of the episodic memory was not required for the processing of the W items.

The irreparable items could be found neither in the mental lexicon nor in the episodic memory. The only possible strategy for the improvement of the task performance and task fluency was the accommodation of these items as novel words. Due to the novelty of the morphophonological structure and to the lack of the attributive information there could be no contribution from the episodic memory to the maintenance of these items. Although the reasons for non-involvement of the episodic memory in the processing of the real words and irreparable nonwords were different, they were tailored exclusively for the task demands. In the light of the task demands that were exerted upon the processing of the W, UD and NC conditions, these items were recognized and treated as words.

The processing of the RD items in the latency range of the LPN component significantly diverged from that of the other conditions. Even though the RD nonwords were non-existent in English, their constituent morphemes were existent and therefore had extensive linguistic information. An important part of this information could be the impossibility of the RD stem morphemes occurring prior to the {-ity} suffix. In order to ensure such impossibility a call upon the episodic memory might become necessary. The failure to find the mentioned morphemes in juxtaposition both in the mental lexicon and the episodic memory led to the increase of cognitive costs. The maintenance of the contextual information, i.e. the meaning of the constituent morphemes, their combinability, and probably also the orthographic form, was indexed by the prominent LPN effect.

3.1.1.3 Discussion: Trisyllabic shortening

The goal of the first two experiments was to determine how regular stem allomorphs are listed in the English mental lexicon. We hypothesized that regular stem allomorphs share a lexical entry. To test our hypothesis, the error detection mechanisms were studied in three violation conditions, viz. *ser[i:]nity* (RD), **ser[aɪ]nity* (UD), and **seromity* (NC), in comparison with the baseline condition *serenity* (W). We designed two word list experiments with different tasks: a lexical decision task and a memory task. We argued that the RD items could be structurally repaired if they share the stem morpheme with the W items. In this case, the error-detection mechanisms elicited by the RD items should be different from those, evoked by the irreparable nonwords (UD and NC conditions). However, if regular stem allomorphs were listed separately, all violation conditions should have elicited similar brain responses. The results of the lexical decision task experiment revealed a graded N400 effect of the type W<RD<UD=NC. The change of the experimental task resulted in a different set of violation responses. Thus, in the early processing stages the RD und UD items elicited PMN effects, while in the late processing stages only the RD condition evoked LPN.

The first experiment employed a lexical decision task to specifically engage the semantic processing. We expected that the error-detection mechanism triggered by the semantic processing would result in the N400 effect. Indeed, the lexical decision task yielded the N400 that was most pronounced for the irreparable items (UD and NC). The RD condition elicited a mild N400 effect. These results were in line with our predictions that the RD items should evoke a mild N400 effect if they can be structurally repaired. Such structural repair could only take place if there was a possibility of accessing the underlying stem morpheme with the subsequent application of the (morphophonological) TSS rule.

The purpose of the implementation of the lexical decision task was two-fold: (1) the elicitation of the semantic processing, and (2) the possibility of structural reanalysis. Based on the first purpose, our expectations were to observe a differential N400 effect for the violation conditions. We adopted the morphological decomposition as a prerequisite for the storage of allomorphs in the mental lexicon. Considering the obligatory decomposition, the RD nonwords were first decomposed into their constituent morphemes and were then recomposed with the combined meanings of those morpheme constituents. The whole procedure would thus be indexed in the attenuated amplitude of the N400 effect. McKinnon et al. (2003) have already employed the N400 as an index of the morphological decomposition. They argued that if all complex words were decomposed prelexically, the nonwords made up of bound morphemes (**intain*, **retrude*) would elicit a similar violation effect as low-frequency bound-stem complex words (*intrude*, *retain*) would. The authors reasoned that a nonword made up of existing though non-productive morphemes should be treated as a low-frequency word, hence the above-mentioned argumentation. The results of the study supported the authors' hypothesis, having revealed a similar mild N400 effect for both bound-stem conditions. In contrast to McKinnon et al. (2003), Koester et al. (2007) claimed that the N400 reflected the process of semantic composition. In an experiment on German compound nouns, they compared the processing of the semantically transparent compounds with the processing of the semantically opaque ones. As only low-frequency semantically transparent compounds evoked an N400-like negativity, the authors deduced that the N400 effect reflected the integration process of the semantics of the morpheme constituents into the compound.

McKinnon et al. (2003) used non-productive morphemes in their study, while Koester et al. (2007) employed a productive means of word formation in German, viz. compounding. These two studies are hardly comparable due to the discrepancies in the structure of the stimulus materials, nevertheless they provide supporting factors for the present study. The lexical decision task experiment employed in the present study differed from McKinnon et al.'s (2003) and Koester et al.'s (2007) studies in the implementation of a productive suffix {-ity} and an existing stem that is never found in the environment of this suffix. More importantly, in order to combine with the suffix {-ity}, this stem has to undergo TSS. This structure of the critical items placed them in an intermediate position in comparison with the stimulation used in the previously mentioned studies. On the one hand, the RD items were zero-frequent, their constituents, on the other hand, were relatively high-frequent morphemes. Though never found in the English vocabulary, the RD nonwords could still be semantically recomposed by accessing the meaning of the constituent morphemes. In line with the arguments put forward by McKinnon et al. (2003) and Koester et al. (2007), the RD items should evoke a reduced N400 effect reflecting both the morphological decomposition and semantic composition processes. The results of the lexical decision task experiment provided evidence for our assumption that semantically transparent complex words are subject to prelexical morphological decomposition.

The second goal of the lexical decision task was devised exclusively for the purpose of ensuring the reanalysis procedure. We were interested in the manner of representation of the TSS rule. If this rule is not included into the lexical entry and is therefore listed in a separate morphophonological layer, the violation thereof must trigger a grave morphosyntactic conflict. According to O'Rourke & Van Petten (2011), the P600 amplitude could be modified by a grave morphological violation. Van de Meerendonk et al. (2008) also claimed that only a grave conflict between the expected and the actual input could trigger the P600 effect. The gravity of the morphological violation or the lack thereof in the RD condition could be explained by the following two factors. First, Chomsky & Halle (1968) put forth the idea that the ability of a stem vowel to undergo the TSS should be listed in the lexical entry and not in a separate morphophonological layer. Following their line of argumentation, the violation of the TSS rule should be reflected in the semantic processing and not in the syntactic one, hence the absence of the P600 effect in the lexical decision task experiment. The second factor is the depth of derivation. The W items underwent the TSS simultaneously with the attachment of the suffix {-ity}, which could describe this kind of word-formation as direct or one-step derivation. The only conflicting input in the RD items was the violation of the expected laxing of the stem vowel. According to the present results, the gravity of this conflict was not sufficient for the induction of the P600 effect.

Summarized, the results of the lexical decision task experiment delivered evidence for the morphological decomposition/ semantic composition of the semantically transparent complex words. Additionally, they provided support for the consolidation of the morphophonological layer into the lexical entry. However, we maintain at this point that this is true, at least, for the trisyllabic shortened stems.

The memory task was introduced in order to shift the focus from the lexical semantics onto the general structure of the stimuli. Considering the fact that the items were presented auditorily in the test block but the probe for the actual task was presented visually, the subjects were not only to memorize the items but also had to re-encode them in another modality. This task required both linguistic processing and the involvement of the short term and episodic memory.

We predicted a pronounced PMN effect for the RD items and a reduced PMN effect for the irreparable nonwords during the initial processing and a distinct LPN for the RD nonwords during the post-retrieval stage. The results of the study provided supporting evidence for our expectations: the PMN effect was mild for the UD and NC items and was most prominent for the RD condition. Only RD items evoked the LPN effect.

The first finding of this study demonstrated the effects of the morphophonological context. Taking into account the homogeneity of the stimulus materials, the expected phonetic form of the stressed stem vowel should be characterized by the TSS, i.e. these vowels should surface as short vowels with a changed height. The RD condition was made up exclusively by violating the TSS rule, yielding tense vowels in the stressed position. The conflict between the expected input and the actual acoustic signal reached its apex during the presentation of the RD items as all of them deviated from the contextual constraints. The irreparable violation conditions consisted of both the trisyllabic shortened vowels and tense vowels in the proportion 50:50. The PMN effect was similarly reduced for these conditions demonstrating an intermediate amplitude value lying between the W and the RD conditions. Though the occurrence of the PMN effect in no manner reflected the organization of the mental lexicon entry, it showed that the amount of deviation from the expected context played an important role at the early processing stages (Connolly & Phillips, 1994; Connolly et al., 1992; Connolly et al., 1990; D'Arcy et al., 2004; Steinhauer & Connolly, 2008). However, we observed PMN exclusively in the memory task experiment. The absence of the PMN effect in the lexical decision task might be explained by the overriding N400 component that could have concealed the initial phonological conflict.

The initial processing stages reflect automatic processes that cannot provide reliable information about the structure of the lexical entry. The stages that are important for the study of the mental lexicon are the retrieval and the post-retrieval stages. During the lexical retrieval stage (300-500 msec post stimulus) no violation effects were observed. The lack of the violation effects in this particular time window could be explained by either the prior PMN effect, which could have reduced possible lexical effects, or by the task demands. The participants did not have to perform a lexical decision task, which distracted them from the lexical semantics. With the semantics out of the picture, the only violation type that required high maintenance cost during the post-retrieval stage was the formal violation, viz. the RD condition. The analysis of the late time window (900-1100 msec) revealed a significant LPN effect for the RD items. The remaining question was, however, how the induction of the LPN effect was possible without the implementation of a recognition paradigm. The paradigm that we employed in the memory task experiment did not involve direct source monitoring. Nevertheless, though different from the standard recognition paradigm, our task still implicated the maintenance of contextual information. On the one hand, the phonetic structure of the stimulus had to be memorized, and on the other hand, the possible ways of conversion of this structure into the orthographic form had to be computed. The items that contained conflicting information increased the context retrieval demands. The effort for the processing of the RD items had to be doubled as has been argued above. First, the stem morpheme had an incorrect surface form that could never be combined with the suffix {-ity}. In order to combine with the suffix, the stem vowel had to be trisyllabic shortened. Therefore, the deviation from the standard phonetic structure required effort from the episodic memory to retrieve the information concerning the occurrence of the stem allomorphs. Second, though completely different in the surface form, the two allomorphs had the same orthographic code. The effort required for the computation of the orthographic form for the RD items contributed to the increase of processing cost. The influence of these two factors resulted in a non-canonical but robust LPN effect.

It could be argued whether the LPN reflected the processing within or without the lexical entry. The arguments against the processing within a shared lexical entry may be the lack of violation effects during the retrieval stage and the non-linguistic nature of the LPN effect. Though valid, such an argument could not explain why irreparable nonwords behaved in the same way the existing words did. During the retrieval and the post-retrieval stages all conditions except the RD items elicited similar brain responses. The surface form of the W items met the requirements of the morphophonological context; besides, these items were existing words. The only necessary effort for the processing of the W items consisted in keeping them in the short term memory. The irreparable items, despite having a faulty phonetic form in half of the cases, did not have a stem that could be retrieved from the mental lexicon. According to the absence of semantic violation responses, these items were accommodated into the episodic memory with both the phonetic and a possible orthographic form, and were simply kept ready for the memory task. Therefore, the lack of necessity (W) or the possibility (UD, NC) to maintain the stem attributes resulted in a normal/ standard processing of the existing words and the irreparable nonwords.

Contrary to that, the maintenance of the stem attributes was necessary for the processing of the RD nonwords. This procedure would be impossible without access to the lexical entry. We assume that this lexical entry is shared by the allomorphs employed in the W and the RD conditions. Otherwise, the violation of morphological combinability should have evoked the structural reanalysis. The impossibility of repairing the surface structure via the offline application of the TSS rule within the mental representation would have caused a strong morphosyntactic conflict indexed by a prominent P600 effect. This was not the case in the present study. The LPN effect elicited by the RD items indicated the access to a single underlying stem morpheme for the regular stem allomorphs.

In sum, the results of the word list experiments run with British participants provided supporting evidence for our hypothesis that regular stem allomorphs share a mental lexicon entry. This conclusion was deduced from the fact that the RD nonwords elicited violation effects that made this condition significantly different from the real word and both irreparable nonword conditions. We posit that these effects were induced by the possibility of structurally repairing the RD items and not by such factors as the frequency of occurrence or the neighborhood size.

3.1.2 Umlaut

The most intensively studied cases of vowel alternation in German are umlaut and ablaut. While umlaut can be found in the derived environment and in the inflectional forms, e.g. *kurz* (short) – *kürzer* (shorter) and *Haus* (house, sg.) – *Häuser* (houses, pl.), the scope of ablaut is confined to the German strong verbs, e.g. *gehen* (to go) – *ging* (went) – *gegangen* (gone). The present chapter focuses on umlaut, which is the phonological fronting of a back vowel: *a* > *ä*, *o* > *ö*, *u* > *ü*. We are particularly interested in the cases where umlaut is highly predictable and regular. Though umlaut is one of the means of plural formation, it is limited to a set of nouns. For this reason, it cannot be regarded as predictable in the plural formation. In derivation, however, umlaut is predictable and productive. In order to study regular stem allomorphy, we shall concentrate on umlaut in derivation. In this chapter we first discuss the nature of umlaut, then we propose our account of the representation of the regular stem allomorphy in the German mental lexicon, and, finally, we provide experimental evidence in favor of our hypothesis.

The umlaut pattern that was chosen as an object of the present study is known as secondary or nonprimary umlaut. This vowel change dates back to the middle of the Old High German (OHG) period, although it came to be held in writing much later during the Middle High German (MHG) period (Iverson & Salmons, 1996; Penzl, 1949). While primary umlaut was characterized by the fronting and raising of the short [a], secondary umlaut was characterized by the fronting of all back vowels. The front vowel [ɛ] obtained by means of primary umlaut was high enough to be orthographically represented with the grapheme “e” and was therefore merged with the phoneme, resulting in differential underlying representations, i.e. *g**a**st* (guest) – *g**e**sti* (guests). The vowels produced by secondary umlaut could not be rendered by the orthographic means that existed in the OHG, so being novel segments they were considered allophonic.

Iverson & Salmons (1996) proposed their own account of the nature of primary and secondary umlaut, claiming that these processes were related yet phonologically distinct. The authors argued that the development of secondary umlaut might have been triggered by the fronting action of primary umlaut. Nevertheless, there were several important differences indicating the temporal and structural independence of primary and secondary umlaut. Table 9 demonstrates these differences with respect to the timing of the process (the second row), the phonetic conditioning (the third row), the Structure Preservation constraint (the fourth row), the inconsistencies in the application (the fifth row), and the orthographic rendering (the sixth row). While primary umlaut was not sensitive to morphological restrictions, secondary umlaut was triggered by a number of morphological configurations. Therefore, even diachronically, secondary umlaut could not be classified as a purely phonological phenomenon. The fact that only a number of bound morphemes triggered such umlaut also provided evidence in favor of marking a stem morpheme as capable of umlaut in certain morphological environments.

Table 9. The key distinguishing properties of primary and secondary umlaut

(Adapted from Iverson & Samons, 1996, p.19)

Primary Umlaut	***Secondary Umlaut***
Early OHG	Middle of OHG period
Specific phonetic conditioning	No clear phonetic conditioning
Structure-Preserving	Creates new segments
Consistently carried through	Inconsistently carried through
Orthographically marked	Marked later

In Modern Standard German the occurrence of umlaut has been accounted for in several different ways. Lieber’s (1987) account was based on the ability of some suffixes, such as {-*e*}, {-*chen*}, {-*lein*}, to trigger umlaut. She claimed that an umlaut-conditioning suffix should have a floating feature [-BACK] in its underlying representation. During the attachment to the stem morpheme, this feature should find an “open slot” in the stem vowel. If the open slot exists, the feature [BACK] of the stem vowel gets delinked. The stem vowel then becomes reassociated with the floating feature [-BACK] of the umlaut-conditioning suffix. The suffixes that sometimes trigger umlaut are proposed to be allomorphic, the one containing the floating feature and the other not having it. Lieber’s account for umlaut in inflectional morphology was even more complicated than that for derivation. It suggested that two separate stem allomorphs should combine with certain inflectional suffixes. Though very detailed, Lieber’s analysis failed to include numerous cases of non-umlaut in the vicinity of the umlaut-conditioning suffixes, viz. *die Frau* (*woman*, fem.) – *das Frauchen* (*mistress*, neut.), *schwach* (*weak*, adj.) – der Schwache (*weak person*, masc.). Furthermore, the mental lexicon would have to accommodate a great number of allomorphs required for the representation of all umlaut-variable suffixes and stems. In sum, Lieber (1987) indirectly proposed two separate umlaut processes: the first based on the delinking and the second based on the allomorphy of stems and suffixes.

Another account, proposed by Wiese (1996), considered the stem and not the suffix to be the source of umlaut. Thus, a stem should contain a floating feature [+FRONT] in the vowel of the final syllable in order to be umlauted in certain morphological environments. Wiese's (1996) analysis offered an explanation for the cases of the non-umlaut in the morphological environment that normally triggers this process. The author claimed that the alternating back vowels should contain a floating feature [+FRONT] in their phonological representation, while the non-alternating back vowels should not have this feature, hence the pattern: *lang* (*long*, adj.) – *länger* (*longer*, adj.) and *rund* (*round*, adj.) – *runder* (*rounder*, adj.) According to Wiese, umlaut could be an instance of a strictly cyclic phonological rule, as "(i) umlaut is found in derived environments only, (ii) umlaut has lexical exceptions, (iii) umlaut is structure preserving, in the sense that its output segments are among the lexically distinctive segments, (iv) umlaut is an obligatory rule, (v) umlaut is restricted to the first lexical level (Wiese, 1996:124)". Although found in morphological configurations, umlaut was characterized as a non-morphological rule. This was attributed to the inability of umlaut to trigger morphological processes on its own, having an accompanying function instead.

Scharinger et al. (2010) proposed an account for the cases of umlaut/non-umlaut in inflectional categories based on the abstract stem vowel representation. The authors claimed that the alternating vowel in the representation was underspecified because it did not possess information about the place of articulation (Lahiri & Marslen-Wilson, 1991; A. Lahiri & H Reetz, 2002). The non-alternating vowel was specified for the place of articulation, i.e. [DORSAL]. Therefore, the problem of the allomorph storage in the case of umlauting stems was resolved on the level of abstract representation by means of mapping both stem allomorphs onto the same underlying morpheme with an underspecified vowel.

The diachronic account (Iverson & Salmons, 1996) presented umlaut as a phonological process that was first triggered by the frontness harmony, but later came to be induced by morphological configurations. The synchronic accounts on umlaut also describe it as a phonological process (Lieber, 1987, 1992) or a cyclic phonological rule (Wiese, 1996). Some experimental evidence even provided supporting factors for the unified representation of the umlauting stems. Thus, Scharinger et al. (2010) put forth the hypothesis that in the inflectional morphology the umlauting vowels are underspecified in the abstract representation. The results of their study verified this hypothesis, having demonstrated a stronger MMN response to the non-alternating vowels (e.g. [ɔ] in *Stoff* (cloth) – *Stoffe* (cloths)) if the deviant word *Stoff* followed a standard fronted stem *Stö*. This effect was observed because the preactivated representation was underspecified for the place of articulation and the feature that was extracted from the speech signal (i.e. the word *Stoff*) was specified for the dorsal/ back place of articulation. Although this study provides a very useful insight into the representation of umlauting vowels in the inflectional morphology, it cannot account for the regular allomorph storage in general. Thus, it does not explain how derived words that at some stage underwent umlaut are listed in the mental lexicon.

An indirect way to answer this question could be a priming study with the derived forms used as primes and their bases employed as targets. If a derived form activates the base, a large priming effect can be observed, indicating the access to the non-umlauted basic morpheme and by implication pointing to the shared underlying stem morpheme. Marslen-Wilson et al. (1994) ran a cross-modal priming study on the organization of the English mental lexicon. A part of this study was focused on the regular stem allomorphy, such as the cases of TSS (*serenity*/*serene*). The results of the study demonstrated a large priming effect in the derived/ base pairs providing evidence for a shared lexical entry. The authors argued that the regular stem allomorphs that were highly predictable in certain morphological contexts should have a common abstract representation with a set of rules defining the surface form of the stem vowel in different morphological combinations. They claimed that successful parsing required the assessment of the possible phonological alternations within the stem in combination with the stem's syntactic and phonological properties. Only after the fulfillment of these requirements did it become possible for a morphosyntactic process to induce a phonological change within the stem.

Though not equivalent, TSS in English and umlaut in German are similar in their regularity, i.e. there are morphological contexts that necessitate TSS/ umlaut. The example of the TSS-inducing morphological context was described in the previous chapter. An instance of the umlaut-triggering morphological context in German could be the conversion of an adjective into a verb: *schwach* (*weak*, adj.) – *schwächen* (*weaken*, v. tr.) [2]. Despite different grammatical categories, the base and the derived word share many characteristics. Both words are phonologically, morphologically and semantically related apart from the stem vowels, which have different places of articulation. We put forth the hypothesis that for the sake of economy regular stem allomorphs should be represented by a single underlying morpheme with a set of morphophonological and morphosyntactic rules. The morphophonological layer within the lexical entry could significantly spare the processing effort in contrast to the separate storage of allomorphs or fully derived forms.

The goal of the present study was the assessment of the organization of the German mental lexicon with respect to the regular stem allomorphy. Our objective was to find out if regular stem allomorphs shared a lexical entry. We developed a violation paradigm that made use of the phonological structure of the stem morpheme. Introducing phonologically motivated violations of the stem vowel, we expected to induce differential error-detection mechanisms. The discrepancies between the standard processing of the non-violated items and the deviant processing of the violated ones could be indicative of the structure of the lexical entry. To be able to assess the structure of the lexical entry, we chose to employ two-step derivation: (1) the conversion of an adjective into a verb *schwach* (*weak*, adj.) – *schwächen* (*weaken*, v. tr.) and (2) the subsequent nominalization by means of the suffix {-*ung*} *schwächen* (*weaken*, v. tr.) – *Schwächung* (*weakening*, n.). The purpose of this decision was two-fold: for one, the conversion induced the vowel change resulting in the application of the morphophonological rule. As the comparative and superlative forms of the adjective also required umlaut, both verbal and adjectival stems would have the same surface form within their paradigms. The verb-to-noun derivation, however, made use of affixation to mark the change of the grammatical category. The use of the deverbal noun should establish a strict morphological relationship between the adjectival base over the verb up to the final product of derivation. For another, such deep derivational process could demonstrate whether the distance to the base played an important role in allomorph storage. Thus, we could assess whether only stem allomorphs participating in immediate derivation shared a common entry or all regular allomorphs of a stem shared an underlying representation.

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[2] Note that the infinitival suffix {-en} does not induce umlaut. The function of this suffix is a mere denotation of the non-finite status of the verb. The change of the grammatical category is marked by umlaut though triggered by conversion.

According to Scharinger (2009), regular stem allomorphs should be represented by an abstract morpheme with the stem vowel underspecified for the alternating feature, i.e. back-front. Following this line of argument, lexical retrieval should not be stopped or hindered even in the case of an allomorph misapplication. As both allomorphs map onto the same underlying representation, the violation of the morphophonological/ morphosyntactic rules should trigger a formal error-detection mechanism, viz. a morphosyntactic violation response. The mental lexicon could also be organized in such a way that every allomorph or a word had a separate entry. Considering this type of structure, the formal repair via the offline application of the morphophonological and morphosyntactic rules would be impossible, resulting in a complete rejection of a violated item as a word.

The most reliable means of investigating the subprocesses that accompany auditory speech perception is the event related potentials (ERP) technique. The ERP technique provides high temporal precision and fairly accurate topographic resolution. As we were more interested in HOW and WHEN than in WHERE exactly the error-detection mechanisms occur, this technique was particularly useful for our objective. The subprocesses involved in the auditory perception of words in isolation include (among others) lexical retrieval and morphosyntactic analysis. Therefore, we expected to elicit the ERP components that reflected lexical retrieval and morphosyntactic processing, viz. the semantic component N400 and the morphosyntactic component LAN.

The present study was made up of two word list experiments that were designed to investigate different aspects of the auditory perception of complex words. The first experiment imposed a lexical decision task that was expected to narrow down the focus on the lexical semantics. The second experiment employed a memory task to widen the scope of attention onto the whole structure. The composition of the stimulus materials is illustrated in Tables 10 & 11, along with our predictions for both experiments. The W condition (second column) represents an existing German word that is derived from an adjective with a back stem vowel, e.g. *schwach* (*weak*), by means of conversion with a simultaneous umlaut of the stem vowel, viz. *schwach* (*weak*) > *schwächen* (*weaken*, v. tr.). In the second step, a noun is derived from the verb by means of attachment of the nominalizing suffix {-*ung*} to the right boundary of the stem: *schwächen* (*weaken*, v. tr.) > *Scwächung* (*weakening*, n.). Thus, the surface form of the W condition has a front vowel ***V*** ([ɛ] [œ] [y]) in the stem morpheme. The RD condition (third column) is formed by omitting the first derivational step, and thus consists of the basic adjectival stem with a back vowel V_1 ([a] [o] [u]) and the suffix {*-ung*}: **Schwachung*. The resulting nonwords are therefore illegal combinations of existing morphemes but are still repairable via combined meanings of their morpheme constituents. The next two non-word conditions are made up by manipulating the stem vowel V_2 (UD), viz. **Schwochung* (fourth column), and by manipulating the stem vowel V_3 and the stem coda consonant C_1 (NC), viz. **Schwickung* (fifth column), yielding non-existing stems. The decision to design the NC condition was triggered by the necessity to control for the purely phonological effects. If the strategy to recover the meaning of the nonwords was induced by phonological effects and not by morphological ones, the degree of deviation from the standard should interact with the type of violation effect.

Table 10. Experimental conditions and predictions for the lexical decision task

*The names of the conditions and their composition are given in the first row: bold italicized **V**s and **C** represent manipulated phonemes, the most important difference being that between the front vowel **V** ([ɛ] [œ] [y]) and the back vowel V_1 ([a] [o] [u]). The example of a graded violation pattern of the German word Schwächung (weakening) is given in the second row. The predictions are divided into rows according to the validity of our hypothesis: valid – single entry, the third row with a graded pattern of N400; invalid – separate entries for all allomorphs, the fourth row, with similar responses for all violation conditions.*

Condition Composition	**W** – Word: Derived stem {C***V***C}+{-ung}	**RD** – related derived: Existing stem illegal in the combination {CV_1C}+{-ung}	**UD** – unrelated derived: Non-existing stem {CV_2C}+{-ung}	**NC** – nonce complete: Non-existing stem {CV_3C_1}+{-ung}
Example	Schwächung	*Schwachung	*Schwochung	*Schwickung
Single underlying stem morpheme	____________	mild N400	large N400	large N400
Separate entries for allomorphs	____________	large N400	large N400	large N400

The predictions for the lexical decision task experiment are summarized in Table 10. We expected the lexical decision task to trigger a specific type of processing, viz. the focus on the lexical semantics. Considering the non-existence of the violated items, all nonwords were predicted to elicit an N400 effect. The prominence of the effect would depend on the organization of the mental lexicon with respect to the regular stem allomorphy. Thus, we predicted a mild N400 effect for the RD items, if their stems shared a lexical entry with the W stems (third row of Table 10). According to our hypothesis, the mapping of the auditory input onto the single underlying morpheme would result in the recognition of an RD item as a nonword, which could nevertheless be structurally repaired by means of the offline application of umlaut. The semantics of the RD items could be restored by combining the meanings of the constituent morphemes. The possibility of the semantic and structural repair makes the RD condition different from the irreparable conditions. We expected the UD and NC items to evoke similar violation brain responses because their stems were non-existent. We also maintained that the amount of deviation from the standard should be irrelevant in this case. Summarized, the results of the lexical decision task experiment should reveal a mild N400 effect for the RD items and a prominent N400 effect for both irreparable conditions, if our hypothesis is valid. The fourth row of Table 10 demonstrates our predictions for the case our hypothesis being invalid. The RD items could not be mapped onto an abstract representation because the morphemic combination is illegal and therefore cannot be listed in the mental lexicon. Both irreparable conditions lack an existing stem, so they cannot be retrieved intrinsically. Without the possibility of accessing the underlying representation, all violation conditions should elicit similar N400 effects.

Table 11. Experimental conditions and predictions for the memory task

The names of the conditions and their composition are given in the first row. The example of a graded violation pattern of the German word Schwächung (weakening) is given in the second row. The third row demonstrates predictions for a single entry with a large LAN effect for RD items, large N400 for NC items and either small LAN or large N400 for UD items, depending on the possibility of reparability. The fourth row shows predictions for separate entries for all allomorphs with similar large N400 effect for all violation conditions.

Condition Composition	**W** – Word: Derived stem {C***V***C}+{-ung}	**RD** – related derived: Existing stem illegal in the combination {CV_1C}+{-ung}	**UD** – unrelated derived: Non-existing stem {CV_2C}+{-ung}	**NC** – nonce complete: Non-existing stem {CV_3C_1}+{-ung}
Example	Schwächung	*Schwachung	*Schwochung	*Schwickung
Single underlying stem morpheme	________	large LAN	small LAN/ large N400	large N400
Separate entries for allomorphs	________	large N400	large N400	large N400

The memory task experiment was developed to investigate the processing of complex words without a superimposed linguistic task. The subjects had to memorize all items from an auditory block to be able to perform the task. Therefore, the existence of an item was not relevant to the task performance. Instead of focusing on the lexical semantics, the participants had to focus on the form of the stimuli in order to recognize the visual probe as already heard. We expected the violation conditions to evoke two distinct ERP components depending on the type of processing. The third row of Table 11 demonstrates the predictions for the validity of our hypothesis. The RD items contained conflicting information that could interfere with the memorization: the surface form of the auditory input would not coincide with the morphosyntactic context, established by the homogeneous deverbal stimuli. Thus, the context required a deverbal noun, which in case of the RD nonwords lacked the most important phonological feature, i.e. the fronting of the stem vowel. Such inconsistency could result in the assessment of the lexical entry triggering a morphophonological repair process. The repair process would be indexed by the LAN effect. The irreparable nonwords, regardless of the degree of violation, were morphosyntactically legal, as there was no information about the grammatical category of the stem and the stem’s capability to umlaut. Therefore, we expected the UD and NC items to evoke a similar N400 effect as an indicator of their lexical status. On the other hand, the participants could simply adopt these items into the short term memory, demonstrating standard processing. If our hypothesis were invalid, we expected all violation items to elicit either similar N400 effects, or in line with the previous argumentation, to be processed in the same way as W items would be (fourth row of Table 11).

In sum, for the validation of our hypothesis we expected the RD nonwords to elicit violation responses that would be significantly different from those evoked by the real words and by the irreparable nonwords. The similarity of the error-detection mechanisms triggered by the violated items would therefore prove our hypothesis wrong.

3.1.2.1 Experiment 3: Lexical decision task

3.1.2.1.1 Methods

Participants

Sixteen subjects (8 male, age range: 21-33 years, mean: 24.75) took part in the word list experiment with a lexical decision task. This relatively small number of participants was chosen due to the homogeneous ERP response pattern that was observed even in the three subjects that had to be excluded due to muscular artifacts and alpha.

Materials

Experimental materials consisted of five sets of di- or trisyllabic nouns (see Table 10 and Appendix B for examples). The critical items were German nouns with the following derivational paradigm: in the first stage of derivation, an adjectival stem with a back stressed vowel undergoes conversion into a verb with the simultaneous fronting of the stem vowel (umlaut: [a] > [ɛ], [o] > [œ], [u] > [y]), e.g. *schwach* (weak) > *schwächen* (weaken). In the second stage, the verb undergoes nominalization by attaching the suffix {-*ung*} to the right boundary of the stem, e.g. *schwächen* (weaken) > *Schwächung* (weakening).

Only relatively frequent words (mean in Celex: 46.78, mean in Mannheimer Corpus: 12457.23) were selected for the W condition. The first two violation conditions were formed by manipulating the stem vowel of the W items, the last violation condition was formed by manipulating the stem vowel and the coda consonant. Thus, the back adjectival stem vowel was preserved in the RD condition resulting in an illegal combination of existing morphemes, e.g. **Schwachung*. The stem vowel in the UD condition was systematically changed yielding a combination of a non-existing stem and the suffix {-ung}, e.g. **Schwochung*. Initially, we tried to keep the [DORSAL] place of articulation constant for both violation conditions, but for almost half of the stimuli it was impossible to find a non-existing stem with a back vowel. Thus, to avoid possible confounds, we balanced front and back vowels as well as diphthongs in the UD condition, so that one half of the stimuli had front vowels and the other half had back vowels. The fourth set of stimuli, the NC condition, was produced by manipulating the stem vowel and the coda consonant of the W items in such a way that only the onset of the first syllable and the suffix were preserved, e.g. *Schwickung. This set was used as a control condition for the UD nonwords to ensure different degrees of deviation from the standard. The fifth set was made up of forty-two existing nouns that were derived from verbs by concatenating the suffix {-*ung*} to the right boundary of the stem, e.g. *Gleichung* (equation). This last set of stimuli was used as Fillers.

A professional Standard German speaker (male) was first trained to produce the experimental items naturally with a varying prosodic pattern and then read them for recording. Because of the fast habituation to the intonation of enumeration, we resorted to a recording of three different prosodic patterns, yielding three tokens of each experimental item. The total 378 words were recorded and digitized.

The stimuli were divided into 3 experimental runs (à 126 words): the first run consisted of the RD condition and the Fillers; the second run was made up of the Fillers and the UD items; the third run combined the Word and NC conditions. The experimental materials were pseudorandomized in such a way that no two items ever appeared in the same context. To control for confounds, such as a list effect, the experimental runs were rotated.

Procedure

The participants were seated in a comfortable EASY chair 1.5 meters away from a computer monitor; their task was to listen to individually presented words. Further, they were instructed to press a corresponding button of the response box if a word existed in German. The subjects were asked to avoid any body or eye movements and to fixate on the cross, but were free to blink when the cross was not displayed during the ISI. Before the experiment, the participants had a short practice block.

EEG Recording

The procedure of the EEG and EOG recording was described in the General Methods chapter. There were no deviations from this procedure in this series of experiments.

Data Analysis

Epochs within an amplitude range of 75 µV of correctly identified items were averaged for each condition and for each participant and were baseline corrected. The approximate rejection rate was 6%.

After the visual inspection of the grand average waveforms and the topographies, we set the time window for the parameterization of data from 400 – 600 msec that corresponds to the latency range in which the N400 component had been reported in earlier studies (Kutas & Federmeier, 2011).

Repeated measures ANOVAs were run with three within-subject factors: Anteriority (anterior, central, posterior), Laterality (Left, Middle, Right), and Stem type (W, RD, UD, NC).

3.1.2.1.2 Results

Behavioral data showed that 1.5% of nonwords were falsely identified as words; however, the error rate did not differ between the experimental conditions. Repeated measures ANOVA with two within-subject factors (Presentation (first to third time) and Condition) revealed no main effects or interactions (all $p > 0.1$).

Figure 7 displays the grand averages and the topographies of the difference waveforms of the type Violation condition–Word. The topographies are shown for the latency range of 400-600 msec. The graded pattern of the N400 effect is most pronounced at the Pz electrode: the W condition (a black solid line) has the most positive value, followed by the RD condition (a green solid line), the UD condition (a red dashed line) is more negative than the RD, with the NC condition (a purple dashed line) being the most negative.

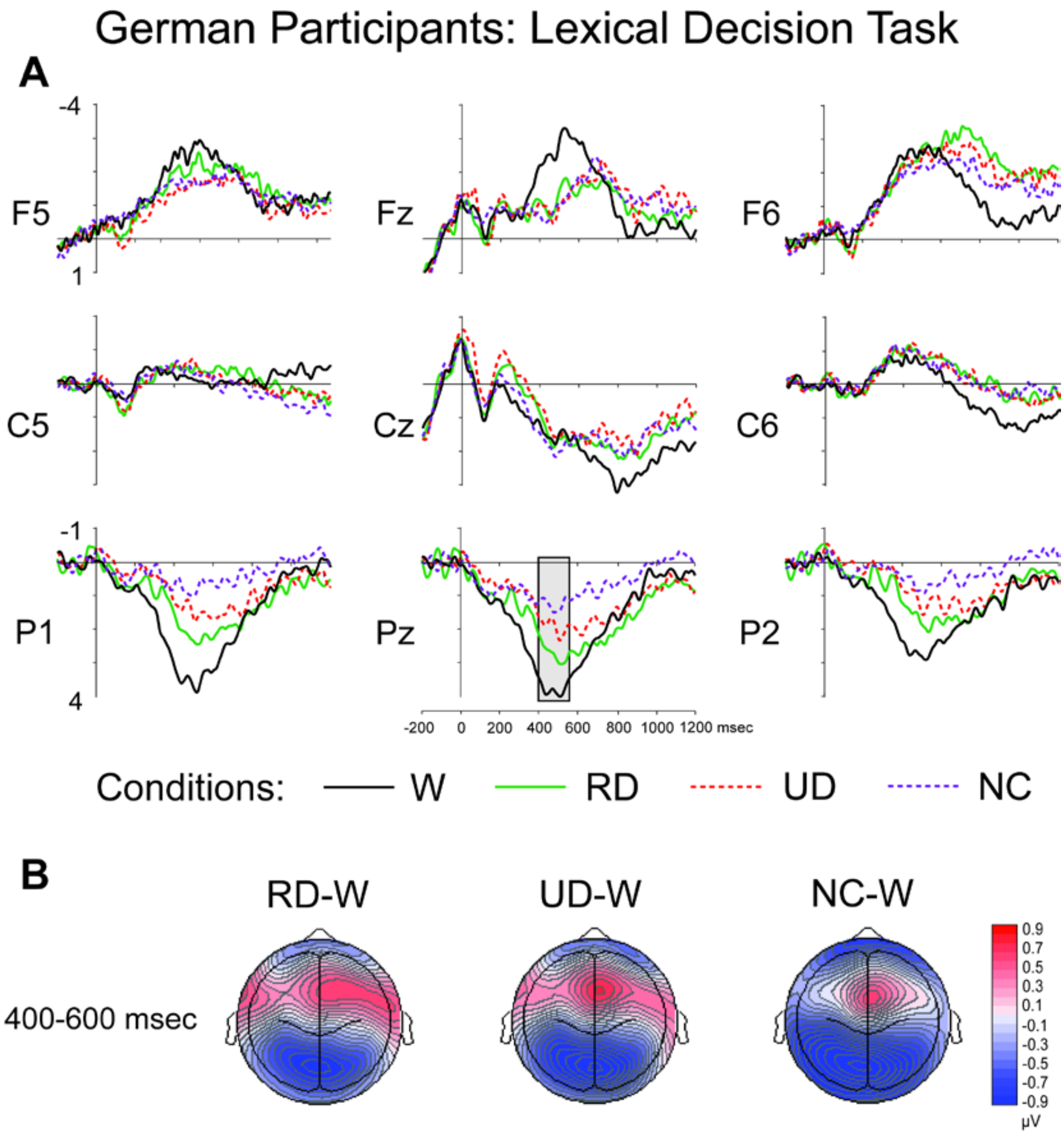

Figure 7. German Participants: Lexical Decision Task

Grand averages (A) and topographies (B) of the difference waveforms are shown for all experimental conditions in the lexical decision task. The N400 effect is highlighted at the Pz electrode. Note that the violation conditions demonstrate a graded pattern: the W (black solid line) condition is the most positive curve, followed by the RD (green[3] solid line) condition. The UD (red dashed line) condition is more negative than the RD curve and the (N)once (C)omplete (purple dashed line) is the most negative. The topographies (B) show a similar scalp distribution for all conditions.

The omnibus 3-way ANOVA revealed a 3-way interaction of the type Anteriority x Laterality x Stem type (F (4.84, 72.62) = 12.032, p < 0.001). A series of post-hoc one-way ANOVAs run within each region (Anteriority x Laterality) for the factor Stem type revealed a prominent the N400 effect at the centro-parietal

[3] We used different colors for the RD condition in the nationality groups, i.e. blue in the British group and green in the German group, to encode the language for the immediate comparison of the nationality groups in subchapter 3.1.3 and for the bilingual pilot study in subchapter 3.1.4.

electrode sites (Pz P1, P2): $F (2.51,50.34) = 9.21$, $p < 0.001$. The mean amplitude values for the N400 component are illustrated in Figure 6. Due to the contamination of the W condition with motor preparation, we further ran a one-way ANOVA without this condition: $F (1.87,42.16) = 3.87$, $p < 0.05$. The contrast analysis revealed a significant difference between the RD and the irreparable nonword conditions UD&NC: $t(45) = 2.5$, $p < 0.05$.

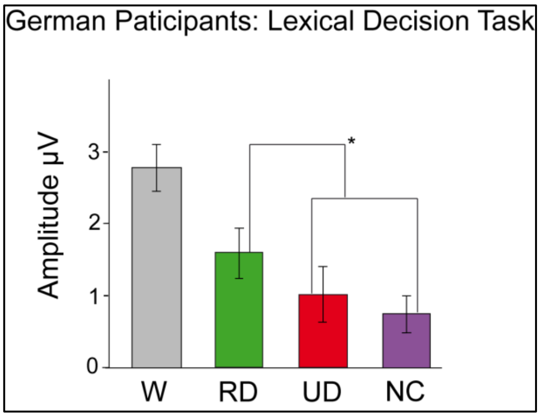

Figure 8. German Participants: the N400 Effect

N400 amplitudes at the Pz electrode are shown for the lexical decision task. The significant difference between the (R)elated (D)erived condition and the two non-word conditions, (U)nrelated (D)erived and (N)once (C)omplete, is marked with an asterisk.

3.1.2.1.3 Discussion

We hypothesized that regular stem allomorphs should share a lexical entry. The lexical decision task was expected to induce a graded N400 effect in the case of our hypothesis being valid. The invalidity of our hypothesis was predicted to be proven if all violation conditions elicited similar N400 effects. The results of the study provided evidence in favor of our hypothesis revealing a mild N400 effect in the RD condition and a pronounced N400 effect evoked by the irreparable nonwords, viz. W<RD<UD=NC. This response pattern reflected a differential goodness of fit for violated items. The goodness of fit did not simply depend on the degree of deviation from the stored standard, as both irreparable conditions induced similar brain responses. This finding delivered evidence against the influence of the phonological overlap on the lexical retrieval process. The deviation from the standard in only one vowel (UD) inhibited the activation of the base in the same way a double deviation did (NC). Therefore, though obtained by manipulating the stem phonemes, the UD and NC nonwords failed to be traced back to the original word due to the lack of morphophonological means. The lack of difference between these two conditions provided supporting evidence for their irreparability.

The violation effect triggered by the RD items was significantly milder than that elicited by the irreparable nonwords. The deviation from the standard in the RD condition was not quantitative but qualitative: both the RD and UD items deviated from the standard in only one phoneme. However, the manipulation employed in the design of the RD condition consisted in the non-application of umlaut, while the stem vowels of the UD items were changed consistently without any phonological bases. The attenuated N400 effect was thus evoked due to the reparability of the RD nonwords (McKinnon et al., 2003). According to our hypothesis, the W and RD stems originated from the same lexical entry with a set of morphophonological and morphosyntactic rules defining the surface form of the stem. The violation of these rules resulted in a mild N400 effect.

Another factor contributing to the graded N400 pattern might have been the type of the experimental task. The participants were asked to press the corresponding mouse-key when they heard an existing German word. After the first couple of trials, the subjects had realized that the stimuli were derived from verbs by attaching the suffix {-*ung*}. Therefore, the most reasonable strategy for the subjects to accelerate lexical retrieval and to increase the task fluency was to focus on the stem in terms of lexical semantics. The auditory presented item was then stripped of the suffix and the stem was mapped onto the verbal stems. The verbal stems derived from adjectives with a back stem vowel by means of conversion had to contain an umlauted vowel in the stressed position. The impossibility of finding a suitable stem for the irreparable nonwords resulted in a robust N400. The stem allomorphy, as in the RD condition, resulted in an attenuated N400 because the non-umlauted stem was existent but not in the necessary grammatical category. The lexical look up did not require online formal repair and resulted in the semantic composition process as reflected in the N400 amplitude (we shall further discuss the semantic composition in *Discussion: Umlaut*). Thus, if a stem variant did not map directly onto a verbal stem, the item was immediately classified as a nonword. This stem-mapping procedure resulted in differential error-sensitivity, as reflected in the graded brain response pattern.

In sum, the results of the lexical decision task experiment provided evidence supporting our hypothesis. The RD condition induced error-detection mechanisms that were significantly different from those triggered by the irreparable nonwords. The stem allomorphy, however, was not a sufficient factor for the classification of the RD items as words, as reflected in the significant difference of these items from the existing words (W). The lexical decision task induced strategic effects, as only a semantic ERP component was observed in this study. To investigate the processing of complex words in more natural experimental settings, we decided to employ a memory task. We expected the change of the experimental task to shift the participants' attention from the lexical semantics of the stimuli to the memorization of the items as a whole.

3.1.2.2 Experiment 4: Memory task

3.1.2.2.1 Methods

Participants

Sixteen participants (8 male, age range: 18-27 years, mean: 22.12) were recruited from the University of Konstanz by advertising. All subjects were native speakers of Standard German.

Materials and Procedure

The materials, the random lists, and the rotation of the runs were the same in this experiment as they were in Experiment 3. This decision was determined by the objective to study the influence of the experimental task on the error-sensitivity. To be able to assess this factor, we had to keep the rest of the factors intact. The experimental procedure of this study differed from the previous one in the following points: (i) the stimuli were presented auditorily in blocks of 3-8 words; (ii) after each block a word was presented on a computer screen; (iii) the subjects were instructed to press a corresponding key if they heard this visually presented probe in the last presented auditory block (Yes/No).

Data Analysis

The data were processed in the same way as in the lexical decision task experiment. The filtering and averaging procedures resulted in the rejection of approximately 6% of the data.

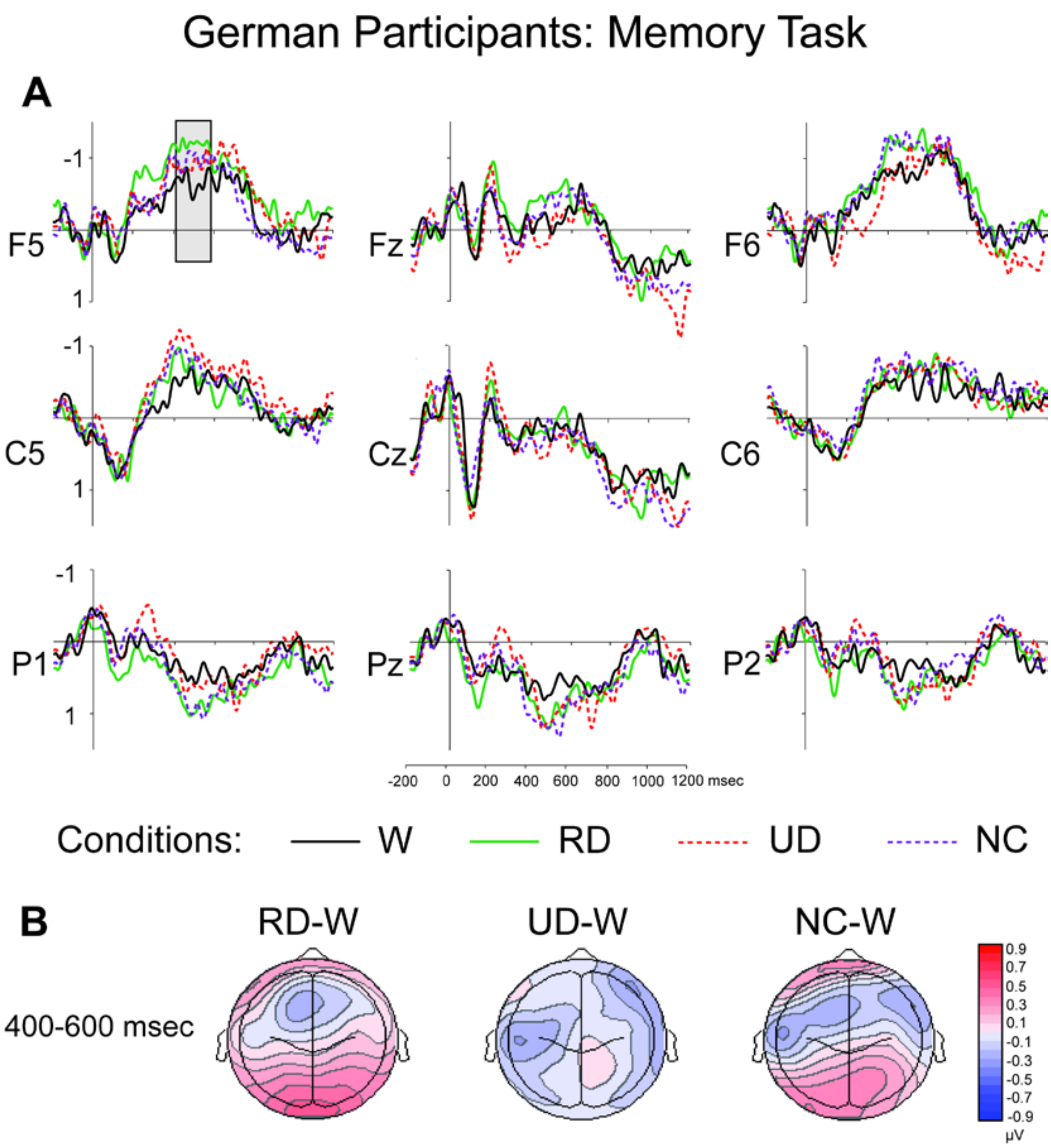

Figure 9. German Participants: Memory Task

Grand averages (A) and topographies (B) of the difference waveforms are shown for all experimental conditions in the memory task. The LAN effect is highlighted at the F5 electrode. The violation conditions demonstrate the following pattern: the RD (green solid line) condition is the most negative curve; the UD (red dashed line) and the NC (purple dashed line) conditions are more positive than the RD condition. The W (black solid line) condition is the most positive curve. The topographies show a similar scalp distribution for all conditions with a slight left hemispheric shift for the NC and UD conditions.

3.1.2.2.2 Results

Figure 9 displays the grand averages and the topographies for the difference waveforms of the type Violation condition–W in the time window of 400-600 msec. The LAN effect is highlighted at the F5 electrode site. The RD condition (a green solid line) has the most negative value, while the UD (a red dashed line) and NC (a purple dashed line) conditions pattern together and have more positive values than the RD condition.

To make sure that the change of the experimental task resulted in differential brain activity, we first ran an omnibus test within the time window of 400-600 msec with Task as a between factor, which revealed a four-way interaction of Task, Anteriority, Laterality, and Stem type ($F(5.55, 166.56) = 10.84$, $p < 0.001$). Further one-way ANOVAs with the factor Stem type were run within each of nine regions (Anteriority x Laterality). The one-way ANOVA reached significance at the left anterior electrode sites: $F(2.08,41.7) = 2.84$, $p < 0.05$, which is where the LAN component had been observed (Friederici, 2002, 2011). Analyses on mean amplitudes were run at the left anterior electrode sites (F5, AF3, AF7) within the time window of 400 – 600 msec. The mean amplitude values for the LAN component are illustrated in Figure 8. The contrast analysis revealed a significant difference of the RD condition from the rest of the conditions: $t(60) = -2.74$, $p < 0.01$.

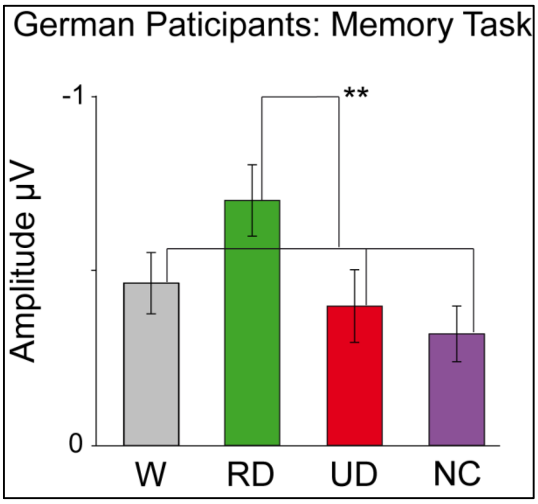

Figure 10. German Participants: the LAN Effect

The LAN effect at the F5 electrode is shown for the memory task. Note that the (R)elated (D)erived condition has the greatest negative value.

3.1.2.2.3 Discussion

We predicted that the change of the experimental task would trigger a different processing strategy as compared to the lexical decision task experiment. We further argued that the RD items would elicit a formal error-detection mechanism, indexed by a morphosyntactic ERP component, if our hypothesis were valid. The results of the study validated our hypothesis yielding a spatial-temporal activation pattern of the brain responses that was different from that of Experiment 3. The results of the memory task experiment revealed a LAN effect in the time window of 400-600 msec evoked only by the RD items. The irreparable violation conditions failed to trigger any error-detection mechanisms and had no significant difference from each other and from the W condition. No other ERP components were observed in this experiment.

In the predictions for the memory task experiment we argued that the presence of the error-detection mechanisms or the lack thereof for the irreparable nonwords might be explained by different processing strategies. Thus, if the meaning of the items was relevant to their maintenance in the short term memory, a semantic ERP component would have been observed. If, however, the new structure, introduced by the irreparable nonwords, was accommodated into the short term memory as a novel word, the processing of these items should not have differed significantly from that of the existing words. The fact that irreparable items failed to induce any violation effects provided evidence in favor of the latter processing strategy. The shift of the focus from the lexical semantics to the whole structure processing led to the reevaluation of processing priorities. Considering the effort required for the simultaneous maintenance of three to eight words in the short term memory, a new processing hierarchy had to be established in order to increase the task fluency. The lexical retrieval and semantic judgment were no longer a prerequisite for the successful task performance; therefore, they were relinquished in favor of the formal structure analysis. Without the possibility of finding a stem representation in the mental lexicon, the irreparable items could not be classified as structurally deviant. Therefore, both the novelty of the item and the novelty of the structure contributed to the accommodation of the irreparable nonwords into the short term memory.

The maintenance of the RD items in the short term memory presented a greater challenge than the rest of the conditions did. Considering the two-step derivation, required for the deverbal noun formation, the parser had to trace back all the steps in search for the missing manipulation. This particular manipulation also had to be memorized in order to produce the correct response during the memory task. Therefore, the omission of the conversion of the adjectival stem into the verbal, as reflected in the umlaut of the stem vowel, triggered a morphosyntactic ERP component LAN (A. D. Friederici, E. Pfeifer, & A. Hahne, 1993; Gunter et al., 1997; Rösler et al., 1993). This finding delivered a solid body of evidence supporting our hypothesis. The morphosyntactic combinatorial possibilities must be listed in the mental lexicon entry, as reflected in the amplitude of the LAN effect. In the case of the invalidity of our hypothesis, the processing of the RD items should have been similar to that induced by the rest of conditions, i.e. without an equivalent structure in the mental lexicon the new item would have been accommodated as a novel word.

3.1.2.3 Discussion: Umlaut

The objective of the present study was the assessment of the German mental lexicon with respect to the storage of regular stem allomorphs. We put forth a hypothesis that for the sake of economy regular predictable stem allomorphs should share a lexical entry. In order to control for both phonological and morphological effects, four conditions were designed. The real word condition (W) was derived in two steps: first, an adjectival stem with a back vowel was converted into a verb with a simultaneous umlauting of the stem vowel – *schwach* (*weak*) > *schwächen* (*weaken*); second, the verb was turned into a deverbal noun by attaching a nominalizing suffix {-ung} to the right boundary of the stem – *schwächen* (*weaken*) > *Schwächung* (*weakening*). The nonword conditions were derived from the W items by manipulating either the stem vowel or both the stem vowel and the coda consonant. The RD violation condition was designed to challenge the morphophonological rules. The RD items neglected the application of umlaut in the first step of derivation: *Schwachung. The resulting nonwords were semantically reconstructible by combining the meanings of the constituent morphemes and structurally reparable via offline application of umlaut. The following nonword conditions were designed as phonological control for the degree of deviation from the standard. The UD condition contained a systematical yet not morphophonologically determined modification of the stem vowel. The resulting stem was non-existent and the meaning of the UD nonword could not be restored, e.g. *Schwochung. The last nonword condition – NC – deviated from the standard in two phonemes: the stem vowel and the coda consonant, yielding non-existent stems, viz. *Schwickung. These items were used in a lexical decision task experiment and in a memory task experiment, with the goal of inducing differential processing of the linguistic material. By comparing brain responses to these four conditions, we expected to determine error-detection mechanisms triggered by qualitatively different violations.

We reasoned that access to the morphophonological rules would result in a pattern of brain responses significantly different from those elicited by purely phonological violations and by existing words. Thus, the error-detection mechanisms induced by the RD nonwords would be distinct from those evoked by the UD and NC items. The significant difference of the RD items from the other conditions should validate our hypothesis. We predicted a similar brain response pattern for all violation conditions in order to refute our hypothesis. The results of the present study provided supporting evidence for our hypothesis, revealing a graded N400 effect of the type W<RD<UD=NC in the lexical decision task experiment and a robust LAN effect elicited by the RD items in the memory task experiment. Except for the RD items, all conditions in the memory task experiment failed to elicit any violation effects whatsoever.

The lexical decision task experiment was designed to specifically induce lexical semantic processing. Considering the ability of the RD items to be semantically re-composed, the N400 elicited by these items should be attenuated in contrast to the irreparable nonwords. The results of the study revealed a mild N400 effect for the RD condition, the UD and NC conditions having evoked a similarly prominent N400. According to our predictions, the intermediate status of the RD nonwords between real words and irreparable nonwords should be indicative of the unified representation of the regular stem allomorphs. Taking into account the characteristics of the N400 component as an index of semantic processing, the sole reliance on the effects reported in the lexical decision task experiment would be unreasonable. Though in line with our hypothesis, the results of this study did not provide direct information about the structural processing of the violation conditions. However, the N400 effect was repeatedly reported in the studies on morphological decomposition. This fact makes the N400 component a useful tool in experiments investigating different strategies involved in the processing of the linguistic material.

The N400 effect observed by McKinnon et al. (2003) was connected to the morphological decomposition. The authors argued that nonwords made up of existing though non-productive (bound) morphemes would elicit an N400 effect similar to that evoked by the real words containing the same bound stem morphemes. This argumentation was determined by the authors' hypothesis that the bound morphemes of the nonwords could be accessed in the mental lexicon after the morphological decomposition. The fact that those bound morphemes existed in the language made it possible to regard the bound morpheme nonwords as real words with a zero frequency of occurrence. As the bound stem words used in McKinnon et al.'s (2003) study were low-frequency words, the brain responses induced by these two conditions should be similar. The results of the study supported the authors' hypothesis, having revealed the predicted response pattern. The stimuli used in our series of studies were relatively frequent complex words that consisted of a free stem and a nominalizing suffix. Considering the frequency of occurrence of the adjectival stem and the degree of deviation from the standard, the effects demonstrated by the RD condition could not be accounted for by the low frequency of occurrence. Thus, the lemma frequency of the adjectival stems was fairly high (mean in Celex: 739.96), while the actual frequency of occurrence of the RD items was zero. The lemma frequency of the adjectival stems being higher than that of the deverbal nouns, the frequency effects might have reversed the observed effects, if triggered at all. The N400 effect elicited by the violation conditions was homogenous in the peak latency and the morphology of the curve. Therefore, we reason that this response pattern was caused by the lexical status of the items and not by the frequency of occurrence or the neighborhood size effects.

The characteristics of the N400 component that could explain the attenuated N400 effect in the RD condition were provided by the Koester et al.'s (2007) study. The authors observed an N400 effect elicited by the head constituents of the low-frequency semantically transparent compounds. The timing of the N400 effect was clearly determined by the head constituent, as only at this point the semantic transparency/ opacity became obvious: e.g. *butter**fat*** – transparent and *butter**fly*** – opaque. Koester et al. (2007) maintained that the N400 effect observed in their study reflected the semantic composition process that occurred after the meanings of the constituent morphemes have been accessed. This line of argument could also explain the effects observed in our study. The morphosyntactic context introduced by the stimulus materials required all experimental items to be deverbal nouns, derived by concatenating the suffix {-ung} to the right boundary of the stem. Therefore, the meaning of the suffix had already been provided before the actual stimulus was heard. The best strategy to improve the task performance would be affix-stripping and mapping of the incoming input onto the representations of the verbal stems. Due to the shared lexical entry, the allomorph employed in the RD condition could be mapped onto its underlying representation but the meaning related to it was not that of a verb. The consequent semantic restoration process via reconstruction of the required grammatical category was reflected in the reduced amplitude of the N400 effect.

The pattern of the N400 effect in the lexical decision task experiment also demonstrated the lack of difference between both irreparable nonword conditions. The irreparable conditions were designed to control for the purely phonological effects, such as the degree of phonological overlap in the W and the irreparable nonword conditions. While the UD items deviated from their W sources in only one phoneme, this deviation did not have any (morpho)phonological bases. The vowel change was not triggered by any morphophonological rules or by regional variants of pronunciation, yielding a non-existent stem morpheme. The mere phonological overlap did not suffice to reconstruct the original stem resulting in a complete rejection of the UD items as words. The NC nonwords were designed as a double phonological deviation from the standard. We argued that if the amount of structural overlap or, by analogy, the degree of deviation played an important role in determining the lexical status, the NC items would be significantly different from the UD items evoking the most pronounced N400 effect. The results of the study showed that the degree of deviation from the standard was irrelevant if this deviation was not triggered by a linguistic phenomenon, hence the N400 pattern W<RD<UD=NC.

While the lexical decision task experiment provided a useful insight into the processing of the RD items it could not answer the question of whether this processing was based on the access to the unified underlying representation with a set of morphophonological and morphosyntactic rules. To ensure the analysis of the morphological structure, we had to widen the scope of the participants' attention. Being concentrated on the lexical status of the items, the participants did not have to pay attention to the rest of the linguistic structure. In order to shift the focus, we introduced the memory task. We predicted that the processing of the morphosyntactic rule violation in case of the RD items would result in a LAN effect (Gunter et al., 2000; Kutas & Hillyard, 1983; Münte et al., 1997; Osterhout & Mobley, 1995; Penke et al., 1997). The results of the study verified our hypothesis revealing a LAN effect for the RD items.

The memory task employed in the reported experiment implied the simultaneous maintenance of three to eight words in the short term memory. The visual probe that occurred after this short auditory block had to be compared to the memorized items. After that a recognition task had to be performed, i.e. if the last auditory block contained the visually presented probe. The task difficulty consisted not only in the act of memorization of multiple items but also in the transformation of the item coding into the visual modality. The W condition did not require additional resources for the maintenance of its items, as those were familiar words. The irreparable items demonstrated the same brain response pattern as the W condition. Considering the lexical status of these nonwords, it was difficult to predict the response pattern that completely corresponded to the standard processing. We reasoned that the lexical status was irrelevant to the task fluency, which is why the irreparable words were accommodated into the vocabulary as novel words. The structure of the irreparable words could not be identified as correct or faulty as the German vocabulary could not provide any comparable items. Without the information about the grammatical category and the capability of the stem vowel to umlaut, the phonological structure was also adopted. This pattern of results provided experimental evidence for the study reported by Augst (1971). In Augst's study the subjects were instructed to produce comparative forms of non-existing adjectives, e.g. *plutt*. The results of the study revealed the prevalence of the non-umlauted forms over the umlauted ones. The author (Augst, 1971) argued that the ability of an adjectival stem vowel to umlaut in the comparative or superlative forms was not intrinsic and therefore should be treated as an exception. An exception has to be listed in the lexicon. We reason here that the exceptions concerning the regular stem vowel alternations should be listed in the mental lexicon entry in form of an unspecified vowel. The set of morphophonological rules should define its surface form in different morphological combinations.

Our results provided experimental support for the accounts by Marslen-Wilson et al. (1994), Wiese (1996) and Scharinger et al. (2009, 2010) in terms of the representation of regular stem allomorphy in the mental lexicon. The account put forth by Marslen-Wilson et al. (1994) proposed that regular stem allomorphs should be represented by a single abstract morpheme with the stem vowel underspecified for the alternating feature. The alternating feature in the German umlaut process would thus be [DORSAL], whilst in the English TSS case this feature would be [TENSE]. Scharinger et al. (2010) accounted for the umlauting process in inflectional morphology also by assuming the underspecification of the stem vowel. However, the difference of Scharinger et al.'s (2010) account from that by Marslen-Wilson et al. (1994) lay in the underspecification of the stem vowel for the place of articulation. Though our objective was not to determine the type of (under)specification of the stem vowel, we demonstrated that regular stem vowel alternations should be governed by the intrinsic ability of the stem vowel to alternate. Wiese's (1996) account also considered umlaut as a phonological rule that can only be triggered if a stem morpheme has a floating feature [FRONT]. While our results did not provide any factors in favor of the floating feature, they demonstrated that umlaut was indeed triggered by the stem.

In summary, the results of the present series of studies provided experimental evidence for the unified representation of regular stem allomorphy in the German mental lexicon. The pattern of results obtained for the nonword condition that violated the morphophonological rule of umlaut significantly differed from the brain responses elicited by the real words and by the irreparable nonwords. The reduced N400 effect in the lexical decision task and the LAN effect in the memory task for the RD items demonstrated semantic composition and structural repair processes respectively. These processes could only have occurred if the morphophonologically deviant input was mapped onto the unified underlying representation.

3.1.3 Sentence Context Experiments

The results of the word list experiments provided supporting evidence for a unified representation of the regular stem allomorphs. The graded N400 effect obtained for the violation of the TSS in the British lexical decision task study was replicated for the violation of umlaut in the German lexical decision task study. However, the brain response patterns elicited in the British and German memory task experiments failed to deliver comparable results. The error-detection mechanism induced by the violation of TSS was qualitatively different from that elicited by the violation of umlaut. The question still open after the word list experiments was, therefore, whether these two Germanic derivational processes involving a vowel alternation were comparable. Or more importantly, if the underlying representation and processing of the regular stem allomorphs was similar in English and German. The replication of the results obtained in the British lexical decision task experiment with the German materials demonstrated a similar processing of the lexical semantics. The discrepancies between the results of the memory task experiments were already considered in the Discussion parts of the previous chapters. Nevertheless, an account that could draw parallels between the processing of regular stem allomorphy in these languages was still necessary for cross-linguistic generalization. For this reason, we decided to run a series of sentence context experiments with a memory task in English and German employing the same critical items. The following sentence context experiments were designed to study the lexical retrieval and morphosyntactic repair processes during auditory perception of complex words in connected speech. We expected the results of these studies to provide insight into the error-detection and formal repair mechanisms when no linguistic task was superimposed, although the syntactic and semantic context created a bias towards a certain structure.

Considering the length of the word list experiments, we decided to employ a restricted number of conditions in the sentence context experiment. The memory task proved hard to perform over a long period of time. While the items that had to be memorized in the word list experiments were three to eight isolated words, in the sentence context experiments the participants had to maintain three to eight sentences in their short term memory. Taking into account the amount of resources required for such task, we chose to use the W condition and only two nonword conditions, viz. RD and UD. The length of the resulting experiments exceeded the length of the word list experiments by six minutes.

The decision to employ a memory task in this series of experiments was determined by two factors: first, we wanted to find out if we could replicate the results of the reported memory task experiments within a sentence context; second, we did not want the participant to deliberately pay attention to the type of violation, which would be impossible with a lexical decision task. In addition, the results of the lexical decision task experiments were unambiguous for both languages and therefore needed no further investigation. The response pattern triggered by the memory task, however, varied from the LPN effect in the British study to the LAN effect in the German one. We argued that the LPN effect reflected the mnemonic processes involved in the maintenance of the contextual information, such as retrieval of the occurrence of TSS from the episodic memory. The lack of structural repair process was then explained by the one-step derivation that was accompanied by TSS yet was not signaled by it. In comparison to the TSS, umlaut not only accompanies the conversion of an adjective into a verb, it also orthographically and phonologically marks the change of the grammatical category. Therefore, the violation of umlaut results in a violation of the grammatical category yielding a morphosyntactic ERP component, viz. LAN.

Our predictions for the sentence context experiments were in line with the previous research. We expected the RD items to either replicate the response patterns from the previous studies or to elicit similar brain responses in both groups based on the chosen strategy. Thus, if lexical semantics were prioritized in the light of sentence context, a mild N400 effect would be observed in both experimental groups for the RD condition. If, however, the lexical retrieval could proceed by means of the structural repair process, we expected to observe a LAN effect. The predictions for the UD condition were also based on the perception of the deviation by the participants. Thus, we expected these items to be classified as nonwords eliciting a prominent N400 effect if the participants considered the UD condition irreparable. On the other hand, the degree of deviation could be relevant to the perception of these items in a sentence context. Taking into account the amount of overlap between the original stem in the W condition and the manipulated stem in the UD condition, the latter could be repaired via access to the pre-activated representation with the major phonological overlap and the appropriate semantic structure. In this case, we expected either a LAN or a P600 effect depending on the timing of the processing. Apart from the early processing of the violated items, we also expected the presence of the sentence context to trigger the reanalysis of the whole sentence, reflecting the integration of the violation conditions into the semantic and syntactic structure. This process would be reflected in the amplitude of the P600 component. The magnitude of the P600 could also be indicative of the gravity of the conflict caused by the deviant input.

In summary, we expected the RD items to elicit both (morpho)syntactic ERP components – the LAN and P600 – due to the violation of morphophonological rules and due to the presence of a sentence context. The UD items were predicted to also induce a P600 component due to the increased gravity of conflict triggered by this condition within a sentence context. As for the earlier processing of the UD nonwords, we expected a strategic prioritization of a certain type of processing. If the UD nonwords failed to be repaired, they would elicit an N400. Conversely, if the possibility of repair was induced by the context, the UD items could evoke a LAN effect.

3.1.3.1 Experiment 5: German participants

3.1.3.1.1 Methods

Participants

Twenty-four participants (12 male, age range: 19-26 years, mean: 22.29) were recruited from the University of Konstanz by advertising. The subjects gave written informed consent and were paid for participation.

Materials

The experimental material consisted of the same di- or trisyllabic German nouns that we used in the word list experiments reported earlier in this thesis. However, we reduced the number of conditions to three: the W condition *Schwächung*, the RD condition **Schwachung*, and the UD condition **Schwochung*. The experimental items were placed in a final position of the sentences that were biased, both syntactically and semantically, towards the critical words (W), e.g. "*Neben Tee und Kaffe finden Sie kleine Snacks zur Stärkung.*" (Apart from tea and coffee you'll find little snacks for ***strengthening***=***some refreshments***). These sentences were selected via the Internet from online newspaper articles. Three sentence frames were selected for each critical word, yielding a total of 63 sentences per condition.

A professional Standard German speaker (male) first practiced to produce all experimental items naturally in isolation and in sentence context and then read them for recording. The sentences were spoken with an assertive falling intonation with a focal stress on the critical word. The total 189 sentences were recorded and digitized. The trigger was set on the third glottis wave of the stem vowel.

The stimuli were divided into 3 experimental runs (à 63 sentences): the first two runs contained both violation conditions; the last run was made up of the W condition. The sentences were pseudo randomized in such a way, that every sentence frame appeared just once per run.

3.1.3.2 Experiment 6: British participants

3.1.3.2.1 Methods

Participants

Twenty-four right-handed native English subjects (12 men) took part in this experiment (age range: 19-33 years, mean: 21.66), after providing a written informed consent. They were students from the University of Oxford and they were born and brought up in the South-East of England.

Materials

The stimulus material consisted of English nouns used in the British word list experiments. Twenty-three nouns with a relatively high frequency of occurrence (mean in Celex: 68.18; Leipziger Corpus: 584.78) were used in the W condition (*ser**e**nity*) that was modified to produce the RD (**ser**[i:]**nity*) and UD (**ser**[aɪ]**nity*).

Sixty-nine sentence frames (3 sentences for each item) were found via online newspapers and articles in such a form that a critical word always appeared in the sentence-final position.

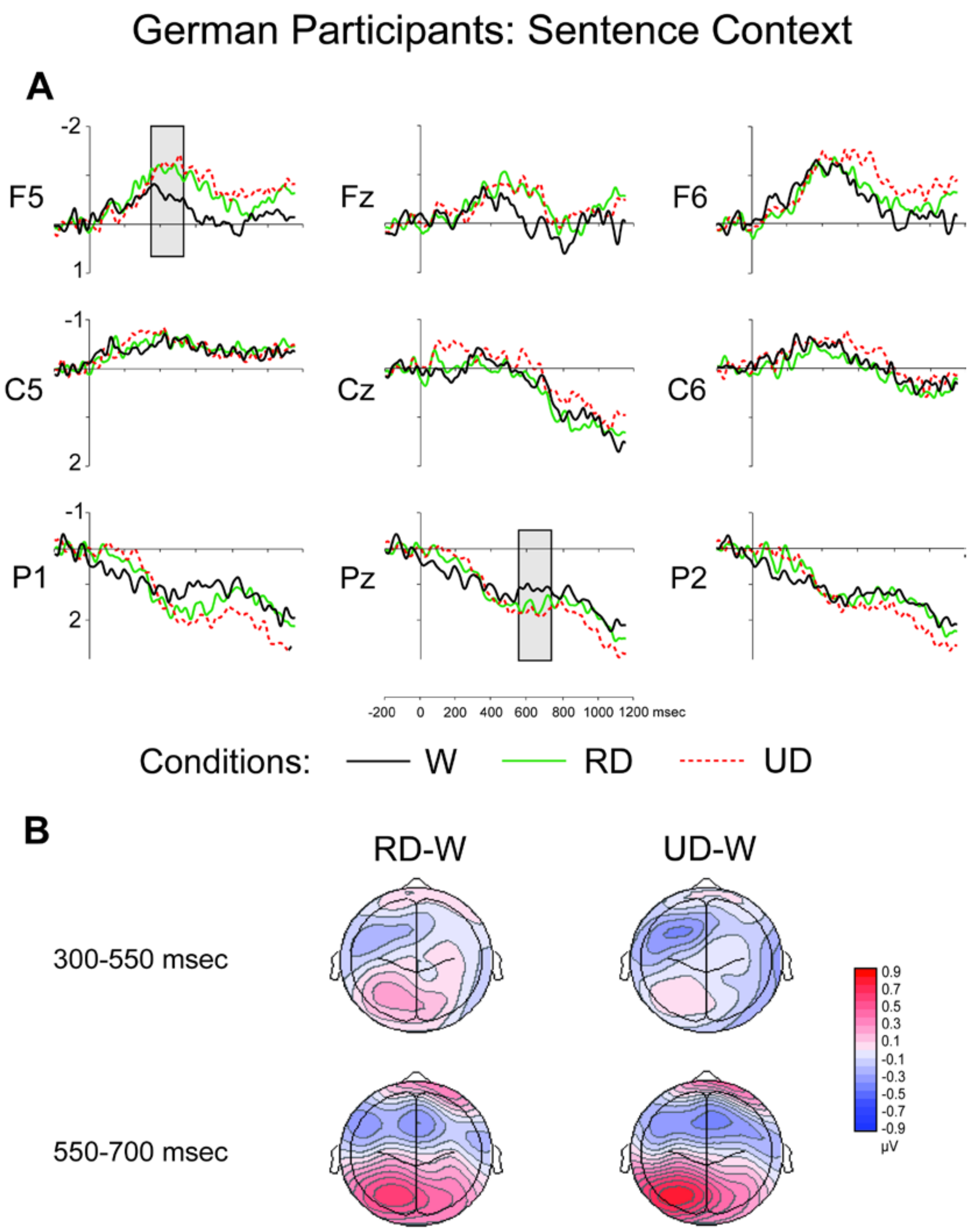

Figure 11. German Participants: Sentence Context

Grand averages (A) and topographies (B) of the difference waveforms are shown for all experimental conditions in the memory task with German participants. The LAN effect is highlighted at the F5 electrode, the P600 effect is highlighted at the Pz electrode. The violation conditions reveal the following pattern: the RD (green solid line) and UD (red dashed line) conditions demonstrate a similar LAN effect at the F5 electrode site and a similar P600 effect at the Pz electrode site The topographies show a similar scalp distribution for both violation conditions in the latencies of the LAN (300-550 msec) and the P600 (550-700 msec) components.

A professional British English (Received Pronunciation) speaker first practiced the 207 sentences, and then read them with a general falling intonation, with the focus on the critical word, for a recording. The same procedure as in the German study was used for digitizing the stimulus materials and setting the triggers.

Procedure

The stimuli were presented binaurally through headphones in blocks of 3-8 sentences, after each block a sentence appeared in the centre of a computer screen. The auditory presentation of the stimuli was synchronized with a fixation cross in order to reduce eye movements. The participants were asked to avoid body and eye movements while the fixation cross was visible. During the 2-second ISI the computer screen remained black. The subjects were instructed to listen silently to the sentences for comprehension and to press a designated computer mouse key whenever a sentence, presented on the screen, corresponded to one of the sentences presented in the last auditory block. The sentence remained on the monitor until the subject pressed the key. The presentation was divided into three runs (12 minutes each) with 5-minute breaks between the runs. The whole procedure, including set up and breaks, took approximately 2 hours.

Data Analysis

Trials with gradient amplitude of over 75 µV were automatically discarded from the analysis; the remaining trials underwent visual inspection for artifacts. In total, approximately 10% of the data were rejected. The epochs were baseline corrected relative to the mean voltage of the 200-msec pre-stimulus interval.

Analyses on mean voltage were performed within the latency windows of 400 – 550 msec and 550 – 700 msec, which correspond to the windows in which the LAN component and the P600 component respectively had been observed in previous experiments (Friederici, 2002; Kuperberg, 2007).

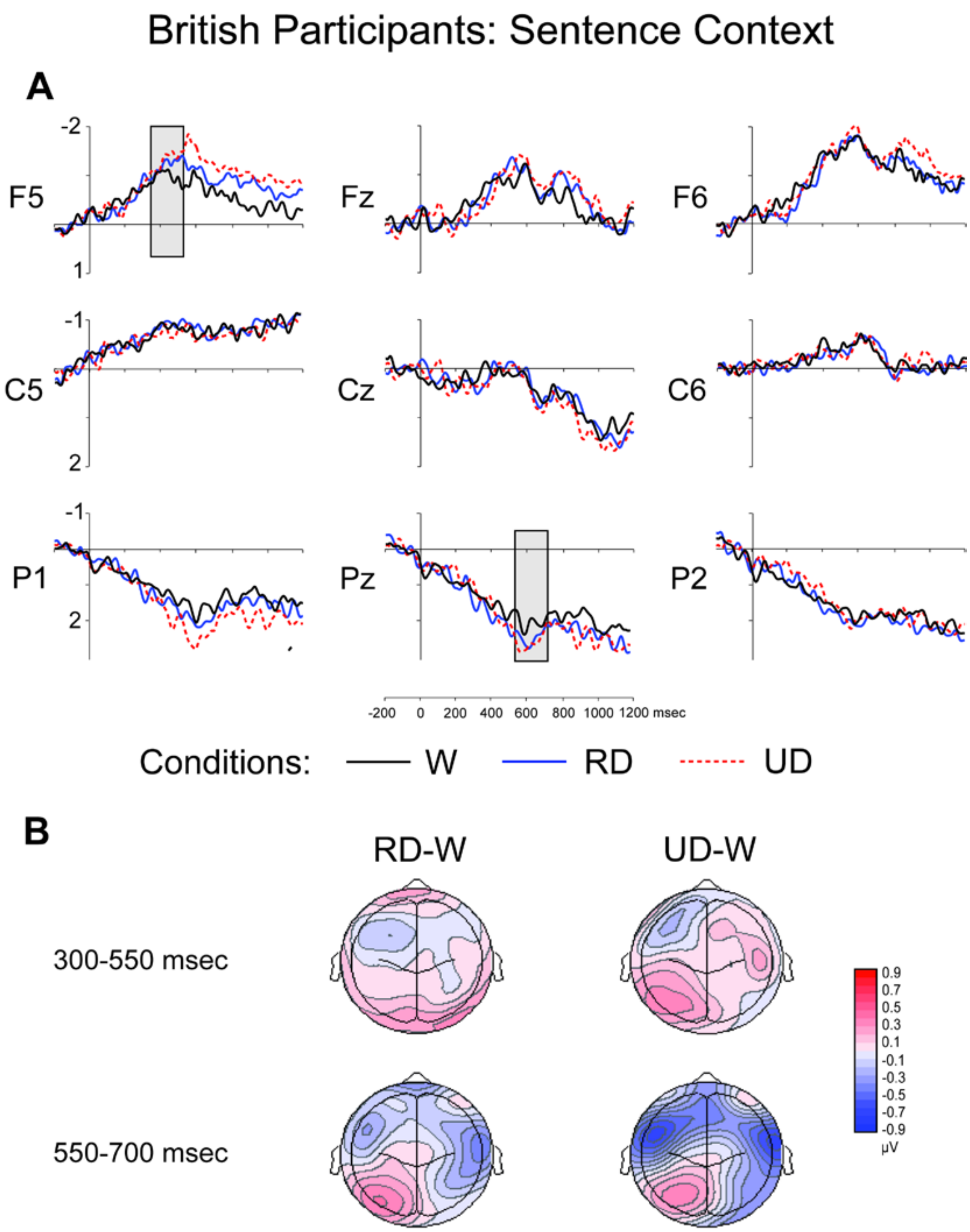

Figure 12. British Participants: Sentence Context

Grand averages (A) and topographies (B) of the difference waveforms are shown for all experimental conditions in the memory task with British participants. The LAN effect is highlighted at the F5 electrode, the P600 effect is highlighted at the Pz electrode. The violation conditions reveal the following pattern: the RD (a blue solid line) and UD (a red dashed line) conditions demonstrate a similar LAN effect at the F5 electrode site and a similar P600 effect at the Pz electrode site The topographies show a similar scalp distribution for both violation conditions in the latencies of the LAN (300-550 msec) and the P600 (550-700 msec) components.

3.1.3.2.2 Results

Repeated measures omnibus ANOVAs were run with three within-subject factors: Anteriority (Anterior, Central, Posterior), Laterality (Left, Central, Right), and Stem type (W vs. RD vs. UD), and with a between-subjects factor Nationality (German vs. English). Data from midline electrode positions were treated separately from the lateral electrode sites. The 4-way interaction did not reach significance in either latency range. This result pattern demonstrated that the experimental groups did not differ from each other in the brain response pattern. The only interactions with the factor Nationality were related to the topography in the latency range of LAN: Anteriority X Laterality X Nationality $F(3.23,148.6)=3.03$, $p<0.05$; and in the latency range of P600: $F(2.64,121.6)=4.31$, $p<0.01$. Significant interactions of the type Anteriority X Laterality X Stem type in the latency range of LAN ($F(5.51,253.89)=3.11$, $p<0.01$) and P600 ($F(4.77,219.63)=4.66$, $p < 0.001$) effects led to further tests at groups of three electrodes within the nationality groups.

400-550 msec: LAN

Figure 11 displays the grand average waveforms and topographies for the German group and Figure 12 demonstrates the same for the British group. The morphology of the LAN effect was similar in both nationality groups: while there was a positive trend in the W condition starting at around 450 msec post stimulus, the ERP responses to both violation conditions became more negative in the same latency range. The analysis of left anterior electrode positions (FC3, FC5, F5) in the time window of 400-550 ms revealed significant main effects of Stem type in both nationality groups: British $F(1.65,56.99)=3.61$, $p<0.05$; German $F(1.65,56.99)=3.23$, $p < 0.05$. Post-hoc paired t-tests revealed a significant difference between W vs. RD (British: $t(23) = 3.3$, $p < 0.01$; German: $t(23) = 3.76$, $p < 0.01$) and W vs. UD conditions (British: $t(23) = 3.57$, $p < 0.001$; German: $t(23) = 4.02$, $p < 0.001$). The comparison between the violation conditions RD vs. UD did not reach significance in both groups.

550-700 msec: P600

A two-way ANOVA in the time window of 550-700 msec revealed significant main effects of Stem type at the centro-parietal electrode sites (Pz, P1, P2) in both nationality groups: British $F(1.8,62.51)=3.38$, $p<0.05$; German $F(1.8,62.51)=5.68$, $p<0.01$. The post hoc paired t-tests showed that the W condition differed significantly from the RD (British: $t(23) = 3.61$, $p < 0.01$; German: $t(23) = 3.04$, $p < 0.01$) and from the UD violation conditions (British: $t(23) = 4.22$, $p < 0.01$; German: $t(23) = 2.55$, $p < 0.05$) in both experimental groups, while there was no significant difference between violation conditions (all ps > 0.4). The mean amplitude values for the LAN and P600 components are illustrated in Figure 13. Despite minor differences between the groups in amplitude intensity, the morphology of the ERP components and their topography remain similar in both experimental groups.

3.1.3.3 Discussion: Sentence Context experiments

The sentence context experiments examined the neural activity associated with the processing of phonological stem variants of complex words within a section of continuous speech, i.e. in the sentence final position. Critical words in both violation conditions evoked LAN followed by the P600 component in both experimental groups. No N400 effect was observed to either the RD or UD critical items.

We hypothesized that if there was an underlying abstract morpheme for the regular stem allomorphs, e.g. {schwAch} in German and {serIn} in English, then the lexical retrieval of the RD items would be facilitated. This could be possible due to the structural repair mechanisms governed by the morphophonological and morphosyntactic rules that define the surface form of the abstract stem morpheme. The offline application of these rules would therefore result in error-detection mechanisms reflecting morphosyntactic processing. At the same time, the repair of the UD items would be impossible due to the lack of substantial linguistic background that could systematize the manipulation of the stem vowel. The product of manipulation being a purely phonological violation, the UD condition should have been perceived as an irreparable nonword. The results of the present study demonstrated the possibility for both violation conditions to be repaired in the presence of a sentence context. The fact that the N400 effect was not observed in this study provided evidence for the successful lexical retrieval of all experimental stimuli. The present pattern of results could be explained by a number of factors. We shall first discuss the external ones and then move over to the internal factors.

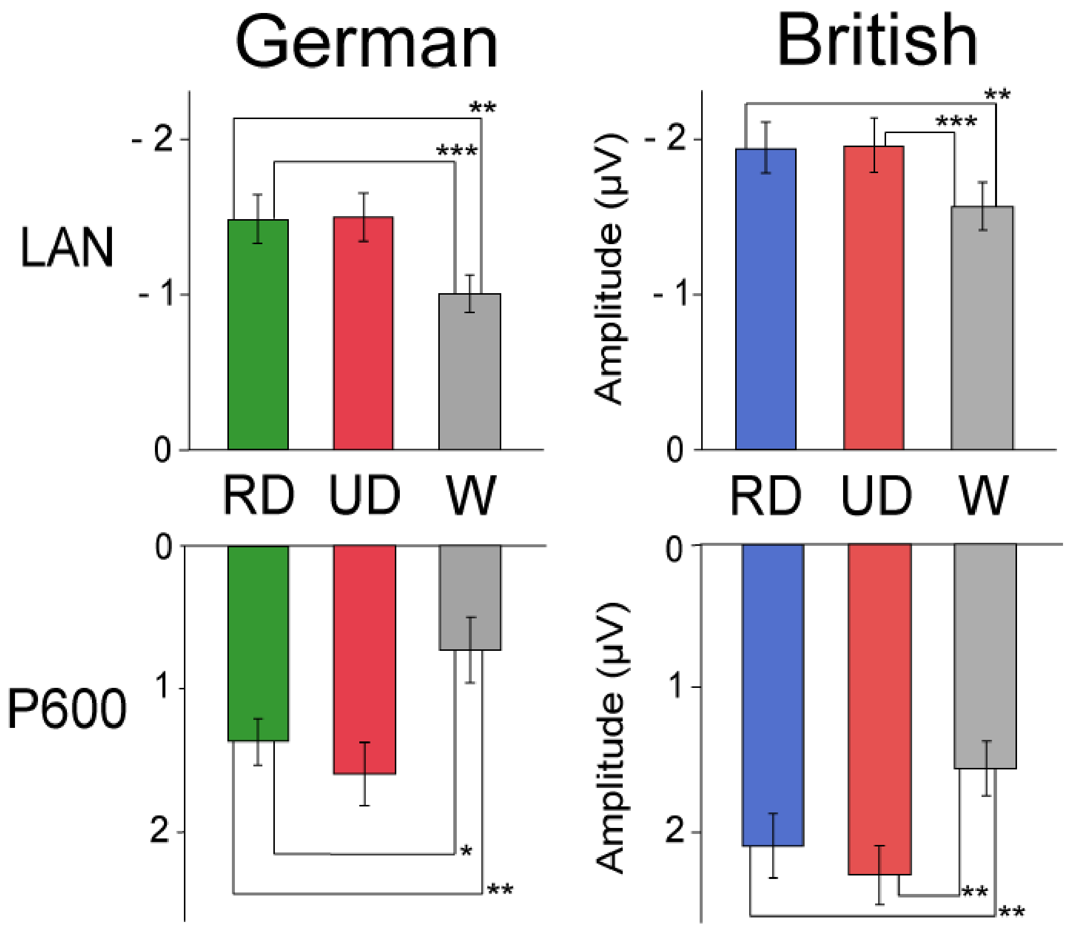

Figure 13. Bar Plots: German and British Participants

Bar diagrams of mean amplitude values (German group: gray bars, English group: white shaded bars) calculated for groups of three electrodes in the latency range and topography of the LAN component – at FC3, FC5, F5 electrode sites (upper part) and P600 component – at Pz, P1, P2 electrode sites (lower part). Standard error of mean is plotted in both directions.

The first factor that could influence the processing of the linguistic material was the composition of experimental blocks. The first two blocks contained only the RD and UD items in the sentence-final position. After a couple of trials the participants might have already realized that all sentence final words were deviant from the expected standard. While the RD items deviated from the expected stem in the violation of a morphophonological rule, the UD items differed from the standard in a sporadic modification of the stem vowel. The mere phonological overlap with the surface structure of the expected word was in this case equal for the nonword conditions. On hearing both kinds of violations and having subtracted the morphological structure, the participants must have come up with the strategy of looking up verbal/ trisyllabic shortened stems in the mental lexicon. The occurrence of the LAN effect in both cases demonstrated the repair processes that were running offline in order to reconstruct the original stem.

The sentence context used in the present study was also an additional factor influencing the processing strategy. The sentence frames were not restrictive or high-cloze probability contexts yet they were constructed with a bias towards the critical words. Thus, there was an extensive syntactic context that elicited the pre-activation of a certain grammatical category, i.e. a noun. The homogeneity of the stimulus materials also provided the information about the morphological structure of the sentence final word, i.e. a deverbal noun in German or a trisyllabic shortened abstract noun in English. The semantic context created an additional filter that helped to narrow down the stems to those that met the semantic requirements. The upcoming input was then matched to the pre-activated mental representations rejecting those that did not have the necessary phonological overlap. The violation conditions differed from the real words only in one phoneme, resulting in a minor phonological deviation from the mental representation. Therefore, the candidate that coincided with the input in all constituents but the stem vowel was retrieved, repaired and then integrated into the sentence context.

We expected the character of the stem violation to affect the processing of the nonwords. The morphophonological violation employed in the RD condition was predicted to elicit the morphosyntactic ERP component LAN (Gunter et al., 2000; Kutas & Hillyard, 1983; Münte et al., 1997; Osterhout & Mobley, 1995; Penke et al., 1997). Although the RD items deviated from the standard in the place of articulation/ the tenseness of the stem vowel, their stems represented one of the steps in the derivation of the critical nouns. The easiest way to reconstruct these nonwords was by the offline application of conversion accompanied by umlaut in German and the TSS in English. The purely phonological violation employed in the UD condition might have induced a number of ERP components. Considering the phonological deviation from the expected input, the PMN component (Connolly & Phillips, 1994; Connolly et al., 1995; Connolly et al., 1992; D'Arcy et al., 2004; Steinhauer & Connolly, 2008) could have been observed. PMN was reported to index the failure of mapping the actual acoustic input onto the expected candidate. However possible in the light of the present experimental conditions, the PMN effect was not observed in either nonword type. We argue here that the product of the stem vowel manipulation resulted in an increased conflict within the sentence context. The gravity of the conflict thus overrode the PMN effect if that should have been induced. In one of our predictions we mentioned the possibility for the N400 (Kutas & Hillyard, 1980, 1983; M. Kutas & S.A. Hillyard, 1984; van Berkum, Hagoort, & Brown, 1999) effect to be elicited by the UD items. The vowel manipulation was not governed by the non-application of morphophonological rules or by regional pronunciation variants, it was rather sporadic. Without a solid linguistic background behind the violation, the original stem could not be structurally restored and the UD items would be processed as irreparable nonwords yielding a prominent N400 effect. The last error-detection mechanism that we contemplated was based on a straightforward analysis of the phonological overlap and the structural repair of the stem vowel based on the pre-activation of the possible word candidates. The resulting processing would be indexed by the LAN yet it would not completely correspond to the processing involved in the retrieval of the RD nonwords.

The gravity of both violation types was sufficient to induce a structural and semantic reanalysis reflected in the amplitude of the P600 effect (Gunter et al., 1997; Hagoort et al., 1993; Morris & Holcomb, 2005; Osterhout & Holcomb, 1992; Osterhout & Holcomb, 1993; Osterhout & Holcomb, 1995). Though the nonwords carried different violation types, they presented comparable impediments for the parsing. According to Zwitserlood (1989), the contextual effects come into play at the point in time when a set of word candidates has already been pre-activated yet the sensory input does not suffice to disambiguate between the pre-activated representations. The lack of disambiguating information, though qualitatively different, had the same quantitative characteristics in the nonword conditions resulting in the elicitation of contextual effects. The increase of the processing demands associated with the reconstruction of the defective phoneme and the consequent integration of the repaired structure into the sentence context yielded a strong conflict. Van de Meerendonk et al. (2008) claimed that a P600 could only be elicited if the gravity of conflict triggered the language monitoring process and structural analysis. Our findings were also in line with the argument advanced by Kolk and colleagues (2003) that growing processing demands were reflected in the magnitude of the P600 effect.

The results of the sentence context experiments showed that a slight phonological deviation from the expected input, whether sporadic or structurally governed, could be morphosyntactically repaired if presented in a biasing context. While structurally different, the TSS and umlaut violations induced similar brain responses in both nationality groups. Considering the homogeneity of the observed effects, a further clarification of the contextual effects is necessary.

Thus, the mentioned external factors could be controlled for if the filler sentences were introduced. This would reduce the proportion of occurrences of violated items. Further, the NC items used in the words list experiments could also be employed in the sentence context studies to control for the degree of deviation from the standard. The difference in processing of the RD and UD items, if it has separate bases, could be investigated by means of functional magnetic resonance imaging (fMRI) providing insight into the structures involved in the repair process. The further investigation of the contextual effects in the processing of regular stem allomorphy should not only be extended via new paradigms and techniques but also via application of new materials, such as *tone*/*tonic* in English and *stark* (*strong*)/ *Stärke* (*strength*) in German.

3.1.4 Regular stem allomorphy in L2

The knowledge of the regularity of morphological processes, including affixation and phoneme alternations, does not come at once as a sudden realization. The rules governing these processes have to be deduced from a great amount of linguistic information that a child starts to absorb in the last months of gestation. In order to acquire a morphological structure, all possible instances of this structure have to be collected and an appropriate analytic tool has to be developed to discern the regularities. In the first language acquisition, a huge amount of linguistic data has to be sorted out during the first years of life. With the acquisition of reading a child starts learning new vocabulary even faster (Anderson & Nagy, 1992; Nagy & Anderson, 1984; Nagy, Herman, & Anderson, 1985). Further, reading helps to establish relationships between words. Learning to read implies learning to decode the orthographic form into the orally acquired vocabulary. However, after the learning stage, reading is no longer a simple decoding mechanism but rather a useful tool for increasing the vocabulary and language awareness in general (Nagy et al., 1985).

During the last years at the elementary school (fourth to sixth grades) students were reported to experience a quantitative and qualitative growth of their vocabularies (Anderson & Nagy, 1992; Nagy & Anderson, 1984; Nagy et al., 1985). Due to the fact that the reading vocabulary at this level includes morphologically complex words, students learn to establish relationships between words sharing a stem morpheme, thus deducing the meanings of new words. According to McCutchen et al. (2008), morphological awareness benefits from the establishment of morphological relationship between phonologically opaque items, such as *signature/sign.* Thus, it takes almost a decade during the acquisition of L1 to grasp the idea of allomorphy. It is up to the first language acquisition researchers to establish how long it takes to generalize the rule governing the allomorph application. In the present thesis, we hypothesize about the structure of the end-product. We claim here that for the regular stem allomorphs there has to be an underlying representation with a set of morphophonological and morphosyntactic rules defining the surface structure of an allomorph. Considering the fact that in the late second language acquisition a person has to undergo at least part of the same processes he/she had to undergo in the acquisition of their first language, we can observe the stages of allomorph learning.

According to the Critical Period Hypothesis (Birdsong, 1999; Weber-Fox & Neville, 1996), late L2 learners cannot achieve native-like proficiency in both perception and production. The hypothesis is based on the general physiological decline of the brain capacity and is connected to the reduction of learning ability. Phonology and syntax, being the formal bases of a language, are considered especially susceptible to the age of acquisition, while the vocabulary is not. This point of view, however, does not take into account the minimal pairs of words containing phonemes that are not used contrastively in the L1, such as *flash*/*flesh* or *rice*/*lice*, etc., nor does it consider the morphosyntax of complex words. If the syntactic structures specific to the L2 cannot be fully acquired after the critical period, the morphosyntactic rules governing the formation of complex words cannot be completely acquired either.

Another view on the development of L2 proficiency was provided on the basis of the declarative/ procedural model (Ullman, 2001a). This model was designed as an approach to describe linguistic processing in the L1. According to this model, the items and structures that can be obtained by application of a rule (e.g. *dance*/*danced*) are processed within the procedural system, while those items that have to be memorized (e.g. *go*/*went*) are processed within the declarative system. During the L2 acquisition a learner undergoes different developmental stages, first, characterized by learning an item or a rule by heart and later, by the deduction of a rule with its generalization. The initial application of a rule unfolds deliberately reflecting a memorized algorithm, i.e. within the declarative system. If the L2 learners can achieve automaticity in the rule application, it should be reflected in the hardwiring of the processing mechanisms resulting in the change of the processing system. In accord with this argumentation, at a definite level of proficiency the L2 learners should transfer rule-based operations from the declarative into the procedural system. Such a change of hardwiring should also become obvious in the error-detection brain responses elicited by morphosyntactic violations.

Hahne (2001) ran an auditory ERP study with a group of high-proficiency Russian learners of German. To explore the acquisition of L2 syntax, the author presented the subjects with sentences containing a phrase structure violation, viz. a preposition followed by a participle: **Das Geschäft wurde **am** geschlossen. - *The shop was **on** closed*. The German control group revealed a pattern consisting of an early left anterior negativity in the time window of 100-250 msec and a P600 effect. The high-proficiency L2 group failed to elicit the automatic error-detection brain response in the latency of the early LAN (ELAN). However, the L2 speakers revealed a P600 effect on the violation of phrase structure that peaked about 150 msec later than in the control group.

Another study (Rossi, Gugler, Friederici, & Hahne, 2006) demonstrated an ELAN reflecting the phrase structure violation not only in the high-proficiency L2 group but also in a moderate proficiency group. Rossi et al. (2006) ran a study with Italian L2 learners of German and German L2 learners of Italian, both groups being divided into moderate and high-proficiency subgroups. The participants were presented with auditory sentences containing a category violation: **Der Junge* ***im*** *singt ein Lied*. - **The boy* ***in the*** *sings a song*; a subject-verb agreement violation: * *Der Junge im Kindergarten* ***singst*** *ein Lied*. - **The boy in the kindergarten* ***sing*** *a song*; and a combined violation: * *Der Junge* ***im singst*** *ein Lied*. - **The boy* ***in the sing*** *a song.* The prepositional phrase (category violation) had to deliver restricting information about the subject already determined by the definite article and its presence was therefore obligatory for the processing of the sentence context. The results in the high-proficiency L2 groups in both German and Italian showed the same response pattern as native speakers for all syntactic violations though some amplitude differences were present. Thus, in the category violation condition an ELAN, an additional negativity reflecting reference-related processes, and late P600 effects were observed. The subject-verb agreement violation condition elicited a biphasic LAN-P600 pattern. The combination of the word category and agreement violations evoked the same ERP pattern as the category violation. An additional finding that contradicted the results of Hahne's (2001) study concerned the timing of the ERP effects. Thus, in the high-proficiency group the timing of the ERP responses corresponded to that of the native speakers. The low-proficiency groups, however, demonstrated a significant delay of the P600 in all violation conditions. More importantly, the low-proficiency groups failed to show a LAN effect in the agreement violation condition providing a significant effect of proficiency. The findings of Rossi et al.'s (2006) study delivered supporting evidence for the hypothesis that with growing proficiency, late L2 learners can demonstrate native-like neural responses. These results provided support for the declarative/ procedural view (Ullman, 2001) upon the development of L2 proficiency.

The processing of an L2 is highly dependent upon the declarative system (Ullman, 2001), i.e. the lexical memory, and employs the application of rules within the procedural system to a much lesser degree than the L1 processing does. However, Ullman claimed (Ullman, 2004) that the amount of practice could increase the reliance on the procedural system. Hahne et al. (2006) tested this hypothesis for morphological processing with late high-proficiency Russian learners of German. According to Ullman's declarative/procedural model (2001, 2004), L2 learners would resort to the full-form storage of inflected words within the declarative system and neglect the implementation of morphological decomposition processed within the procedural system. The authors examined (i) the production of nonword participles and the acceptability judgment of plural forms of nonword nouns in behavioral experiments; and (ii) the perception of correctly/ incorrectly inflected participles and correct/ incorrect plural forms of nouns. The results of the study demonstrated that the L2 learners overgeneralized the regular {-*t*} suffixation rule in the nonword participle production experiment. In the participle ERP experiment, they demonstrated a biphasic LAN-P600 pattern that was similar to the native-speaker results already reported in the literature (Friederici, Steinhauer, & Pfeifer, 2002; Lück et al., 2006; Osterhout & Holcomb, 1992; Penke et al., 1997; Rodriguez-Fornells et al., 2001; Weyerts et al., 1997). In the acceptability judgment task, the L2 speakers showed the plural formation preference patterns that resembled those reported by Marcus et al. (1995) for the native speakers of German. These differences were also evident in the L2 brain responses: the misapplication of the default {-*s*} plural rule induced a P600 effect, while the misapplication of irregular plural formation patterns evoked an N400 component. Considering the default nature of the {-s} plural formation, it was remarkable that the L2 learners failed to demonstrate a LAN. The authors argued that the results provided support for the hypothesis that L2 learners relied on both processing systems.

The stem allomorphy employed in the violation paradigm of the present series of studies is predictable and highly regular: the nominalizing suffix {-*ung*} can only attach to verbal stems, while the umlauted stem vowel signals the change of an adjective into a verb. The initial accommodation of the rule by an L2 speaker should unfold within the declarative memory, while growing experience should induce the increase in the involvement of the procedural memory. Our predictions for the lexical decision task in the present pilot experiment are demonstrated in Table 12. We expected the lexical decision task to trigger the concentration on the lexical semantics. The obligatory procedure in this case would be the lexical look-up. Considering the reported overreliance of the low-proficiency L2 speakers on the declarative system and the deliberate task performance, we expected the RD items to be behaviorally recognized as nonwords. The offline application of a memorized rule would thus help to distinguish real words. At the same time, the brain responses to the existing - though illegal in this combination - stem allomorphs could result in the absence of the N400 effect. The moderate experience with the language should be manifested in the lack of online morphosyntactic rule application that unfolds within the procedural system. Without the application of the suffixation rule, the affix stripping procedure would not be activated, resulting in the lexical look-up of words with the most phonological overlap. This factor could also contribute to the absence of the N400 effect demonstrating the response pattern similar to that elicited by real words. The prominence of the N400 effect evoked by the RD items would thus depend on the accommodation of the rule: the greater the degree of rule accommodation into the procedural system, the larger the N400. We expected the UD and NC items to elicit similar large N400 effects because their stems were non-existent and therefore could not be retrieved.

Table 12. Experimental conditions and predictions for the pilot study

*The names of the conditions and their composition are given in the first row: bold italicized **V**s and **C** represent manipulated phonemes, the most important difference being that between the front vowel **V** ([ɛ] [œ] [y]) and the back vowel $\boldsymbol{V_1}$ ([a] [o] [u]). The example of a graded violation pattern of a German word Stärkung (strengthening) is given in the second row. The predictions are divided into rows according to the degree of rule accommodation: into the procedural system – the third row with a graded pattern of N400; into the declarative system – the fourth row, with no violation response for the RD items and similar large N400 for the UD and NC conditions.*

Condition Composition	**W** – Word: Derived stem {C***V***C}+{-ung}	**RD** – related derived: Existing stem illegal in the combination {C$\boldsymbol{V_1}$C}+{-ung}	**UD** – unrelated derived: Non-existing stem {C$\boldsymbol{V_2}$C}+{-ung}	**NC** – nonce complete: Non-existing stem {C$\boldsymbol{V_3}$$\boldsymbol{C_1}$}+{-ung}
Example	Schwächung	*Schwachung	*Schwochung	*Schwickung
Reliance on the procedural system	____________	mild N400	large N400	large N400
Reliance on the declarative system	____________	_________	large N400	large N400

In summary, the results of the lexical decision task experiment should reveal no violation effects for the RD items if their processing unfolds within the declarative system. If, however, the L2 learners could apply a morphosyntactic rule relying on the procedural system, a mild N400 effect for the RD items should be observed. We expected both irreparable conditions to elicit a prominent N400 effect, as so they cannot be retrieved intrinsically.

3.1.4.1 Experiment 7: Pilot Study with Bilingual Participants

3.1.4.1.1 Methods

Participants

Five right-handed native Italian (3 men) and three native Spanish (1 man) subjects took part in this experiment. They were Erasmus exchange students at the University of Konstanz. The participants were classified as low-proficiency on the basis of a standardized German proficiency test (B1 Zertifikat Deutsch, Modellsatz © ÖSD). Only those subjects who scored more than 80% took part in the ERP experiment, after providing written informed consent.

Materials and Procedure

We used the same items and random lists as in the Experiment 3. The procedure was also the same, except for the proficiency test that was run prior to the general experimental procedure. The examples of the stimulus materials are demonstrated in Table 12 and in Appendix B.

Data Analysis

After the filtering, approximately 12% of the data were rejected. The epochs were baseline corrected relative to the mean voltage of the 200-msec pre-stimulus interval.

Analyses of mean voltage were performed within the latency window of the N400 component, i.e. 300 – 500 msec.

3.1.4.1.2 Results

Repeated measures ANOVAs were run with one within-subject factor: Stem type (W vs. RD vs. UD vs. NC) and the between-subjects factor Group (Bilingual vs. German). The 2-way interaction reached significance at the parietal electrode sites: Pz, P1, P2. The significant two-way interaction Stem type X Group (F(2.89, 63,6)=3.29, p<0.05) led to further tests within the bilingual group.

Behavioral data showed that 3% of nonwords were falsely identified as words; however, the error rate did not differ between the experimental conditions. Repeated measures ANOVA with two within-subject factors (Presentation (first to third time) and Condition) revealed no main effects or interactions (all p > 0.1).

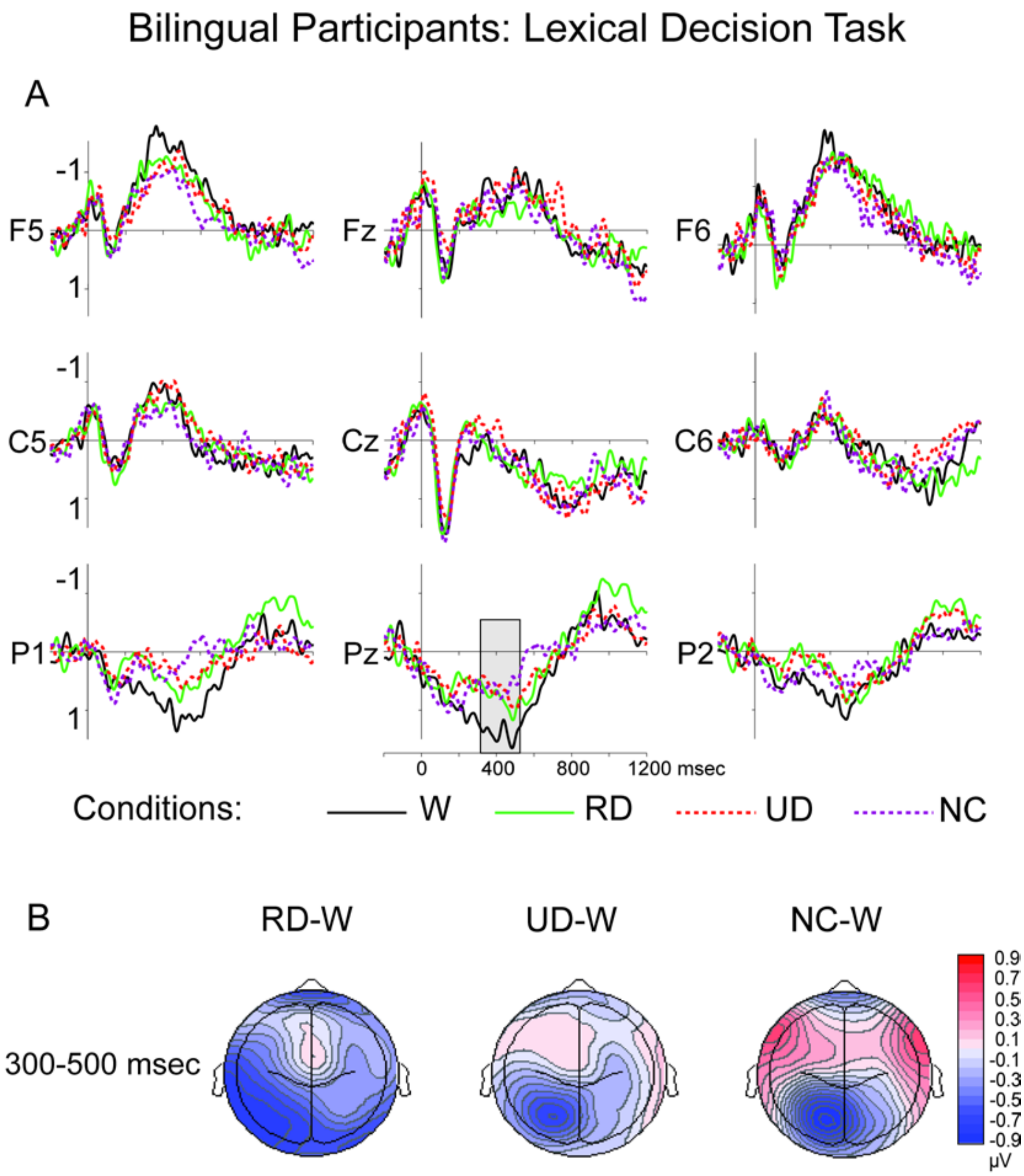

Figure 14. Bilingual Participants: Lexical Decision Task

Grand averages (A) and topographies (B) of the difference waveforms for all conditions in the lexical decision task experiment with bilingual participants. The N400 effect is highlighted at the Pz electrode. The violation conditions RD (green solid line), UD (red dashed line) and NC (purple dashed line) pattern together. The W (black solid line) condition is the most positive curve. The topographies show a similar scalp distribution for all violation conditions.

Figure 14 displays the grand averages and the topographies of the difference waveforms of the type Violation condition–W. The topographies are shown for the latency range of 300-500 msec. The N400 effect is most pronounced at the Pz electrode: the W condition (a black solid line) has the most positive value, followed by the RD condition (a green solid line), the UD condition (a red dashed line) is more negative than the RD, with the NC condition (a purple dashed line) being the most negative.

The N400 effect has been reported to be most pronounced at the parietal electrode sites; hence we focused our further analyses on the following parietal electrode sites: Pz, P1, P2. A one-way ANOVA for the time window of 300-500 msec revealed a significant main effect of Stem type (F (2.88,26.96) = 5.97, p<0.01). The mean amplitude values for the N400 component are illustrated in Figure 15. The post hoc paired t-tests revealed that the W condition was significantly different from the NC violation condition (t(7) = -3.23, p < 0.01). The difference between the other conditions did not reach significance.

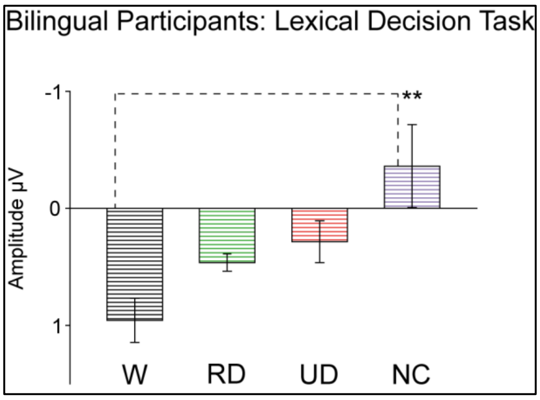

Figure 15. Bilingual Participants: the N400 Effect

Bar diagrams of mean amplitude values calculated for the group of three electrodes (Pz P1 P2) in the latency range and topography of the N400 component. Standard error of mean is plotted in both directions.

3.1.4.2 Discussion: Regular stem allomorphy in L2

The present pilot study was designed to explore the processing and representation of regular stem allomorphy in a second language. The stem allomorphy employed in this study was not only regular but also highly predictable. The regularity and predictability of the stem allomorphy were governed by the application of morphosyntactic rules that first converted an adjective into a verb with a simultaneous umlauting of the stem vowel, and then attached a nominalizing suffix to the verbal stem. In line with the declarative/procedural model (Ullman, 2001, 2004), we reasoned that the initial accommodation of these morphosyntactic rules by an L2 speaker should proceed within the declarative system, while growing experience should increase the reliance on the procedural memory.

We expected the lexical decision task to trigger a search for a lexeme within the declarative system. Taking into account the overreliance of the low-proficiency L2 speakers on the declarative system and the non-existence of the RD items in the German vocabulary, we expected the RD nonwords to be behaviorally classified as such. The factors contributing to the behavioral recognition of the RD items as nonwords would be (i) the failure to find these items in the long term memory and (ii) the application of a memorized umlauting rule offline. Both factors require the involvement of the declarative memory for the task performance. The reliance on the declarative memory was expected to be reflected in the brain response pattern: we expected the participants to demonstrate a semantic integration effect for the RD items similar to that elicited by the real words. The involvement of the procedural memory should be manifested in the sensitivity of the L2 learners' perceptual system to the violation of the morphosyntactic rules, i.e. in the elicitation of the N400 by the RD items. The UD and NC items were expected to elicit similar large N400 effects due to the non-existence of their stems.

The results of the pilot study provided empirical evidence for the reliance of the low-proficiency L2 learners on the declarative system: a significant N400 effect was revealed for the NC violation condition. The RD items failed to significantly differ from the W condition. Although the violation-related brain response pattern was reminiscent of that elicited in the native-speaker group, it failed to provide significant difference between the critical conditions (W vs. RD and RD vs. UD). We argued that the acquisition of a morphosyntactic rule required a definite amount of time to get accommodated into the procedural system.

According to the first language acquisition research (Anderson & Nagy, 1992; Nagy & Anderson, 1984; Nagy et al., 1985), the establishment of the morphological relations between words is observed by the end of the first decade of life and, for the most part, due to reading. The L1 children have to run numerous analyses on the linguistic material they perceived/learnt during the first ten years of life and establish connections between the words with a certain phonological or orthographic overlap. Some children might deduce the morphological structure/relatedness on their own, while the others might need instruction to do so. Therefore, the first language acquisition combines, on the one hand, an analytic work done by a child on his/her own, and on the other hand, the supportive work performed by the parents and teachers. Following this logic, the most important difference between the L1 and the late L2 acquisition is the form of the initial instruction. A late L2 learner comes into the classroom with an already established concept of the linguistic structure of the L1. The acquisition of the new language proceeds via the accommodation of the novel rules into the already existing system as either an equivalent or a superstructure. In both cases the initial rule learning and application proceeds within the declarative system (Ullman, 2001a, 2004). The growing proficiency of the L2 learners should be reflected in the transition from the declarative system to the procedural one (Pliatsikas, Johnstone, & Marinis, 2014). This transition would mean the change of hardwiring/involvement of certain brain structures indexed by the error-detection brain responses elicited by morphosyntactic violations.

The present ERP pattern demonstrated that the low-proficiency L2 speakers over-relied on the declarative system. A follow-up study with a high-proficiency L2 group could shed light onto the development of the L2 acquisition with respect to the change of hardwiring. According to Hahne (2001), even a high-proficiency L2 group would fail to demonstrate a native-like response pattern in terms of the automatic error-detection (e.g. ELAN). However, she did observe a delayed P600 effect in the L2 group in her study. Taking into account the design used in the present experiment and the semi-automatic characteristic of the N400 component, this violation effect might be observed in the high-proficiency L2 group.

The N400 effect elicited by the NC condition in the present study had the same latency as the N400 observed in the German. This finding was in line with Rossi et al.'s (2006) study, which showed that the timing of the ERP responses in the high-proficiency L2 group corresponded to that of the native speakers. Our findings, having revealed a similar timing of the N400 in both experimental groups, provided the evidence for a slow change of hardwiring. Considering a very small sample size of the present study, we could expect the critical comparisons to reach significance if the sample size should increase. The number of significant comparisons would be the index of a morphosyntactic rule acquisition, i.e. W vs. RD and/or RD vs. UD. With the increasing proficiency the reliance on the procedural system will grow (Ullman, 2004) revealing native-like brain responses to morphosyntactic errors (Friederici, Steinhauer, et al., 2002; Lück et al., 2006; Osterhout & Holcomb, 1992; Penke et al., 1997; Rodriguez-Fornells et al., 2001; Weyerts et al., 1997). In order to finalize the present pilot study, the sample size should be increased and a high-proficiency L2 group should be tested. Only in this case, we can demonstrate the transition from the declarative to procedural system with reliable results.

3.2 Discussion: Representation of regular stem allomorphy

The first part of the present thesis was focused on the derivation employing regular stem allomorphy in two Germanic languages, viz. English and German. We conducted two word list experiments with British participants and two word list experiments with German subjects. The word list experiments were designed to investigate the processing of complex words and nonwords in isolation. The objective of the follow-up sentence context experiments conducted in each nationality group was the exploration of the lexical retrieval and processing of the complex words and nonwords in a biasing context. We finalized this series of studies with a pilot experiment run with low-proficiency L2 learners of German. The last study investigated the acquisition of a morphosyntactic rule, i.e. the transition from the reliance on the declarative memory in application of a morphosyntactic rule to the reliance on the procedural memory. Considering the limited possibilities of studying allomorph processing with young children, the bilingual study could offer insights into the L1 acquisition of morphological relations, such as singling out the morphosyntactic rule and accommodation thereof into the procedural system (Ullman, 2001, 2004).

The goal of the British word list experiments was the determination of how regular stem allomorphs were listed in the English mental lexicon, while the German word list experiments investigated the representation of regular stem allomorphs in the German mental lexicon. We hypothesized that regular stem allomorphs shared a lexical entry. To test this hypothesis, we studied the error-detection mechanisms triggered by three violation conditions, viz. **ser[i:]nity/*Starkung* (RD), **ser[aɪ]nity/*Sturkung* (UD), and **seromity/*Stögung* (NC), in comparison with the baseline condition *serenity/ Stärkung* (W). The critical items were used in two word list experiments with either a lexical decision task or a memory task. We argued that a unified representation of the regular stem allomorphs would enable the structural repair of the RD items. Therefore, the error-detection mechanisms triggered by the RD items should differ from those evoked by the irreparable nonwords (UD and NC conditions). The separate representation of the regular stem allomorphs would not allow for the structural repair resulting in similar brain responses for all violation conditions. The results of the lexical decision task experiments in both Nationality groups revealed a graded N400 effect of the type W<RD<UD=NC. The change of the experimental task resulted in a different set of violation responses in both groups. Thus, the violation of the TSS rule evoked a PMN effect in the early processing stages, whereas in the late processing stages the RD items elicited the LPN. The violation of umlaut, on the other hand, resulted in a LAN effect.

The lexical decision task experiments were aimed at specifically triggering semantic processing. We expected that the instruction to react only to existing words would ensure the structural reanalysis. The participants were thus to (i) listen to the stimuli, (ii) analyze them in terms of their affinity to the given language vocabulary, and (iii) realize the discrepancies between the expected information and the actual input if (ii) did not apply. Based on the proposed algorithm, we predicted a differential N400 effect for the violation conditions. Considering the similarity of the semantic processing stages in both languages, the N400 effect was expected to be comparable in both Nationality groups. The reduction of the N400 amplitude in case of the RD items should be indicative of the morphological reanalysis of the faulty input. The N400 effect was expected to index the initial decomposition of the RD items into their constituent morphemes with the following semantic re-composition of the combined meanings of those morpheme constituents (Koester et al., 2007; McKinnon et al., 2003). The results of both lexical decision task experiments revealed an attenuated N400 effect for the RD condition and a similarly prominent N400 for the UD and NC items. This result pattern supported our hypotheses, as a unified representation of the regular stem allomorphs was expected to enable the repair process placing the RD items between existing words and irreparable nonwords.

The lack of difference between the irreparable nonword conditions, viz. UD and NC, demonstrated that the observed N400 effect was not triggered by a mere phonological overlap. The RD and UD conditions deviated from the baseline W in a single phoneme, i.e. the stem vowel. However, the RD deviation from the standard was governed by the non-application of TSS/umlaut, while the only requirement for the UD condition was the equal quantity of the front/back and tense/lax vowels. Thus, the UD deviation was not triggered by morphophonological rules or by a regional variant of pronunciation, yielding a non-existent stem morpheme. The quantitatively similar amount of overlap in the RD and UD conditions did not elicit similar violation-related brain responses. While the RD items could be semantically recovered, the UD items failed to be semantically recomposed. The failure to reconstruct the original stem resulted in a complete rejection of the UD items as existing words. Though deviating in two phonemes from the standard, the NC nonwords evoked an N400 effect that was similar to that elicited by the UD condition. We maintained that, at least during the presentation of words in isolation, the amount of phonological overlap did not contribute to the determination of the lexical status unless it was governed by misapplication of a morphophonological rule. Although the N400 effect could not be regarded as a direct measure of the morphological processing, in the present series of studies it served as an indirect index of the morphological decomposition/ semantic composition of the semantically transparent complex words. Despite the difference in the derivational patterns that we chose for this investigation, they both involved a morphophonological rule in the regulation of a surface form of the stem vowel. Only via the offline application of this rule the original structure could be recovered. The present pattern of results therefore pointed to the consolidation of the morphophonological layer into the lexical entry.

The results of the lexical decision task experiments showed that complex words and nonwords were decomposed online and could be structurally repaired. However, that experimental design was not appropriate for the assessment of the repair strategies connected to the degree of structural deviation or to the depth of derivation. The British study represented a case of one-step derivation, viz. simultaneous attachment of the suffix {-ity} and TSS, while the German study employed a two-step derivation, viz. conversion with the simultaneous umlaut and thereafter an attachment of the suffix {-ung}. To distract the participants' attention from the semantics of the stimuli and instead to focus it on the general structure of the stimuli, we employed the memory task. Another purpose of the memory task was the re-encoding of the stimuli in the visual modality. The stimuli were presented auditorily with only the probes for the memory task displayed on the computer screen. Taking into account the phonological opacity of the TSS forms in English, we expected the involvement of the short term and episodic memory. The German spelling being more transparent, only the semi-automatic processing without the involvement of the episodic memory was expected.

In the British memory task experiment, we predicted a pronounced PMN effect for the RD items and a reduced PMN effect for the UD and NC nonwords (Connolly, Forbes, & Phillips, 1994; Connolly & Phillips, 1994; Connolly et al., 1992; D'Arcy et al., 2004; Steinhauer & Connolly, 2008). Considering the automatic nature of the PMN, this response was a direct index of the perception of the TSS violation. For the post-retrieval stage, however, we predicted only the RD items to evoke a distinct LPN (Evans et al., 2010; Herron, 2007). This prediction was based on the high-maintenance of the RD nonwords due to the existence of their stems and due to the non-existence of the orthographic means to legally represent the lack of TSS. The results of the study proved our predictions: the PMN effect was mild for the UD and NC items and was most prominent for the RD condition. Only the RD items evoked the LPN effect. In the German memory task experiment, the processing of the morphosyntactic rule violation in case of the RD items was expected to trigger a LAN effect (Gunter et al., 2000; Kutas & Hillyard, 1983; Münte et al., 1997; Osterhout & Mobley, 1995; Penke et al., 1997). Considering the presentation of items in isolation and the word internal morphophonological conflict, we did not expect to observe the P600 (Alemán Bañón et al., 2012; O'Rourke & Van Petten, 2011; van de Meerendonk et al., 2008; Van Petten & Luka, 2012). The results of the study verified our hypothesis revealing a LAN effect for the RD items.

Though the initial processing stages reflected in the amplitude of the PMN component index the phonological processing, they cannot provide reliable information about the structure of the lexical entry. Therefore, we were especially interested in the ERP components reflecting the retrieval (300-500 msec post stimulus) and post-retrieval (900-1100 msec) stages. During the lexical retrieval stage only the German group demonstrated a LAN effect for the RD items. The British group failed to show any violation effects in this time window. The presence of the LAN effect in the German group and the lack thereof in the British group could be explained by the depth of derivation. While the TSS violation represented the omission of the phonological alternation that always happens simultaneously with the attachment of the suffix, the violation of umlaut caused the omission of the derivational step that produced a verbal stem. The suffix {-ung} being able to attach only to verbal stems, the violation of umlaut resulted in an aggravated morphosyntactic violation compared to the violation of TSS. The analysis of the post-retrieval stage revealed a significant LPN effect for the RD items in the British group but not in the German group. While the German RD items had to be structurally memorized as a combination of an adjectival stem and the suffix {-ung}, the British RD nonwords required the memorization of the phonetic structure of the stimulus and the computation of the orthographic rendering of this structure. During the actual task performance, the German group only had to match the non-umlauted adjectival stem and the suffix. The British group, on the other hand, had to double the effort: first, the stem morpheme was illegal in the combination with the suffix {-ity}; and second, though phonetically different, the W and RD stem allomorphs had the same orthographic code. The influence of these two factors resulted in a robust LPN effect.

The results of the word list experiments provided evidence supporting our hypothesis that regular stem allomorphs share a mental lexicon entry. This conclusion was based on the fact that the structurally repairable RD nonwords triggered error-detection mechanisms that were quantitatively and qualitatively different from the existing words and both irreparable nonword conditions. We argue that the unique status of the RD items was caused by the possibility for the structural repair via access to the shared representation. This argument is in line with the accounts by Marslen-Wilson et al. (1994), Wiese (1996) and Scharinger et al. (2009, 2010). Marslen-Wilson et al. (1994) and Scharinger et al. (2010) put forth the idea that regular stem allomorphs should be represented by a single abstract morpheme with the stem vowel underspecified for the alternating feature, viz. [TENSE] in case of TSS and [DORSAL] in case of umlaut. Wiese's (1996) account considered umlaut as a phonological rule that can only be triggered if a stem morpheme has a floating feature [FRONT]. Our objective was not the validation of the accounts proposed by Marslen-Wilson et al. (1994), Wiese (1996) and Scharinger et al. (2009, 2010), but we managed to demonstrate that regular stem vowel alternations should be governed by the inherent ability of the stem vowel to alternate. We suggest that this ability should be listed in the mental lexicon entry.

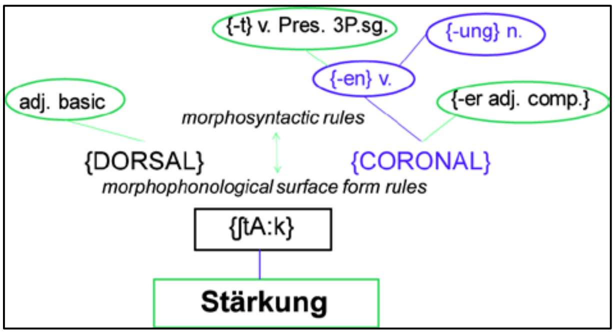

Figure 16. A speculative model for a unified lexical entry

The purple lines display the retrieval of the German word *<u>Stärkung</u>* *(strengthening).*

We maintain that a unified representation of the regular stem allomorphs should consist of an abstract morpheme with a set of morphophonological surface form rules and morphosyntactic combinatory rules (see Figure 16). The relations between the rule layers should be bidirectional to ensure production, perception and repair in case of faulty/ foreign pronunciation. Figure 16 displays lexical retrieval of a German word *Stärkung* (strengthening). On hearing a coronal vowel, the verbal stem is activated with the consecutive affixation in form of the nominalising suffix {-ung}.

Taking into account the requirements imposed by the context of the word list experiments, the verbal stem node could be activated precociously mapping only the stem vowel from the auditory input onto the representation. The failure to match the auditory input onto the preactivated structure is demonstrated in Figure 17. Although a verbal stem with a coronal vowel is expected, the auditory signal carries the acoustic characteristics of a dorsal vowel that can only surface with a basic adjectival stem (purple lines). The structural repair proceeds via the bidirectional node. This node connects the morphosyntactic and morphophonological rule layers. The ability of the stem vowel to surface as a coronal vowel in a derived environment is revealed at the morphophonological rule layer. The nodes ascending from the coronal surface form of the stem vowel lead to the affix extracted from the signal, viz. {-ung}. The repair is thus run within the lexical entry by means of the reversed rule application.

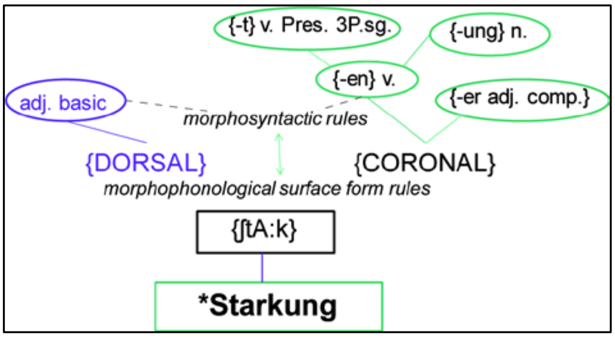

Figure 17. The structural repair process for the RD item *Starkung

The purple lines display the initial access to the lexical entry, the dashed lines representing the activation of the necessary verbal node via reversed application of the morphosyntactic rules.

The results of the sentence context experiments showed that structural repair was possible even if a violation was not morphosyntactically motivated provided it was presented in a biasing context. The RD and UD conditions, though structurally different, induced similar brain responses in both nationality groups. According to Zwitserlood (1989), contextual effects should be observed if the incoming information does not suffice to choose a word candidate. This was presumably the case in our sentence context experiments. Thus, the morphosyntactic repair was run on perceiving the RD items. We hypothesize that the UD items triggered a phonological repair process. Considering the homogeneity of the observed effects in EEG, further research could make use of imaging techniques, such as fMRI or MEG, to differentiate between the phonological and morphosyntactic repair.

Although the RD and UD conditions elicited similar violation-related brain responses, we do not consider these results contradictory to our hypothesis. First, sentence context provided the possibility of repair by means of top-down processing. By the end of a sentence, the participants could make a prediction about the grammatical category, the semantics and, with a sufficient amount of input, the structure of a word candidate. An insignificant phonological deviation could be immediately repaired. The word list experiments, on the other hand, only primed the subjects with a structure. Second, the sentence context experiments contained only three conditions, the violated items being grouped together and the W items being presented in a separate run. Therefore, the subjects simply activated the repair mechanisms for the two violation runs. In contrast, the word list experiments had more variable stimulation, which reduced the proportion of the critical items. This factor could be controlled for if filler sentences and sentences with the NC items were introduced. Third, the stimulus materials could be extended with other instances of regular stem allomorphy, such as *tone*/*tonic* in English and *stark* (*strong*)/ *Stärke* (*strength*) in German. To summarize, the extension of the stimulus materials and a slight modification of the experimental design could contribute to the functional separation of the mechanisms underlying the repair of the RD and UD items.

Despite a limited number of participants, the results of the pilot study provided supporting evidence for our hypothesis. The L2 learners demonstrated a brain response pattern that was indicative of their overreliance on the declarative system (Ullman 2001, 2004). We argued that the amount of L2 exposure and growing proficiency should trigger the transformation of hardwiring with respect to the L2 rule application. Thus, the reliance on the declarative system in rule application should be overridden by reliance on the procedural system. The overreliance on the procedural system in L2 usually results in overgeneralizations (Birdsong & Flege, 2001; Coughlin & Tremblay, 2013; Labelle & Morris, 2011; Rossi et al., 2006). To verify the transition from the declarative to the procedural system, a larger sample of low-proficiency L2 learners should be provided. Furthermore, to establish the final stage of L2 rule acquisition, a high-proficiency L2 group should be included in this study.

Taken together, the results of the present series of experiments demonstrated that (i) semantically transparent complex words are subject to morphological decomposition (Taft & Forster, 1975, 1976; Taft & Hambly, 1985; Taft & Kougious, 2004); (ii) regular stem allomorphs in English and German share a lexical entry (W.D. Marslen-Wilson et al., 1994; Scharinger, 2009;

Scharinger et al., 2010); (iii) the insignificant deviations from the stored standard can be repaired within a biasing context (Zwitserlood, 1989); and (iv) low-proficiency L2 learners apply morphophonological and morphosyntactic rules within the declarative system (Ullman, 2001a, 2001b, 2004). Though we demonstrated that semantically transparent complex words are morphologically segmented, we do not imply that all word forms should be stored in a decomposed manner. Regular stem allomorphy being the object of the present series of studies, we assume that semantically transparent complex words derived by means of morphophonological and morphosyntactic rule application share a lexical entry. Our results can be regarded as supporting Dual-Mechanism models (Clahsen, 1999; Fleischhauer, 2013; Munte, Say, Clahsen, Schiltz, & Kutas, 1999; Sonnenstuhl, Eisenbeiss, & Clahsen, 1999) provided their definition of regularity is extended to derivation. In the following chapter, we explore the representation and processing of irregular stem allomorphy in German. The combined results of the first and second part of the present thesis could contribute to either the Full Decomposition (Taft & Forster, 1975, 1976; Taft & Hambly, 1985; Taft & Kougious, 2004) or Dual-Mechanism models (Clahsen, 1999; Fleischhauer, 2013; Munte et al., 1999; Sonnenstuhl et al., 1999).

4 Irregular stem allomorphy

4.1 Overview

The term *irregular stem allomorphy* implies that no phonological rule can account for the alternations and they are, therefore, phonologically unpredictable. The phonological relationship between such pairs of words is thus arbitrary and must be processed with the involvement of the declarative memory (Ullman, 2001a, 2001b, 2004). Irregular stem alternations can be observed in both derivational and inflectional morphology (Pinker, 1999; Clahsen, 1999; Friederici et al, 1993; Marslen-Wilson & Tyler, 1997, 1998, 2003, Ullman, 2001, Pinker and Ullman, 2002). Derivational morphology may generate new words by changing meaning and/or syntactic class. The product of derivation must be adapted into the mental lexicon and thus it could be argued that it needs a separate lexical entry that comprises all changes. Irregular alternations that a basic word undergoes within its paradigm might also be reflected in the storage form in the mental lexicon. Irregular alternations with the minimal deviation from the basic form that could be generalized into a rule, e.g. the plural formation *child-children* or *goose-geese*, might share a lexical entry. Irregular alternations that involve a set of patterns, i.e. the ablaut (*catch-caught*), or make use of an entirely different stem, i.e. suppletion (*go-went*), might be too complex to be listed within a single underlying representation. The important question is, therefore, how the irregular stem allomorphy should be represented.

The objective of the present chapter is to account for the irregular stem alternations involved in the past tense formation of German strong verbs concerning their representation in the mental lexicon. We assume that German strong and weak verbs are subject to obligatory morphological decomposition. Morphological decomposition enables the access to the stem morpheme. We seek to find out whether the irregular stem allomorphs employed in the ablaut patterns share a unified representation or whether these allomorphs are represented separately. In the following subchapters we shall first consider the German ablaut, then introduce the series of EEG experiments and finally discuss the results of these experiments with respect to the representation of the irregular stem allomorphy in the mental lexicon.

4.1.1 Ablaut

The comparison of umlaut with ablaut exemplifies the difference between a predictable and unpredictable phonological alternation. While umlaut can be described as a *phonological fronting of a vowel*, ablaut is regarded as a set of vowel patterns. Umlaut can be generalized into a rule. Ablaut patterns though morphologically quite predictable cannot be unified into a single rule and therefore have to be memorized (Wiese, 1996). Umlaut is usually observed in derived environments and is characterized by the capability of a stem vowel to alternate between the CORONAL (front) and DORSAL (back) place of articulation. The stem vowel capable of this alternation always surfaces as a front vowel if it underwent umlaut. In contrast, the directionality of change of the place of articulation as well as the tenseness of a stem vowel that undergoes ablaut is unpredictable (Wiese, 1996). The only common feature characteristic of ablaut is the domain of its application. In Modern German, ablaut alternation exists in the past tense and past participle forms of German strong verbs (*schießen-schoss-geschossen* – "shoot-shot-shot") and in cases of the conversion from a strong verb to a noun (schießen-Schuss – "to shoot-a shot"). However, the limitation of ablaut to these grammatical categories does not provide a solid ground for the definition of a rule. Wiese (1996) delivered a list of the ablaut patterns demonstrated in Table 13. The first column demonstrates twenty distinct vowel patterns containing various phonological alternations. It is obvious that the alternating segment is always the rhyme of a monosyllabic verb, while the onset remains unaffected. Ablaut can therefore be described as a phonological phenomenon affecting the nucleus[4] of the stems of German strong verbs and nouns converted from those verbs.

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[4] The verb *essen* (eat) could be considered as an exception to this rule as its past tense form *aß* demonstrates the alternation of the initial vowel. The alternation of the verb *sein* (be) within its paradigm should probably be regarded as a case of suppletion and not as ablaut: *sein-war-gewesen*.

Table 13. Ablaut patterns for strong verbs

The first column provides orthographic representations of the vowel patterns employed in ablaut. The following three columns exemplify the infinitive, Past tense and Past Participle forms of a strong verb corresponding to the vowel pattern. The last column provides an English translation. (Wiese, 1996:.129-130).
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Vowel pattern	*Infinitive*	*Past tense*	*Past Participle*	*Gloss*
a i a	fallen	fiel	gefallen	“fall”
a u a	tragen	trug	getragen	“carry”
e a e	lesen	las	gelesen	“read”
e a o	stehlen	stahl	gestohlen	“steal”
e o o	heben	hob	gehoben	“lift”
e i a	hängen	hing	gehangen	“hang”
i a u	finden	fand	gefunden	“find”
i a o	schwimmen	schwamm	geschwommen	“swim”
i a e	bitten	bat	gebeten	“ask”
i o o	bieten	bot	geboten	“offer”
o i o	stoßen	stieß	gestoßen	“push”
o a o	kommen	kam	gekommen	“come”
ö o o	erlöschen	erlosch	erloschen	“go out”
ö u o	schwören	schwur	geschworen	“swear”
u i u	rufen	rief	gerufen	“call”
u a a	tun	tat	getan	“do”
ü o o	lügen	log	gelogen	“lie”
ai i i	gleiten	glitt	geglitten	“slide”
au i au	laufen	lief	gelaufen	“run”
au o o	saufen	soff	gesoffen	“booze”

Wiese (1996) proposed an account on the representation of the ablaut forms in the mental lexicon that consisted of the listing of all three phonological forms in the verb entry. The author suggested that a lexical entry of a strong verb should contain sub-entries specifying the phonological form of this verb for the past tense and the past participle, i.e. (a) /tʀiŋk/ [V] (b) /tʀaŋk/ [V, +pas t] (c) /tʀʊŋk/ [V,+part]. The retention of unproductive (irregular) phonological stem variants on a sublevel within a lexical entry was also proposed by Wunderlich (1996) and Wunderlich & Fabri (1995). Therefore, these three authors implied a unified lexical entry for strong verbs containing all phonological stem variants of a given verb. Generalized, a lexical entry would consist of a higher-order level with a basic stem morpheme and sub-levels containing irregular stem variants. Figure taken from Wunderlich (1996:96) illustrates the representation of a German strong verb *werfen* (to throw). The basic stem [vɛrf] is at the top level of the hierarchical lexical entry. The stem variants are placed at the lower levels inheriting the features from the upper levels except for those that the new subnodes replace or add. Thus, the 2nd and 3rd person singular in the present tense form inherit the feature [+V] from the higher node and replace the stem vowel. The subnode representing the imperative form inherits the raised stem vowel. Wunderlich (1996) and Wunderlich & Fabri (1995) suggested that inflectional affixes should be stored separately from the stem morphemes. A paradigm structure would license certain inflectional affixes projecting them into syntax. Therefore, the representation of inflectional forms should comprise three information sources: (i) the stem storage, (ii) the affix storage, and (iii) paradigm structures (Wunderlich, 1996; Wunderlich & Fabri, 1995). Apart from the sub-level containing the irregular allomorphs, the lexical entries for both strong and weak verbs as well as the synthesis of the inflectional forms are structured in a similar way.

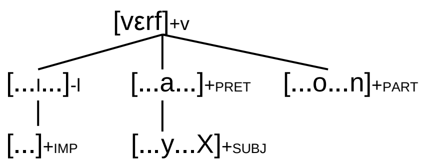

Figure 18. The structure of a mental lexicon entry of a strong verb

A lexical entry for the German verb werfen – to throw (Wunderlich 1996:96). *The entry is organized hierarchically with the lower subnodes inheriting the features from the upper subnodes. The lower subnodes also add marked features, such as tense or mood.*

Scharinger (2006) and Scharinger et al. (2009) investigated the processing and representation of German strong, weak and mixed verbs. The authors assumed that strong verbs were represented by an underspecified stem morpheme and their processing would thus be similar to that of weak verbs. In a series of delayed priming experiments using an auditory lexical decision task the authors presented the subjects with infinitives (*schlafen* – to sleep) as targets and semantically or morphologically related/unrelated verbs in the 2nd Pers.Sg.Pres. (e.g. *schläfst* – you sleep) as primes. The results of the experiments showed that the 2nd Pers.Sg.Pres. form of weak and strong verbs primed their respective infinitives in a similar way. Therefore, both verb classes were demonstrated to be subject to morphological decomposition. Despite the alternating stem vowel in the 2nd Pers.Sg.Pres. form of some strong verbs (i.e. *schläfst* – you sleep) their stems were mapped onto the underlying representation via a nomismatch relation between the coronal vowel in the signal and the underspecified vowel in the lexicon (Lahiri & Marslen-Wilson, 1991; A. Lahiri & H. Reetz, 2002; Lahiri & Reetz, 2010; Plank & Lahiri, 2015). According to Scharinger (2006), morphological decomposition was assumed for the inflected preterit forms of strong verbs, i.e. *schliefst* – you slept. The author also suggested that if the preterit stems could not be derived in a productive manner, they should be stored separately with an additional morphological feature [past]/[preterit] (Scharinger 2006:211).

The underspecification account on the representation of irregular stem allomorphs was also considered by Clahsen and colleagues (Clahsen, Eisenbeiss, Hadler, & Sonnenstuhl, 2001). They ran a series of psycholinguistic studies with the objective to investigate the storage manner of inflected forms of strong verbs, viz. as whole forms vs. in a morphologically decomposed form. Furthermore, if inflected strong verbs should be subject to morphological decomposition, Clahsen et al. (2001) sought to find out if the lexical entry of a strong verb was organized hierarchically. The first two visual lexical decision task experiments provided evidence for (i) the decomposition of inflected strong verbs into stem and affix and for (ii) the separate mental representations of preterit stems of strong verbs. The last experiment was designed to explore the structure of the lexical entry. The authors wanted to find out whether irregular stem allomorphs of strong verbs were fully specified for morphological features such as tense or were organized hierarchically on the basis of underspecification of these features. Clahsen and colleagues hypothesized that the stems' feature specifications would affect the priming effect in such a way that marked stems would be more difficult to prime than unmarked stems (Clahsen et al. 2001:531). The results of this experiment provided evidence in favour of the authors' hypothesis. Thus, preterit forms primed present tense targets better than vice versa, i.e. *warft-werft* (you threw Pl. – you throw Pl.) vs. *werft-warft*. The asymmetry of the priming pattern was attributed to the underspecification of the basic (infinitive or present tense) stem for the tense feature. Conversely, the preterit stem was argued to be marked for tense, viz. for the feature [+PRET]. These findings demonstrated similarities in the mental representation and processing of weak and strong verbs. Both verb classes, if regularly inflected, were found to be subject to morphological decomposition. As a result of morphological decomposition, a mental representation of a lexeme was accessed. While the mental representation of a weak verb contained a single stem with a non-alternating stem vowel, the lexical entry of a strong verb was assumed multi-tiered containing a basic stem at the top of the hierarchy and marked stems at the subnodes.

The account by Marslen-Wilson & Tyler (1998) on the past tense formation of English verbs also suggested some similarities in the manner of representation of regular and irregular verbs. The empirical evidence provided by the review under discussion demonstrated that irregular forms shared their semantic properties with the regular forms. However, the authors claimed that irregular forms should be represented as complete units in the phonological domain, while the regular forms should not. Whilst the regular forms should be morphophonologically assembled in order to fit a certain syntactic structure, the irregular forms should be chosen from the phonological domain in accordance with the syntactic context. Taking into account the requirements of a context, the morphosyntax should be the overlapping structure where the combinatorial rules employed in the regular formation met with the phonological variants of irregular verbs. Marslen-Wilson & Tyler (1998) put forward the idea that the production and processing of irregular past tense forms could not be explained solely within the framework of a single or dual mechanism. Rather it must be served by a combination of at least two separable systems.

Penke et al. (1997) ran a series of ERP experiments on German verb inflection inserting incorrectly inflected irregular, regular and nonce past participles in a word list, a simple sentence or a story. Across all experimental settings, the incorrectly inflected irregular participles, such as **gekomm-t* (*came-ed) elicited a left fronto-temporal negativity reminiscent of LAN; incorrectly inflected regulars (**getanz-en* – danced), on the other hand, failed to significantly differ from the correctly inflected regulars. The nonce participles elicited a similar N400 effect for both expected and unexpected endings. The authors argued in support of a dual-mechanism model (Fleischhauer, 2013; Marcus et al., 1995; Pinker, 1999; Pinker & Ullman, 2002) that the differential brain responses elicited by the incorrectly inflected irregular and regular participles demonstrated that these complex words were processed by separate mechanisms. According to the dual-mechanism model, some complex words (irregulars) are stored as a whole while the others are formed by means of morphosyntactic rules. Thus, regular inflectional patterns, such as present and past tense paradigms of weak and strong verbs, and regular stem vowel alternations (umlaut) involved in inflection and derivation should be formed via morphosyntactic rules (Clahsen et al., 2001). Irregular inflectional forms, such as past participle forms of strong verbs, on the other hand, should be stored as a whole (Clahsen et al., 2001; Sonnenstuhl et al., 1999). The only morphosyntactic rule violation in Penke et al.'s (1997) study was the over-regularization of the regular *–t* past participle formation rule. The misapplication of this rule in case of a memorized form, i.e. a past participle of a strong verb **gekomm-t* instead of *gekommen*, resulted in the elicitation of a LAN effect. The non-existence of the *–n* past participle formation rule resulted in the normal processing of the incorrectly inflected regular items. The discrepancy in the violation brain responses was explained by Penke et al. (1997) as empirical evidence in favor of the dual-mechanism model.

A number of neurophysiological and neuro-imaging studies run by Marslen-Wilson, Tyler and colleagues led them to put forth the idea that lexical access to regular inflected forms should proceed on the basis of morphophonological decomposition while irregular inflected forms should be accessed directly (W.D. Marslen-Wilson & Tyler, 1997, 1998, 2003, 2007; Post, Marslen-Wilson, Randall, & Tyler, 2008). According to this account, every string of sounds that could be interpreted as a regular inflectional suffix, i.e. /t/, /d/ or /ɪd/ for {-*ed*} in the English past tense formation or /s/, /z/ or /ɪz/ for {-*s*} in the plural formation – the English inflectional rhyme pattern, undergoes automatic morphophonological segmentation. In an auditory speeded judgment experiment, Post et al. (2008) investigated the influence of the English inflectional rhyme pattern on the perception and processing of the regular inflection in English. The authors found out that any stimulus, which could be interpreted as a regular inflectional suffix regardless of its actual morphological status (*fil**led**-fill, mi**ld**-mile*), decelerated response times in comparison to the response times to monomorphemic stimuli (*be**lt**-bell*). The transfer of this result pattern onto the German material cannot be simple as the German morphosyntax employs a large number of inflectional suffixes that vary in their frequency of occurrence. Even the comparison of the regular past participle forms ending in *–t* (*getanzt* – danced) with the irregular ones ending in *–en* (*gesehen* – seen) cannot be used in favor of the non-decomposition of the latter. Although there is no morphosyntactic rule for the *–en* past participle formation, the morpheme {*–en*} is used to mark the infinitive, the plural form of the 1st and 3rd persons of a verb in present and past tenses as well as the plural form of a number of nouns, etc. Following the logic of Post et al. (2008), all German words that seem to have an inflectional suffix must be morphophonologically parsed. The results of Penke et al.'s (1997) study demonstrated that such disassembly, if present, took place prelexically, hence the lack of violation responses in the incorrectly inflected regular participles.

These findings were supported by Smolka et al. (2014), who demonstrated morphological priming effects in semantically opaque pairs of prefixed German verbs, such as *entbinden* (to deliver a child) and *zubinden* (to tie).

Smolka et al. (2014) provided evidence for the obligatory morphological decomposition in German prefixed verbs despite semantic opacity. This finding suggests that German complex words should be subject to obligatory morphological decomposition despite the regularity or irregularity of their structure. Contrary to English, the problem that arises with the representation of complex words in German is not the storage of a whole inflected form but rather the storage of an alternating stem morpheme. The first part of the present thesis provided experimental evidence supporting a unified stem representation for regular predictable, and, more importantly, productive stem alternations, such as *sane-sanity* in English and *stark* (strong) – *Stärkung* (strengthening) in German. Taking into account that the alternation is governed by a single (morpho)phonological rule, it is reasonable for this rule to be listed in the lexical entry. The ablaut patterns, employed in the inflectional paradigm of the German strong verbs, are not only irregular and unpredictable, they are also unproductive. Additionally, there are certain forms, such as imperatives and subjunctives (Konjunktiv II), that are derived from either the present tense or the past tense forms of irregular verbs accompanied by umlaut or raising: *lesen* (to read) – *Lies*! (read!), *saß* (sat) – *säße* (would sit). The listing of all above-mentioned (irregular and regular) forms of an irregular verb within a single mental representation means abundance of morphophonological and morphosyntactic rules. For the sake of parsimony and for the acceleration of the lexical retrieval process, it would make sense to store the irregular allomorphs of strong verbs on a separate level within a single lexical entry based on the underspecification of phonological and morphological features (Clahsen et al., 2001; Lahiri & Marslen-Wilson, 1991; A. Lahiri & H Reetz, 2002; Lahiri & Reetz, 2010; Plank & Lahiri, 2015; Scharinger et al., 2010; Scharinger et al., 2009).

The goal of the present study was the investigation of the structure of the German mental lexicon with respect to the irregular stem allomorphy. Our objective was to determine whether irregular stem allomorphs shared a lexical entry or were stored separately. To establish the manner of representation of irregular stem allomorphs, we decided to investigate the time course of verb recognition process when the verb's morphological structure was violated. The violation of such morphological feature as tense in present and past tense allomorphs was expected to trigger similar processing (i.e. parsing triggered by allomorph misapplication), if irregular stem allomorphs have separate fully specified lexical entries. If, however, irregular stem allomorphs of strong verbs were stored based on the underspecification of morphological features, distinct violation effects would be observed.

We hypothesized that the lexical entry of a strong verb was organized hierarchically on the basis of underspecification. To validate our hypothesis, we developed a violation paradigm that specifically aimed at violation of the morphological feature [tense] and at the violation of morphosyntactic suffixation rules. In the development of the violation paradigm we made use of a peculiarity of the German verb inflection. Thus, a strong verb in the 3rd person singular requires an inflectional suffix {-*t*} in the present tense, while in the past tense the same person form is rendered by means of the past tense allomorph without suffixation, e.g. *singt* – *sang* (sings – sang). In contrast, weak verbs require suffixation in both of the above-mentioned cases, i.e. {-*t*} – *tanzt* (dances) and {-*te*} – *tanzte* (danced) respectively. To be able to assess the structure of the mental lexicon with respect to the irregular stem allomorphy, we planned to compare the standard processing of the non-violated irregular verbs with the deviant processing of the violated ones. A similar comparison was also done for the regular verbs. We argued that the error-detection mechanisms triggered by the violated items would be similar for regular and irregular verbs, if the latter are represented by a single underlying stem morpheme. Conversely, the error-detection mechanisms triggered by the violated irregular verbs should be qualitatively different from those triggered by the violated regular verbs, if the former have separate representations for their allomorphs within a lexical entry. Furthermore, the violation of the tense feature of strong verbs, i.e. allomorph misapplication, should trigger similar violation related brain responses if the present and past tense allomorphs are fully specified for the feature [tense]. On the other hand, the violation brain responses triggered by allomorph misapplication should be qualitatively (spatially and temporally) different, if the lexical entry of a strong verb is based on the underspecification. The violation types that we designed for the irregular and regular verbs had a morphosyntactic character. Being existent stem morphemes, the violation conditions were meant to trigger morphosyntactic parsing or hinder semantic integration process, which could be traced by means of the ERP technique. The ERP components sensitive to morphosyntactic constraints are assumed to be LAN and P600 (see subchapters *1.2.1.3* and *1.2.1.4* for a detailed account of these components).

The “semantic” ERP component – N400 – was described in the subchapter *1.2.1.2*.

The present study was made up of two sentence context experiments that were designed to explore the auditory perception of correctly and incorrectly inflected verbs within a temporal (past vs. present) context. Both experiments employed a memory task that distracted the participants from the linguistic structure of the stimuli. A deliberate distraction from the linguistic structure was expected to widen the scope of attention from the local violations onto the whole structure therefore disposing of the linguistic task effects. The composition of the stimulus materials is illustrated in Tables 14 – 16, along with our predictions for both experiments.

The predictions for the Past Context experiment are summarized in Table 14. We expected the immersion into the past tense context to trigger a specific type of processing, i.e. the expectation of a finite verb in the past tense form. Additionally, all sentences were built in such a way that the subject required a verb in the 3rd person singular – *ging* (C condition). The Past tense does not involve the addition of an affix in the 1st and 3rd person singular, thus, the EI – Extensive Inflection – items (third column of Table 14) instantiated the violation of a morphosyntactic suffixation rule, i.e. an illegal combination of the past tense stem allomorph *ging* and the regular 3rd person singular suffix {-*te*} – **ging-te*. The BaS – Bare Stem – items, on the other hand, represented the violation of the morphophonological structure of the expected morpheme being an uninflected basic stem morpheme: **geh*. If irregular stem allomorphs share an underlying stem, the lexical entry should entail a combination of the morphophonological and morphosyntactic rules. Consequently, the violation of the morphophonological (BaS irregular items – **geh*) and morphosyntactic (EI items – **gingte*) rules employed in the formation of the violated items should elicit a LAN effect. The prominence of the effect would depend on the organization of the mental lexicon entry: the set of morphosyntactic rules should be related to the surface form of a stem morpheme that had to be determined by a morphophonological rule (third row of Table 14). The morphophonological layer should therefore govern the subsequent morphosyntactic layer in such a lexical entry. Thus, we predicted a large LAN effect for the BaS items as these violated a higher-order morphological rule in comparison with the EI items. The mapping of the auditory input onto the single underlying morpheme would result in the retrieval of the generic semantic information of a verb and in the recognition of the violation of a morphosyntactic rule in case of the EI items or a morphophonological rule in case of the BaS items. The possibility of the structural repair of both violation conditions via the offline application of the rules was expected to trigger a similar error-detection mechanism.

Table 14. Experimental conditions and predictions for the Past Context experiment

The names of the conditions and their composition are given in the first line. The example of a violation pattern of a German strong verb gehen *(go) is given in the second row in isolation (underlined) and in a sentence context (bold italicized). The predictions are divided into rows according: single underlying stem morpheme, the third row with a graded LAN effect; separate fully specified representations for allomorphs, the fourth row, with a mild LAN for EI condition and a large P600 for BaS condition; unified lexical entry for stem allomorphs based on underspecification, the fifth row, with a LAN for EI condition and an N400 for BaS condition.*

Condition Composition	**C** – control: The Past form of a strong verb in 3rd Pers. Sg.: {Past}	**EI** – excessive inflection: The Past form of a strong verb in 3rd Pers. Sg. and the suffix of the Past 3rd Pers. Sg.: {Past}+{-te}	**BaS** – basic stem: The Present form of a strong verb without affixes: {Present}
Example	ging Gestern ***ging*** er zur Arbeit zu Fuß. Yesterday – ***went*** – he to work on foot.	*gingte Gestern ***gingte*** er zur Arbeit zu Fuß. Yesterday – ***went(ed)*** – he to work on foot.	*geh Gestern ***geh*** er zur Arbeit zu Fuß. Yesterday – ***go*** – he to work on foot.
Single underlying stem morpheme	____________	mild LAN	large LAN
Separate fully specified representations for allomorphs	____________	mild LAN	large P600
Unified lexical entry for stem allomorphs based on underspecification	____________	LAN	N400

We expected the EI and BaS items to evoke differential violation brain responses if their stems were represented separately. If the mental representations of irregular allomorphs were fully specified for the tense feature, i.e. [+PRET] and [-PRET], we expected the following violation related brain response pattern (the fourth row of Table 14). The violation of a morphosyntactic rule in the EI violation condition should result in a LAN effect. The BaS violation, on the other hand, instantiates an application of a wrong stem morpheme marked for the feature [-PRET]. The mismatch between the past context of the sentence frame and the feature [-PRET] in the mental representation of the basic stem should induce an aggravated syntactic conflict demonstrated by a prominent P600 effect (van de Meerendonk et al., 2008). However, if the lexical entry of a strong verb was organized hierarchically on the basis of underspecification (the fifth row of Table 14), we would expect the EI violation condition (*gingte), whose stems is marked for tense [PRET], to elicit a morphosyntactic violation brain response, viz. LAN. The BaS irregular items (*geh), whose stems are underspecified for tense, we expected to trigger an N400 effect as a result of a semantic clash between the past tense context and a bare basic stem not specified for tense.

Table 15. Experimental conditions and predictions for the Present Context experiment

The names of the conditions and their composition are given in the first row. The example of a violation pattern of a German strong verb gehen (go) is given in the second row in isolation (underlined) and in a sentence context (bold italicized). The predictions are divided into rows according: single representation, the third row with a graded LAN effect; separate fully specified representations for all allomorphs, the fourth row, with a large P600 for EI condition and a mild LAN effect for BaS condition; unified lexical entry for stem allomorphs based on underspecification of morphological features, the fifth row, with an N400 effect for BaS condition.

Condition Composition	**C** – control: The Present form of a strong verb in 3rd Pers. Sg.: {Present}+{-t}	**EI** – excessive inflection: The Past form of a strong verb in 3rd Pers. Sg. and the suffix of the Present 3rd Pers. Sg.: {Past}+{-t}	**BaS** – basic stem: The Present form of a strong verb without affixes: {Present}
Example	geht Normalerweise ***geht*** er zur Arbeit zu Fuß. Usually – ***goes*** – he to work on foot.	*gingt Normalerweise ***gingt*** er zur Arbeit zu Fuß. Usually – ***went(s)*** – he to work on foot.	*geh Normalerweise ***geh*** er zur Arbeit zu Fuß. Usually – ***go*** – he to work on foot.
Single underlying stem morpheme	____________	large LAN	mild LAN
Separate fully specified representations for allomorphs	____________	large P600	mild LAN
Unified lexical entry for stem allomorphs based on underspecification	____________	____________	N400

Table 15 demonstrates the predictions for the Present Context experiment. The C items (second column) are made up of the present tense allomorph and the inflectional suffix {-*t*} – *geht*. The EI (excessive inflection) condition (third column) is formed by violating the morphosyntactic combinability rule, and thus consists of the past tense stem allomorph *ging* and the suffix {-*t*}: **gingt*. The BaS (bare stem) condition (fourth column) is made up of a stripped infinitive, i.e. the present tense stem allomorph **geh*. The decision to design two violation conditions was triggered by the necessity of controlling for the paradigm structures in past and present. Thus, the EI condition in the past demonstrates the violation of the suffixation rule, while this rule is preserved in the same condition in the present. At the same time, this condition in the present represents a misapplication of an allomorph. Conversely, the BaS condition in the past violated the allomorphy, yet preserved the paradigmatic suffixation rule. The BaS items in the present, on the other hand, violated the suffixation rule being a bare stem.

In the Present Context experiment we expected the inversion of the violation brain responses observed in the Past Context experiment if irregular stem allomorphs had a single underlying stem morpheme. The violation of the morphophonological and morphosyntactic rules should have elicited a LAN effect. Since the BaS items (**geh*) are phonologically closer to the C condition (*geht*), they should evoke a mild LAN effect, while the EI items (**gingt*) should elicit a large LAN (third row of Table 15). If irregular stem allomorphs are represented separately by mental representations fully specified for tense, we expected the EI and BaS items to trigger differential error-detection mechanisms (fourth row of Table 15). Thus, the violation of the allomorph application in the EI violation condition (**gingt*) should result in a P600 effect. The violation of the suffixation rule in the BaS condition should elicit a LAN effect reflecting difficulties in the reconstruction of the local syntactic relations. If our hypothesis is valid, i.e. irregular stem allomorphs are represented separately in a unified lexical entry based on underspecification of morphological features, we expected only the BaS irregular condition to trigger a violation effect. The EI items (**gingt*) carried a stem morpheme marked for tense and, additionally, a correct suffix. The BaS irregular items (**geh*), on the other hand, lacked any temporal characteristics again, their stem being underspecified for tense and the suffixes bearing this information being absent. The clash between the temporal (present tense) context and the verb missing tense characteristics was expected to trigger an N400 effect (fifth row of Table 15).

In contrast to the strong verbs, the German weak verbs require suffixation within both tense paradigms. The stem morpheme of a weak verb undergoes no morphophonological changes. Therefore, the assessment of the processing of a weak verb in the Past and Present Context experiments would present a baseline for the processing of a verb represented by a single underlying morpheme. Taking into account the lack of morphophonological alternations within the regular verb stem, we could not design an EI violation for this verb group. But, it was possible to construct the BaS regular violation. The stimulus materials are shown in Table 16 along with our predictions for the regular verbs in both experiments. The composition of conditions is demonstrated in the second row of the table, while the examples of stimuli in isolation (underlined) and in a sentence context (bold italicized) are given in the third row. Based on the violation of the suffixation rule, we predicted a LAN effect for the BaS condition in both tense contexts. If irregular stem allomorphs are represented by a single underlying morpheme then the processing of the irregular verbs in the BaS condition should be similar to that of the regular ones. Conversely, if the irregular stem allomorphs are represented separately, the processing of the irregular verbs in the BaS condition should differ in the topography and/or latency and magnitude of the violation effects from those of the regular verbs.

Table 16. Experimental conditions and predictions for weak verbs

The table is subdivided into two parts: Past and Present Context experiments. The names of the conditions and their composition are given in the second row. The example of a violation pattern of a German weak verb <u>schenken</u> *(present/give) is given in the third row in isolation (underlined) and in a sentence context (bold italicized). The predictions are demonstrated in the fourth row: a LAN effect for the BaS regular condition in both experiments.*

Context	**Past**		**Present**	
Condition Composition	**C** – control: {stem}+{-te}	**BaS** – basic stem: {stem}	**C** – control: {stem}+{-t}	**BaS** – basic stem: {stem}
Example	<u>schenkte</u> *1917* ***schenkte*** *Schönberg das Manuskript Heinrich.* *1917-**presented**-Schönberg-the-manuscript-Heinrich.*	*<u>schenk</u> *1917* ***schenk*** *Schönberg das Manuskript Heinrich.* *1917-**present**-Schönberg-the-manuscript-Heinrich.*	<u>schenkt</u> *Normalerweise* ***schenkt*** *man Blumen zum Geburtstag.* *Usually-**presents**-one-flowers-for-birthday.*	*<u>schenk</u> *Normalerweise* ***schenk*** *man Blumen zum Geburtstag.* *Usually-**present**-one-flowers-for-birthday.*
Predictions	____________	LAN	_____________	LAN

Taken together, the results of the Past and Present Context experiments should provide indirect evidence for the structure of the German mental lexicon with respect to the irregular stem allomorphy. The similarity of the error-detection mechanisms triggered by both violation conditions could be associated with a simultaneous activation of the past and present tense allomorphs within a single underlying stem morpheme. Considering the restrictions imposed by the temporal structure of the sentence context on the verb forms, the differential violation related brain responses triggered by both tense forms should point to a unified lexical entry with either a sub-level (Wunderlich, 1996; Wunderlich & Fabri, 1995) or a phonological level (W.D. Marslen-Wilson & Tyler, 1997, 1998, 2003; Post et al., 2008) for the irregular allomorphs. Furthermore, differential allomorph processing indexed by topographically and temporally distinct error-detection mechanisms would be associated with separate representations for irregular allomorphs within a lexical entry based on underspecification. The brain response pattern for the violated regular verbs should provide a baseline for the processing of verbs represented in the mental lexicon by a single underlying morpheme. The similarities in the violation brain responses between regular and irregular verbs would indicate a similar processing manner, and vice versa.

4.1.1.1 Experiment 8: Past context

4.1.1.1.1 Methods

Participants

Twenty students of the University of Konstanz (10 male, age range: 19-26 years, mean: 22.29) took part in this experiment. The subjects gave written informed consent and were either paid for participation or received a practice certificate for the Psychology Department.

Materials

The experimental material consisted of 42 weak and 42 strong verbs. Only relatively high frequency verbs were used in the study (mean in Leipziger Corpus for the past form of strong verbs: 669.69, for the weak verbs: 376.26 ($F(1,82)=12.39$, $p<0.001$)). The control (C) condition was made up of the past tense form of the verbs in the third person singular, i.e. the past tense allomorph of a strong verb without affixation – *wusch* (washed) or the past tense suffixation in the 3rd person singular of a weak verb – *tanz-te* (danced). The number of violation conditions was different for the weak and strong verbs in order to keep the number of non-violated items constant. Thus, the strong verbs had two violation conditions: excessive inflection (EI) and bare stem (BaS irregular), while the weak verbs had only the BaS regular violation condition. The EI condition was composed of the past tense allomorph and the suffix {-te}: **wuschte* (washed-ed). The BaS condition contained only the present tense stem: **wasch* (wash) for BaS irregular, **tanz* (dance) for BaS regular. The experimental items were placed into sentences after the adverbial modifier of time, i.e. in the second position: *Bereits zu Urzeiten wusch man Gold im Sand des Flusses Otava.* (Already - in primitive times – washed – one – gold - in the – sand - of the – river - Otava). The sentences were not created but selected via the Internet from online newspaper articles. To avoid repetitions of the sentences, three sentence frames were found for each verb, yielding a total of 126 sentences per condition in each verb group.

All experimental sentences were read naturally be a female speaker of standard German. The total 756 sentences were recorded and digitized. The trigger was set on the third glottal wave of the stem vowel.

The stimuli were divided into 3 lists (à 252 sentences) so that each sentence was presented once during the experiment. Each list was made up of three experimental runs (each run consisting of 84 sentences): the first run contained the EI violation condition (**wuschte*) and the C condition (*tanzte*) of the weak verbs; the second run was made up of the BaS irregular condition (**wasch*) of the strong verbs and the C condition (*tanzte*) of the weak ones; the last run was composed of the C strong verbs (*wusch*) and the BaS regular condition (**tanz*) of the weak verbs. Therefore, we kept the number of violated and non-violated items equal. The runs were pseudo randomized in such a way that the sentence frames never appeared in the same environment. The runs and the lists were rotated.

Procedure

Before the experiment, the participants were specifically informed that the whole experiment would contain sentences in the simple past tense. Since the simple past is not used frequently in everyday speech, we wanted the participants to pre-activate this grammatical structure before the actual experiment started.

The stimuli were presented binaurally through headphones in blocks of 3-8 sentences, after each block a sentence appeared in the center of a computer screen. During the auditory presentation of the stimuli a white fixation cross was visible in the center of the computer monitor in order to reduce eye movements. The participants were instructed to avoid eye movements when the fixation cross was visible and were free to blink during the 2-second ISI when the fixation cross disappeared. The subjects were instructed to listen to the blocks of sentences for comprehension. When a sentence was visually presented on the computer screen, the participants had to press a corresponding mouse key to indicate that this sentence was/was not presented in the last auditory block (Yes/No). The sentence remained on the monitor until the subject pressed the key. The experiment was divided into three runs (15 minutes each) with 5-minute breaks between the runs. The whole procedure, including set up and breaks, took approximately 2 hours.

Data Analysis

Trials with gradient amplitude of over 75 µV were automatically discarded from the analysis; the remaining trials underwent visual inspection for artifacts. In total, approximately 8% of the data were rejected. The epochs were baseline corrected relative to the mean voltage of the 200-msec pre-stimulus interval.

After the visual observation of the waveforms, we chose to perform the analyses on mean voltage within the time windows of 400 – 500 msec, 550-650 msec and 700 – 900 msec, approximating the latency ranges of the LAN, N400 and the P600 components.

4.1.1.1.2 Results

Repeated measures ANOVAs were run separately for the regular and irregular verbs due to the difference in the number of conditions. The repeated measures ANOVA for the irregular verbs was run with three within-subject factors: Stem type (C vs. EI vs. BaS), Laterality (left vs. right vs. central), and Anteriority (Anterior vs. Central vs. Posterior). The 3-way interaction reached significance in the time windows of 400-500 ($F(3.75, 71.21) = 4.81$, $p < 0.01$) and 550-650 ($F(4.06, 77.1) = 4.48$, $p < 0.01$) msec.

The analyses for the regular verbs were run with three within-subject factors: Stem type (C vs. BaS), Laterality (left vs. right vs. central), and Anteriority (Anterior vs. Central vs. Posterior). The 3-way interaction reached significance ($F(2.70, 51.29) = 5.85$, $p < 0.01$) in the time window of 700-900 msec. Significant main effects and the 3-way interactions in these omnibus ANOVAs led to further tests at groups of three electrodes within the verb groups.

Figure 19 displays the grand average waveforms and topographies for the irregular verbs in the Past Context experiment. Based on the results of the omnibus tests that revealed 3-way interactions in the latency range of the LAN and N400 effects, we ran one-way ANOVAs in the groups of three electrodes. The results of the one-way ANOVAs reached significance at the left anterior electrode sites (F5 FC5 FT7) in the time window of 400-500 msec: $F(1.91,54.6) = 7.92$, $p < 0.001$. This time window and topography corresponds to the characteristics of the LAN component as reported in the literature (Friederici, 2002, 2011).

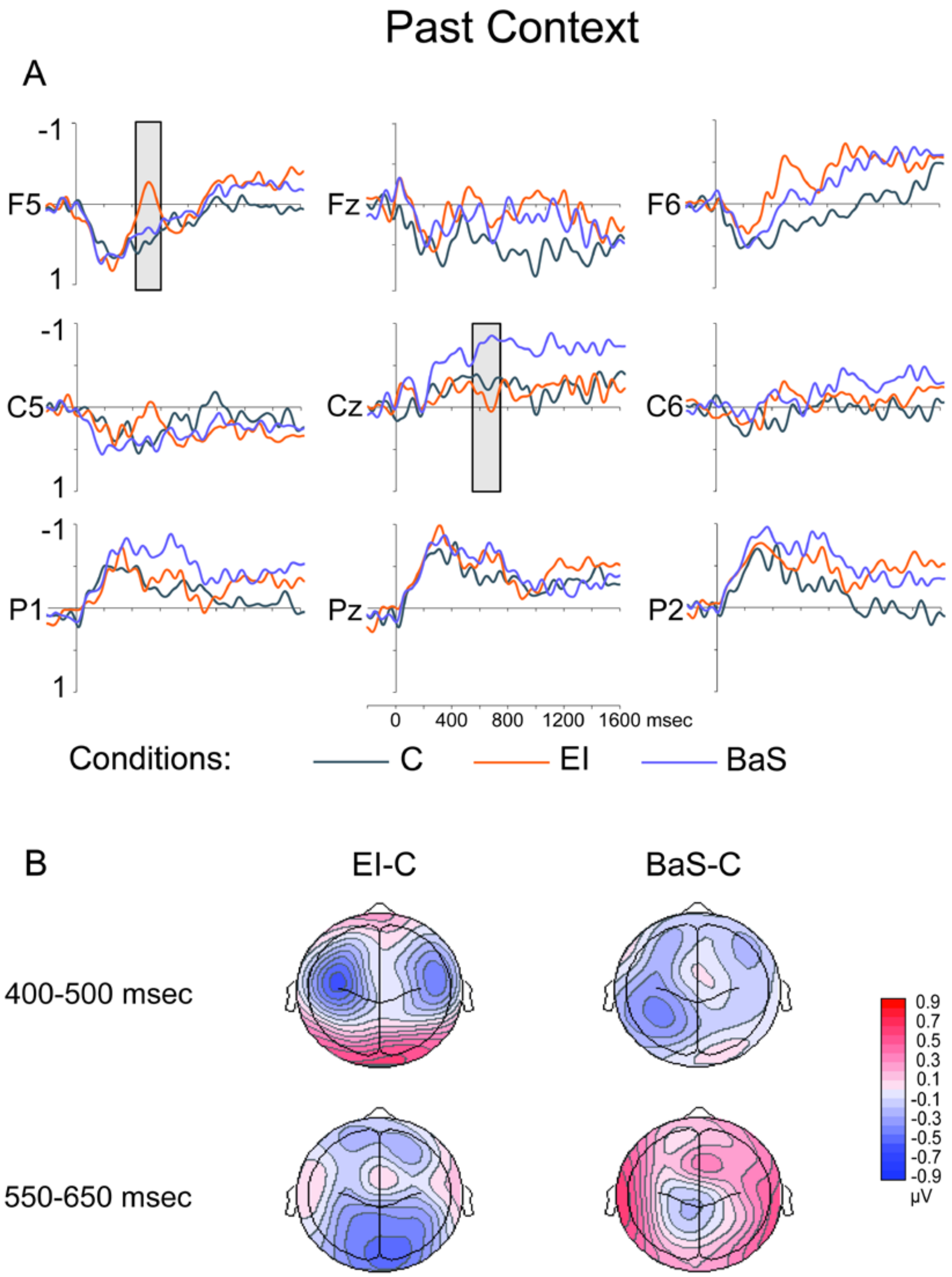

Figure 19. Strong Verbs: Past Context

Grand averages (A) and topographies (B) of the difference waveforms are shown for all conditions in the Past Context experiment. The LAN effect is highlighted at the F5 electrode: The EI condition (orange line) is most negative while the BaS (purple line) and the C (grey line) conditions pattern together. The N400 effect is highlighted at the Cz electrode: the BaS condition is most negative while the EI and C conditions pattern together. The topographies (B) demonstrate differential scalp distribution of the Effects.

The post-hoc paired t-tests (see Figure 23 for bar plots) in the time window of 400-500 msec revealed a significant difference in the C vs. EI ($t(19) = 3.83$, $p < 0.001$) and EI vs. BaS ($t(19) = -4.1$, $p < 0.001$) conditions. The difference between C and BaS conditions did not reach significance.

The one-way ANOVA run in the 550-650 msec time window reached significance at the centro-parietal electrode sites (Cz CPz Pz): $F(1.82,52.04) = 3.22$, $p < 0.05$. The latency and morphology of the effect corresponded to that of N400 (Kutas & Federmeier, 2011). The post-hoc paired t-tests (see Figure 24 for bar plots) revealed a significant difference between C and BaS ($t(19) = 3.3$, $p < 0.01$) and EI vs. BaS conditions ($t(19) = 2.27$, $p < 0.05$). The comparison between C vs. EI failed to reach significance in this time window. No effects were found for the strong verbs in the late time window of 700-900 msec.

The grand average waveforms (A) and the topographies (B) of the difference waveforms for the regular verbs in both experiments are presented in Figure 20. According to the omnibus test, the only time window that demonstrated a significant violation effect for the regular verbs in the Past Context experiment was 700-900 msec. A one-way ANOVA in this time window revealed a significant violation effect at the left anterior (F5 FC5 FT7) electrode sites: $F(1, 38) = 12.68$, $P < 0.001$. This effect seemed to be projected onto the parietal (P1 PO1 PO2) electrode sites: $F(1, 38) = 11.14$, $p < 0.01$. The bar plots of the mean amplitudes of the violated and non-violated regular verbs for both experiments are demonstrated in Figure 21.

4.1.1.1.3 Discussion

The brain activity during the Past Context experiment revealed a differential ERP response pattern to the violated regular and irregular verbs. The EI items (**wuschte*) elicited a LAN effect, while the BaS irregular (**wasch*) items induced an N400. The BaS regular items (**tanz*), on the other hand, elicited a rather late LAN effect that projected onto the parietal electrode sides. No other violation effects were observed.

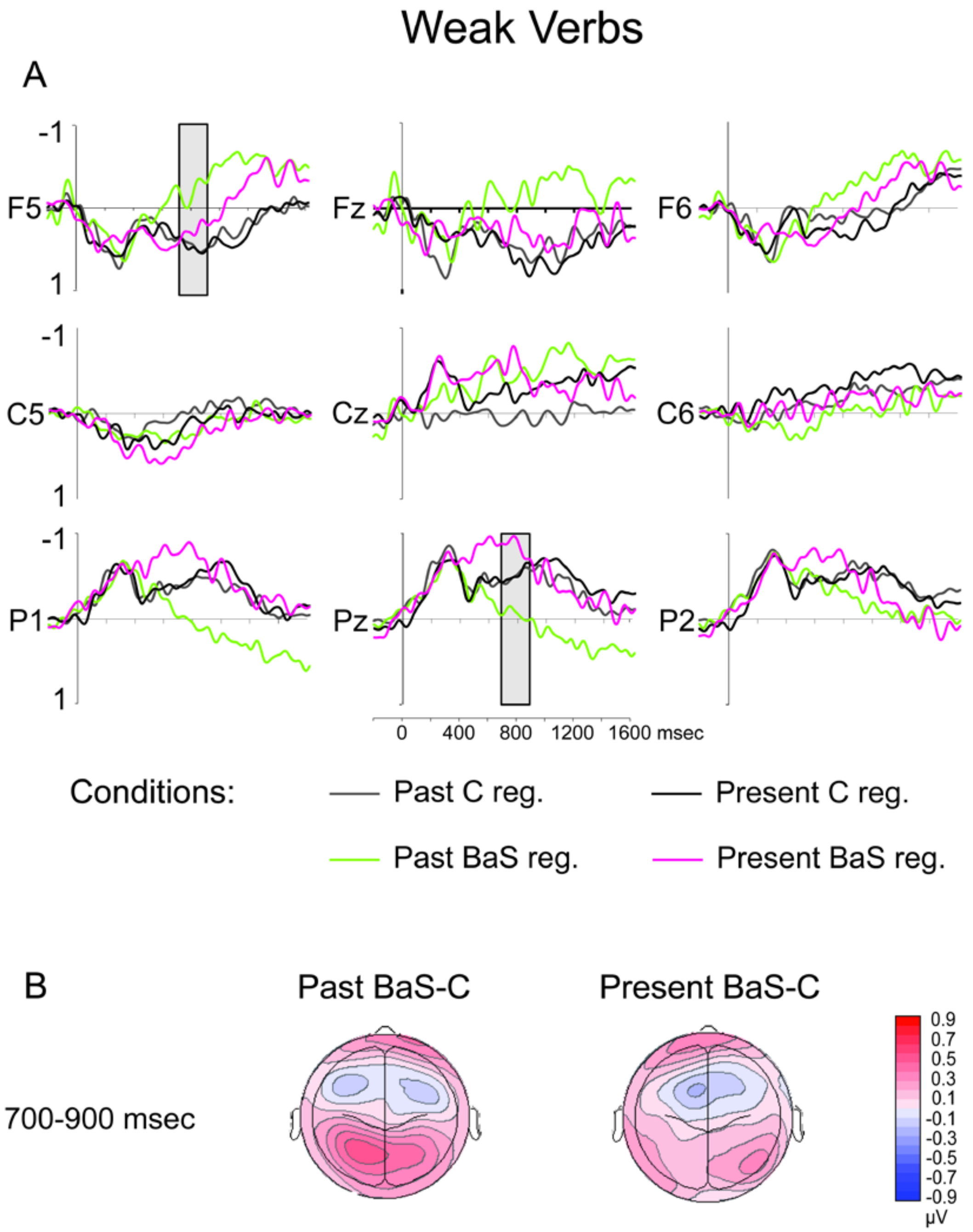

Figure 20. Weak Verbs: Past and Present Context

Grand averages (A) and topographies (B) of the difference waveforms are demonstrated for all weak verb conditions in both experiments. The LAN effect is highlighted at the F5 electrode: The BaS conditions in the past (lime green line) and the present (magenta line) are most negative and pattern together. The C (grey line for the past and black line for the present) conditions are most positive and similar to each other. The inverted effect is highlighted at the Pz electrode: the Past BaS condition is most positive while the C conditions pattern together and are most negative with the Present BaS condition having an intermediate position. The topographies (B) demonstrate similar scalp distribution of the LAN effects in both experiments.

We hypothesized that irregular stem allomorphs should be represented separately within a hierarchical lexical entry based on underspecification of morphological features (Wunderlich, 1996; Wunderlich & Fabri, 1995). For the validation of our hypothesis, we expected the EI items (**wuschte*) to induce a LAN effect as these items represented the violation of the non-suffixation rule for strong verbs in the 3rd person singular in the past tense form. The BaS irregular items (**wasch*) were predicted to trigger an entirely different error-detection mechanism due to the incompatibility of the underspecified present tense allomorphs with the temporal structure of the sentence. This error-detection mechanism was expected to be indexed by the N400 component. The BaS regular items (**tanz*) were predicted to elicit a LAN effect due to the violation of the past tense suffixation rule. The results of the present experiment confirmed our predictions. Thus, the EI items triggered, as predicted, the formal error-detection mechanism reflected in the amplitude of the LAN component. The violated weak verbs also evoked a LAN effect. The violation-related brain responses in the BaS irregular condition pointed to the difficulty in the semantic processing as reflected in the amplitude of the N400 component.

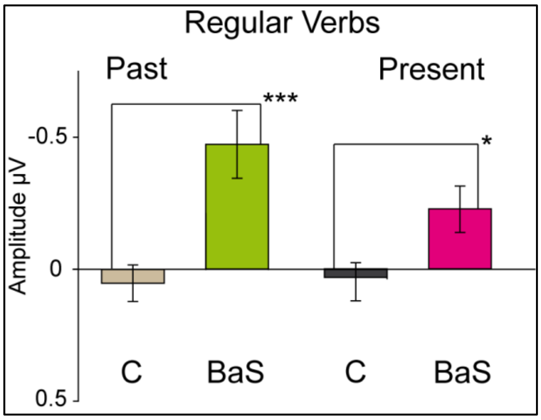

Figure 21. Weak Verbs: the LAN Effect

Bar diagrams of mean amplitude values in the latency range and topography (F5 FC5 FT7) of the LAN component. Standard error of mean is plotted in both directions. The right part of the plot illustrates mean amplitude values of the C and BaS conditions in the Past Context experiment, while the left part of the graph demonstrates mean amplitude values of the C and BaS conditions in the Present Context experiment.

The participants were specifically informed about the tense form of the verbs employed in the present study, i.e. the simple past/ preterit. This was made in order to encourage the participants to develop a strategy of dealing with the context and with the grammatical material. We expected the subjects to pre-activate the past tense paradigms for both verb classes. Taking into account that all sentences contained a subject in the 3rd person singular, the participants should have expected zero-suffixation in case of a strong verb and the suffix {-te} in case of a weak one. The violation of the suffixation/ non-suffixation rule was expected to elicit a LAN effect. Both EI (**wuschte*) and BaS regular (**tanz*) violations indeed evoked a LAN effect that was rather delayed when triggered by the BaS regular items. Despite the fact that the violation in both, EI and BaS regular, cases was word-final, the predictions about the possible structure were quite different and therefore entailed differential processing. The presence of the {-te} suffix after the past tense allomorph of a strong verb became obvious during the co-articulation phase. Therefore, the error-detection mechanism was triggered relatively early as evident from the reported brain response pattern. The delayed LAN elicited by the BaS regular items could be caused by the expectation of the inflectional suffix. The lack thereof led to the immediate calculation of the probable local syntactic relations reflected in a delayed LAN effect. Another important difference between the EI and the BaS regular conditions was that the EI items already carried the temporal information, which was missing in the BaS regular items. Therefore, the local syntactic relations for the EI items were not only established early enough, but were also “double checked” by the excessive inflectional information contained in the suffix {-te}. Conversely, the inflectional information was entirely absent in the BaS regular items, which resulted in the necessity of receiving a greater amount of sensory input, in contrast to EI, until the relation between the predicate and the subject could be established.

The BaS irregular (**wasch*) violation condition consisted of a present tense allomorph without any affixation or stem vowel alternations that could be indicative of the inflectional form. This particular non-inflected form of a strong verb did not carry any information about the finiteness of the verb or about the subject of a sentence. Taking in to account these factors, we expected the BaS irregular items to trigger an aggravated syntactic conflict indexed by the P600 effect if irregular stem allomorphs were fully specified for tense. Conversely, we expected these items to evoke an N400 effect if the mental representations of irregular stem allomorphs were underspecified for tense. Our predictions for this condition differed from those for the BaS regular condition due to the different number of allomorphs that strong and weak verbs possess. The stem of a weak verb, having only one representation, should be unspecified for tense, the latter being rendered by means of suffixation. Thus, the past context triggered the pre-activation of past tense paradigms, which in the case of the weak verbs consisted in the attachment of the suffix {-te} to the right boundary of the stem morpheme. The strong verbs, on the other hand, already had an allomorph specified for tense that had to be used with zero-suffixation in the 3rd person singular. The past tense allomorphs of the irregular verbs differed from their present tense counterparts in the stem rhyme. Therefore, during the perception of the stem vowel, at the latest, it became obvious that a wrong allomorph was used. The misleading temporal information was expected to induce a P600 or an N400 effect depending on the structure of the lexical entry. The reported violation response was the N400 effect.

The N400 could have been induced by several factors. First, the temporal characteristics of strong verbs could be hard-wired in the lexical entry in an underspecified manner, i.e. the preterit allomorph is marked by the feature [+PRET] and the basic stem is underspecified for that feature. The violation of the temporal structure would thus result in the elicitation of an N400 effect. Though very plausible, this hypothesis needs testing in the present tense. Should it be valid, we expect the BaS irregular items to repeatedly elicit an N400.

The second factor could be the stem vowel quality. Compared to the BaS regular condition that only required an affix in order to agree with a subject in the past or present tense, twelve irregular verbs employed in this study required a stem vowel alternation in order to produce the 2nd and 3rd person singular forms in the present tense. Some strong verbs require umlaut (ä/ö/ü for a/o/u) or raising (i for e) in these inflectional forms. For example, the stem vowel of the verb *waschen* (wash) has to be umlauted in the above-mentioned forms: *er wäscht* (he washes), while the stem vowel of the verb *lesen* (read) has to be raised: *er liest* (he reads). The ability of a stem vowel to regularly alternate could interfere with the processing of a bare stem. Although we did not find any significant interactions with the stem vowel or main effects thereof, the ability of this vowel to alternate could be marked as typical of the present tense form of the strong verbs. Considering the distance between the expected input (a past tense allomorph) and the actually perceived truncated form, the contextually triggered expectation could have induced a semantic composition process, i.e. an attempt to construct a meaningful item out of the presented input. The Present Context experiment, having a shorter distance between the expected and actual input, could provide evidence supporting or refuting this assumption.

The last factor that could have influenced the elicitation of the N400 component could be the imperative mood. The German imperative in the 2nd person singular is built by means of the present stem morpheme in the 2nd person singular with the optional suffix {-e} instead of the 2nd person singular suffix {- st}: *gehen* (to go) – *geh!* (go!). The imperative constructions in the singular are used without a subject. If an irregular verb undergoes umlaut to produce the 2nd and 3rd person singular in the present, its stem vowel does not have to alternate to generate an imperative form. However, if a stem vowel has to undergo raising to produce the 2nd and 3rd person singular in the present, this vowel is inherited by the imperative: *lesen* (to read) – *lies*! (read!). The imperative form of strong verbs used in the present study, with the exception of six verbs, corresponded to the BaS irregular condition. Taking into account that the subject followed the predicate in the experimental sentences, the structure could easily be initially interpreted as an imperative. An imperative construction is normally used for ordering or requesting something. Considering the time scope of an order or a request, an adverbial modifier of time should define the (nearest) future, past tense adverbials being highly unlikely in imperatives. The N400 effect observed in the present study could have been triggered by the perception of the BaS irregular condition as an imperative construction that clashed with either the presence of the past time adverb/ adverbial modifier of time or with the presence of a subject that immediately followed the verb.

The reported pattern of results could also be influenced by the experimental design, the memory task and the instruction. The subjects were specifically informed about the tense form used in the present experiment, which should have triggered the preference for certain grammatical structures: indicative mood, the preterit paradigms for both verb categories, past tense adverbial modifiers, etc. The second position of a predicate in a sentence meant that syntactic relations could be established only locally due to the limited amount of linguistic input. Therefore, we controlled for the contextual effects only having a structural “priming”, i.e. all sentences started with an adverbial modifier of time (past in this case), followed by a predicate and then by a subject in the 3rd person singular. The memory task, however, required the memorization of the whole sentence in exactly the same way as it had been previously presented. The memorization of the stripped infinitives involved the maintenance of the non-finite form, while the memorization of the EI items required additional combinatorial resources.

The combinatory violations, i.e. the EI and BaS regular items, triggered the formal morphosyntactic error-detection mechanisms. As these faulty constructions had to be kept in the memory for the task performance, the parsing had to be run first to reanalyze these items’ composition in order to be able to correctly reconstruct them. The N400 effect, on the other hand, could have been induced by a number of factors that were discussed above. All of them, however, required the involvement of the semantic memory, be it for the maintenance of the temporal clash, the semantic composition processes or the violation of the indicative mood structure.

The Past Context experiment provided evidence for differential processing of weak and strong verbs, demonstrating that strong verbs had separate representations for irregular allomorphs within a lexical entry. The following experiment should shed light onto the effects caused by the temporal characteristics. If the N400 effect perseveres, the underspecification account should be considered proven. If the violation pattern reverses, or EI items elicit a P600, then the listing of the temporal characteristics within the lexical entry should be considered more thoroughly.

4.1.1.2 *Experiment 9: Present context*

4.1.1.2.1 Methods

Participants

Twenty participants (10 male, age range: 19-26 years, mean: 22.29) took part in this experiment. They were students of the University of Konstanz. The subjects gave written informed consent and were either paid for participation or received a practice certificate for the Psychology Department.

Materials

The 42 weak and 42 strong verbs previously used in the Past Context experiment were employed in the present study. The mean frequency of occurrence of the irregular verbs in the present tense form was relatively high – 2921.11 according to the Leipziger Corpus. The mean frequency of occurrence of the weak verbs was the same as in the previous study: 376.26. The control (C) condition was made up of the present tense form of the verbs in the third person singular, i.e. the present tense allomorph of a strong verb with the 3rd person singular suffix – *wäsch-t* (washes) or the stem of a weak verb with the same affix – *tanz-t* (dances). The number and the composition of the violation conditions was the same as in the Past Context experiment with the exception of the EI items. Thus, the EI condition was composed of the past tense allomorph and the suffix {-t}: **wuscht* (washed-s). The experimental items were placed in the sentences after the adverbial modifier of time: *Normalerweise wäscht man feine Sachen von Hand.* (Normally - washes – one – delicate - things – by - hand). The sentences were selected via the Internet from online newspaper articles. To avoid repetitions of the sentences, three sentence frames were found for each verb, yielding a total of 126 sentences per condition in each verb group. The recording and digitizing procedure were similar to those reported in the previous study. The composition of the lists and runs as well as the pseudo randomization procedure were also similar to those from the Past Context experiment. We provide the examples of the stimuli and repeat the predictions for the Present Context experiment in Table 17.

Table 17. Experimental conditions and predictions for the Present Context experiment

The names of the conditions and their composition are given in the first row. The example of a violation pattern of a German strong verb gehen *(go) is given in the second row in isolation (underlined) and in a sentence context (bold italicized). The predictions are divided into rows according: single representation, the third row with a graded LAN effect; separate fully specified representations for all allomorphs, the fourth row, with a large P600 for EI condition and a mild LAN effect for BaS condition; unified lexical entry for stem allomorphs based on underspecification of morphological features, the fifth row, with an N400 effect for BaS condition.*

Condition Composition	**C** – control: The Present form of a strong verb in 3rd Pers. Sg.: {Present}+{-t}	**EI** – excessive inflection: The Past form of a strong verb in 3rd Pers. Sg. and the suffix of the Present 3rd Pers. Sg.: {Past}+{-t}	**BaS** – basic stem: The Present form of a strong verb without affixes: {Present}
Example	geht Normalerweise ***geht*** er zur Arbeit zu Fuß. Usually – ***goes*** – he to work on foot.	*gingt Normalerweise ***gingt*** er zur Arbeit zu Fuß. Normally – ***went(s)*** – he to work on foot.	*geh Normalerweise ***geh*** er zur Arbeit zu Fuß. Normally – ***go*** – he to work on foot.
Single underlying stem morpheme	____________	large LAN	mild LAN
Separate fully specified entries for allomorphs	____________	large P600	mild LAN
Unified lexical entry for stem allomorphs based on underspecification	____________	____________	N400

Procedure and Data Analysis

The participants were informed that the sentences employed in this experiment would be used in the present tense. The presentation procedure and the instructions were the same as in the Past Context experiment so as to make certain that the results of the Past and Present Context experiments could be comparable. The experiment was divided into three runs (15 minutes each) with 5-minute breaks between the runs. The whole procedure, including set up and breaks, took approximately 2 hours.

After filtering and correction for eye artifacts, the trials with gradient amplitude of over 75 µV were automatically rejected. The remaining trials underwent visual inspection for artifacts. In total, approximately 8% of the data were rejected. The epochs were baseline corrected relative to the mean voltage of the 200-msec pre-stimulus interval.

To ensure the comparability of the results, we performed the analyses on mean voltage within the same time windows as in the Past Context study, i.e. 400 – 500 msec, 550-650 msec and 700-900 msec.

4.1.1.2.2 Results

Repeated measures ANOVAs were run separately for the weak and strong verbs due to the difference in the number of conditions. The repeated measures ANOVAs for the strong verbs was run with three within-subject factors: Stem type (C vs. EI vs. BaS), Laterality (left vs. right vs. central) and Anteriority (anterior vs. central vs. posterior), and a between subject factor Tense (Past vs. Present). The 4-way interaction failed to reach significance in all time windows providing evidence for the similarity of the effects in both experiments. The analyses for the weak verbs were run with three within-subject factors: Stem type (C vs. BaS), Laterality (left vs. right vs. central) and Anteriority (anterior vs. central vs. posterior), and a between subject factor Tense (Past vs. Present). The 4-way interaction also failed to reach significance. The omnibus repeated measures ANOVAs within the Present Context experiment revealed a significant 2-way interaction of the type Stem X Laterality for the strong verbs in the time window of the N400 effect: $F(2.86, 54.36) = 3.48$, $p < 0.05$. The same tests run with the weak verbs revealed a significant 3-way interaction Stem X Laterality X Anteriority in the 700-900 msec time window: $F(3.06, 58.21) = 3.22$, $p < 0.05$. The reported interactions led to further tests at groups of three electrodes within the verb groups.

The grand average waveforms (A) and topographies (B) for the strong verbs in the Present Context experiment are illustrated in Figure 22. Taking into account that the results of the between-group omnibus tests failed to demonstrate a 4-way interaction in the latency range of the LAN and N400 effects, we chose to run the one-way ANOVAs on the same groups of electrodes and time windows as in the Past Context study. The results of the one-way ANOVAs reached significance at the left anterior electrode sites (F5 FC5 FT7) in the latency range of the LAN effect: $F(1.91,54.6) = 3.93$, $p < 0.05$ (Friederici, 2002, 2011; Friederici, Hahne, & Saddy, 2002). The post-hoc paired t-tests (see Figure 23 for bar plots) demonstrated that only the violation conditions EI vs. BaS significantly differed from each other: $t(19) = -2.33$, $p < 0.05$. The other conditions failed to show significant difference from each other. The one-way ANOVAs run in the latency range of the N400 component reached significance at the centro-parietal electrode sites (Cz CPz Pz): $F(1.82,52.04) = 4.55$, $p < 0.05$ (Kutas & Federmeier, 2011). The post-hoc paired t-tests (see Figure 24 for bar plots) showed that the conditions C vs. BaS ($t(19) = 2.94$, $p < 0.01$) and EI vs. BaS ($t(19) = 3.6$, $p < 0.01$) significantly differed from each other. The comparison of the C vs. EI failed to reach significance in this time window. No significant effects were found for the strong verbs in the 700-900 msec time window.

Figure 20 demonstrates the grand average waveforms (A) and the topographies (B) of the difference waveforms for the weak verbs in both experiments. Based on the results of the omnibus test, we decided to run a series of one-way ANOVAs in the time window of 700-900 msec on the same groups of electrodes, as in the Past Context experiment. The results of the one-way ANOVAs reached significance at the left anterior (F5 FC5 FT7) electrode sites: $F(1, 38) = 4.87$, $p < 0.05$. No projections onto the parietal electrode sites were observed. The mean amplitudes of the violated and non-violated regular verbs are illustrated in Figure 21.

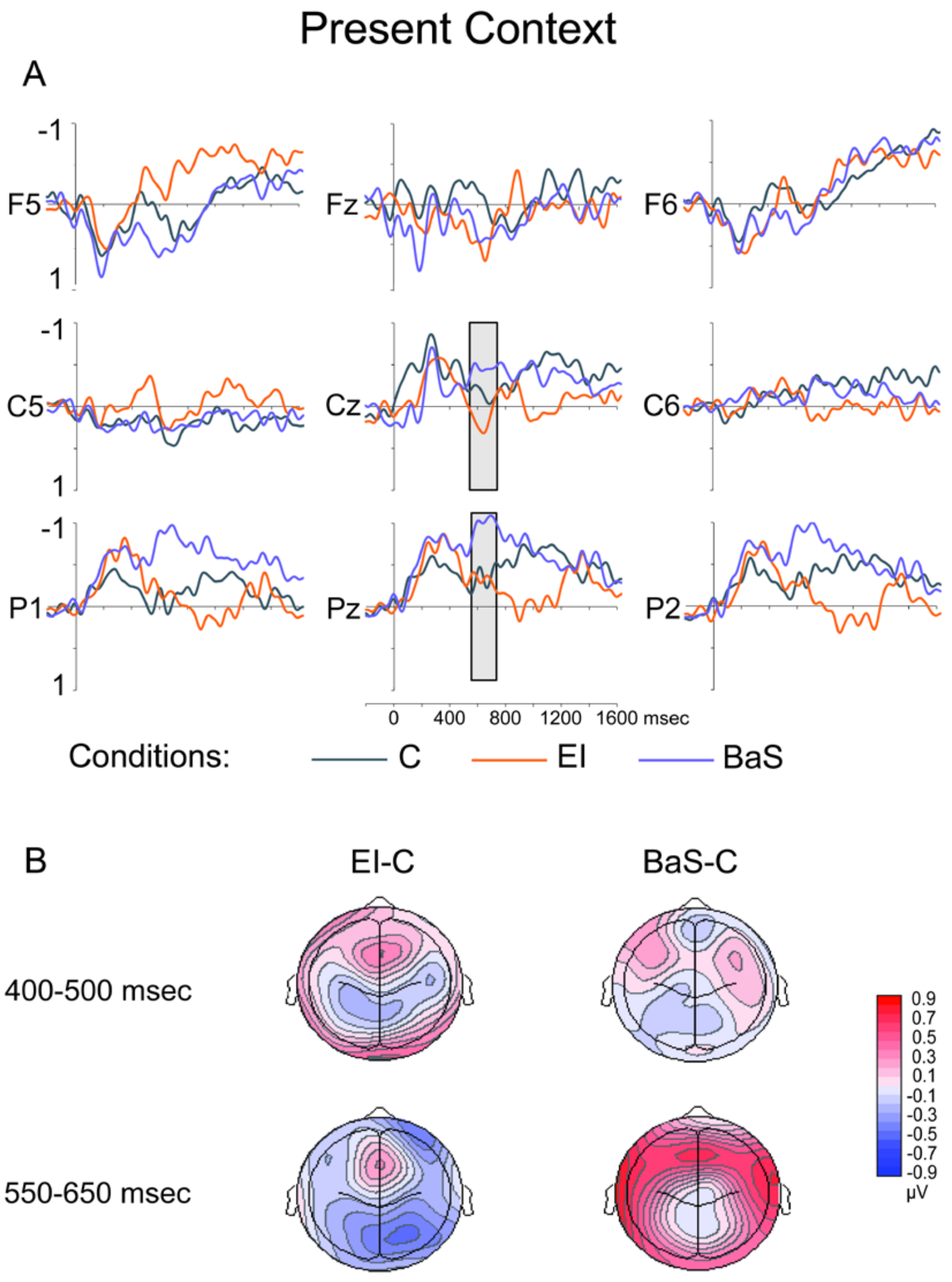

Figure 22. Strong Verbs: Present Context

Grand averages (A) and topographies (B) of the difference waveforms are shown for all conditions in the Present Context experiment. The N400 effect is highlighted at the Cz and Pz electrodes: the BaS condition (purple line) is most negative while the EI (orange line) and C (grey line) conditions pattern together. The topographies (B) demonstrate the scalp distribution of the N400 effect.

4.1.1.2.3 Discussion

We predicted a similar violation related brain response pattern for strong and weak verbs if irregular stem allomorphs shared a mental representation, i.e. a LAN effect. If irregular stem allomorphs were stored separately within a lexical entry and were fully specified for tense, we expected the allomorph misapplication condition (EI - **wuscht*) to elicit a P600 effect due to the mismatch between the temporal (present tense) context and a past tense allomorph. The BaS irregular (**wasch*) items were expected to evoke LAN. Our last predictions concerned the underspecification of the tense feature. Here, we expected the BaS irregular items to trigger N400 due to the missing temporal (tense) characteristics. The EI items, though a case of allomorph misapplication, were marked for tense and carried a suffix necessary for the present tense paradigm. Therefore, we did not expect these items to elicit any violation effects. The violation-related brain responses during the Present Context experiment demonstrated a differential response pattern to the violated weak and strong verbs. The BaS regular items elicited a late LAN effect, while the BaS irregular items evoked an N400. No other violation effects were observed.

We hypothesized that irregular stem allomorphs should be represented separately within a lexical entry based on underspecification of morphological features. For the validation of our hypothesis, we expected the violated strong verbs to trigger error-detection mechanisms that would be qualitatively different from those triggered by the violated weak verbs. The EI items (**wuscht*) were not expected to induce any violation effects, while the BaS irregular items (**wasch*) were predicted to trigger an N400 effect due to their underspecification for tense and missing inflection. The BaS regular items (**tanz*) were expected to elicit a LAN effect due to the violation of the suffixation rule. The results of the present experiment provided evidence supporting our hypothesis. Thus, the EI items failed to elicit any violation brain responses. The BaS irregular items demonstrated the same response pattern as in the Past Context experiment, i.e. they induced an N400 effect. The BaS regular items repeatedly evoked a LAN effect. Thus, the violation-related brain response pattern reported in the Past Context experiment was for the most part (except for the EI condition) replicated in the present experiment.

Before the experiment, the participants were informed about the present tense form of the verbs used in the present study. Therefore, we kept the possible co-variables, such as the instruction, stable throughout this series of studies. This was also meant as a contribution to the complete immersion into the temporal context. Taking into account the invariability of the temporal context, as provided by the adverbial modifiers of time, we expected the participants to pre-activate the present tense paradigms for both verb categories. Considering that the experimental sentences had a subject in the 3rd person singular, the participants should have expected the suffix {-t} for weak and strong verbs, as well as an umlauted/ raised vowel in the stem of twelve strong verbs that were also part of the stimulus materials. The violation of the morphosyntactic rules was expected to elicit a LAN effect.

Despite the use of the wrong allomorph, the EI items (**wuscht*) failed to induce any violation brain responses. We expected these items not to trigger any violation related brain responses only if the lexical entry of a strong verb was organized on the basis of underspecification (Clahsen et al., 2001; Lahiri & Reetz, 2010; Plank & Lahiri, 2015; Scharinger et al., 2009). Thus, sentence context carrying temporal information requires a predicate marked for tense either by means of intrinsic characteristics (markedness for tense) or by means of inflectional suffixes rendering these characteristics (if the verbal stem is underspecified for tense). The combination of a marked stem and a correct inflectional suffix was expected to evoke non-deviant processing. This prediction was also in line with the results of Penke et al.'s (1997) study, which demonstrated normal processing of the violated items (**getanzen* instead of *getanzt*) when the necessary suffixation rule was not violated. The participle formation rule, employed in Penke et al.'s (1997) study, concerned regular verbs only and consisted in the attachment of the prefix *ge-* to the left boundary of the stem[5] and the simultaneous attachment of the suffix {-t} to its right boundary. The participles of strong verbs, on the other hand, have the suffix {-en} and these items have to be memorized and not built according to a productive morphosyntactic rule. Following this logic, the past participles ending in {-en} should be searched for in the long-term memory as they cannot be decomposed without a morphosyntactic rule. The absence of a morphosyntactic rule violation resulted in the normal processing of the violated items. Conversely, if a rule is misapplied to an item that does not involve a formation-by-rule, a LAN effect should be elicited. In the present study, the requirement for all verbs was the

[5] There are several verb classes that do not require the attachment of the prefix *ge-* to form a past participle. These are particle verbs (Müller, 2002; Wurmbrand, 2000): *anerkennen* (recognize) – *anerkannt* (recognized, past participle); and verbs with the stem rhyme *–ier*, i.e. *reparieren* (repair) – *repariert* (repaired, past participle).

attachment of the suffix {-t} to the right boundary of the stem morpheme, which was indeed the case in the EI condition. Therefore, the morphosyntactic/ suffixation rule was properly applied, resulting in the normal syntactic processing, i.e. in the establishment of the correct subject-predicate relation (Penke et al., 1997; Rodriguez-Fornells et al., 2001).

The absence of violation brain responses in the case of allomorph misapplication could have been caused by another factor: the difference in the frequency of occurrence of the present and past tense allomorphs. While the mean frequency of occurrence of the present tense allomorphs is 2921.11, the mean frequency of occurrence of the past tense forms is only 669.69. According to McKinnon et al. (2003), the nonwords made up of existing morphemes should be processed as low-frequency words due to the access to the meanings of these morphemes. Taking into account the memory task requirements, the EI items were initially processed at the level of morphosyntax in order to establish the local syntactic structure. The syntactic structure being correct, the semantics of the EI items were composed using the generic meaning of the allomorph and the meaning of the inflectional suffix. The low frequency of occurrence of the verb allomorph did not hinder the subsequent sentence processing, hence the lack of violation brain responses.

The rest of the violation conditions replicated the results of the Past Context experiment: the BaS regular items elicited a delayed LAN, while the BaS irregular items evoked an N400. The delayed LAN was triggered by the calculation of the probable local syntactic relations set off by the missing inflectional suffix. Although both BaS conditions were characterized by the lack of inflectional information, the violation-related brain responses evoked by them were qualitatively different. The paradigmatic information of weak verbs is rendered by means of inflectional affixes, the stem remaining intact throughout the paradigm. The lack of the inflectional suffix in the BaS regular condition resulted in the violation of the local syntactic relations, i.e. subject-predicate agreement, as revealed by LAN. The strong verbs contain partial paradigmatic information within their stems, such as the past tense form, the past participle and the basic/present tense form. Taking into account that some *modus irrealis* (imperatives, subjunctives) forms are built on the basis of present or past tense allomorphs, the capability of the latter to do so should be reflected in the lexical entry. A bare non-umlauted stem of a present tense allomorph could function as a command/ an imperative, therefore changing the meaning of the sentence (Austin, 1962; Searle, 1969). We argued in the previous sub-chapter that the presence of an adverbial modifier of time and the presence of a subject in the vicinity of an imperative form could cause a clash reflected in the N400. The Past Context experiment contained the adverbials defining the past tense. Considering the time scope of a directive, it was possible that the clash was triggered by the past tense adverbials in the previous study. The present study, on the other hand, employed present tense adverbials, which were in line with the time scope of the imperative. Yet the present pattern of results demonstrated the latency and magnitude of the N400 effect similar to that observed in the Past Context study. This finding showed that the N400 effect was possibly triggered by the initial perception of the BaS irregular items as imperatives.

In the previous section, we put forth several factors that could have triggered the N400 effect. The first factor – the interpretation of the BaS irregular items as imperative constructions – has already been discussed. Another factor that we brought up was the stem vowel quality, i.e. the phonological distance between the actual input and the expected one. Twelve strong verbs used in this series of studies required an umlaut/ fronting of the stem vowel to produce the 2nd and 3rd person singular forms in the present tense: *waschen* (wash) – *er wäscht* (he washes), *lesen* (read) – *er liest* (he reads). We ran statistical analyses with the vowel quality as factor within and between the experimental groups and found no significant interactions with the stem vowel or main effects thereof. The bare stem vowels being phonologically closer to the present tense paradigm of strong verbs, we should have found an interaction of the N400 component with the Tense. However, the N400 effect was statistically proven to be similar in both experiments. These findings suggested that the stem vowel quality should not have triggered the N400 effect.

The last factor that we considered was the assumption that the lexical entry of a strong verb was organized on basis of underspecification of morphological features, one of them being [+PRET]. We reasoned that in this case the application of a stem allomorph underspecified for tense in a sentence context would trigger an N400 effect. Taking into account the lack of temporal characteristics in the BaS irregular items (**wasch*), these verbs could not be semantically integrated into the sentence context. The present pattern of results provided evidence for the underspecification hypothesis, as the violation of the temporal structure of a sentence by means of an uninflected underspecified stem allomorph triggered a semantic ERP component, viz. N400.

4.2 Discussion: Representation of irregular stem allomorphy

The *second* part of the present thesis investigated the representation of irregular stem allomorphy employed in the past tense formation of German strong verbs. The secondary goal of this part was to find out whether there was a prioritization of one tense form over the other. We chose to use the German strong verbs as an object of study because they employ a non-productive and unpredictable stem vowel alternation – ablaut – to generate past tense and past participle forms. We assumed that the unpredictability of the ablaut patterns could not be generalized into a single morphophonological rule and, therefore, should lead to the separate representation of the present tense, past tense and past participle forms of the strong verbs. We hypothesized that these separate representations should be listed within a single hierarchical lexical entry based on the underspecification of morphological features (Clahsen et al., 2001). To test our hypothesis, we designed two ERP experiments that ensured immersion into the temporal context (past/present). The purpose of the temporal context was the activation of the corresponding tense paradigms for strong and weak verbs. The brain responses to the misapplication of the allomorph or to the violation of the morphosyntactic suffixation rule should be indicative of the processing and representation of the irregular stem allomorphs. We compared the deviant processing of the violated strong verbs to the normal processing of these verbs within and between the temporal contexts. Another control condition was the suffixation violation of the weak verbs. German weak verbs generate all paradigmatic forms from the same stem morpheme. We argued that significant difference between the processing of the violated strong and weak verbs should be indicative of differential representation thereof, i.e. multiple stem morphemes within a lexical entry vs. a single stem morpheme respectively.

The results of the Past Context experiment revealed a differential brain response pattern elicited by the violated regular and irregular verbs. The EI items (**wuschte*) elicited a LAN effect, while the BaS irregular items (**wasch*) induced an N400. The BaS regular items (**tanz*) elicited a delayed LAN effect. For the validation of our hypothesis, we expected the EI and the BaS irregular items to trigger brain activity with differential spatial-temporal characteristics. The EI condition was predicted to induce a LAN effect due to the violation of the morphosyntactic subject-verb agreement rule, i.e. non-suffixation of the strong verbs in the 3rd person singular in the past tense form. The BaS irregular items, on the other hand, were predicted to trigger an N400 caused by the incompatibility of the uninflected present tense allomorphs underspecified for tense with the temporal structure of the sentence. The BaS regular condition was expected to elicit a LAN effect triggered by the violation of the past tense suffixation rule. The results of the Past Context experiment supported our hypothesis. Thus, the violation of the morphosyntactic rules – the subject-verb agreement in the EI condition (**wuschte*) and the omitted suffixation in the BaS regular items (**tanz*) – elicited a LAN effect. The BaS irregular items (**wasch*) evoked an N400 pointing to the abnormal semantic processing. The reported pattern of results was partially replicated in the Present Context experiment that revealed a LAN effect for the BaS regular items and an N400 for the BaS irregular ones.

The predictions presented in the Ablaut subchapter implied differential processing of the stem allomorphs as an index of separate mental representations. A very important difference between the first and the second part of the present thesis should be made here: while the illegal combination of a stem and a derivational affix results in a non-existing word, the illegal combination of a stem and an inflectional suffix generates an ungrammatical word form. Assuming a similar manner of representation and processing of weak and strong verbs, the violation of inflectional form, be it subject-verb agreement or the omission of an inflectional suffix, should trigger a semi-automatic error-detection mechanism, manifested in the LAN, or the reanalysis, indexed by the P600. The present pattern of results falsified this assumption having revealed qualitatively different ERP components elicited by strong and weak verbs.

The effects elicited by the EI condition could be explained by the requirements of the past and present tense paradigms (Figure 23). If the subject of a sentence carries the characteristics of the 3rd person singular, the paradigmatic morphosyntactic rules require (i) a bare past tense stem allomorph of a strong verb in the past context, and (ii) a present tense stem allomorph[6] of a strong verb/ a stem of a weak verb in combination with the suffix {-t}. The EI items violated the morphosyntactic rules imposed by the past tense paradigm, as indexed by the LAN effect (Bakker, MacGregor, Pulvermüller, & Shtyrov, 2013; Marcus et al., 1995; Penke et al., 1997; Weyerts et al., 1997). At the same time,

[6] There are several strong verbs – twelve were used in the reported series of studies – that undergo either umlaut or a change of height to generate the 2nd and 3d person singular: *waschen* (wash) – *wäscht* (washes), *lesen* (read) – *liest* (reads).

these items met the requirements of the present tense paradigm by containing the necessary inflectional suffix, hence the lack of violation effects (Krott & Lebib, 2013; Penke et al., 1997). The ungrammaticality of the combination, i.e. the wrong allomorph and the correct inflection, did not hinder the initial syntactic processing. Another factor contributing to the lack of violation effect in the EI condition in the Present Context experiment was the markedness of this stem allomorph for tense [+PRET]. The sentence context, i.e. a statement, requires a predicate that entails certain temporal characteristics either inherent (the stem is specified for the tense feature) or provided by the inflectional suffixes.

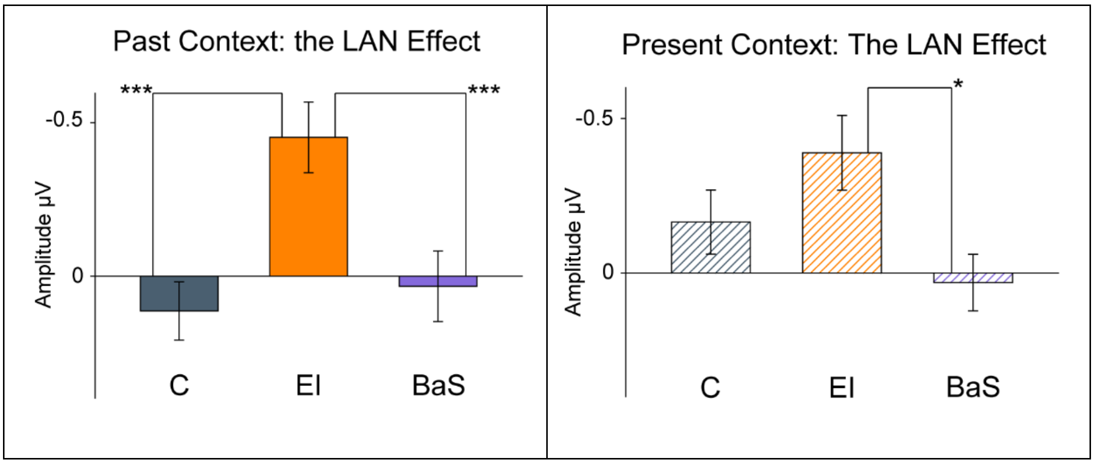

Figure 23. Strong Verbs: the LAN Effect

*Bar diagrams of mean amplitude values in the latency range and topography (F5 FC5 FT7) of the LAN component. Standard error of mean is plotted in both directions. The left part of the plot illustrates mean amplitude values of the C, EI and BaS conditions in the Past Context experiment, while the right part of the graph demonstrates mean amplitude values of the C, EI and BaS conditions in the Present Context experiment. Significant differences are marked with asterisks (*** = p<0.001, * = p<0.05)*

The BaS regular (**tanz*) violation condition being a bare uninflected stem consistently evoked a LAN effect (Figure 21). The neglect of the necessary inflectional suffixation triggered the calculation of the local syntactic relations indexed by the LAN (Angrilli et al., 2002; Holland, Brindley, Shtyrov, Pulvermüller, & Patterson, 2012; Molinaro, Barber, & Carreiras, 2011; Rossi, Gugler, Hahne, & Friederici, 2005; Silva-Pereyra & Carreiras, 2007; Vincenzi et al., 2003). The peculiarity of the BaS regular condition in comparison to the previous research done on the subject-verb agreement was that the BaS verb did not carry any inflectional information but for the possible imperative interpretation. The occurrence of the LAN could thus either be due to the lack of inflectional markers of the subject-verb agreement or due to the presence of a subject if the BaS regular items were perceived as an imperative construction. Taking into account the presented arguments, a similar processing should be triggered by the BaS irregular items (**wasch*) if strong verbs were represented in the same manner as weak ones.

The BaS irregular violation condition (**wasch*), though very similar to the BaS regular one, had intrinsic information that was missing from its regular counterparts, i.e. a basic/present tense allomorph. Following the morphosyntactic logic, an uninflected present tense allomorph of a strong verb should have met the requirements of the past tense paradigm. Therefore, we did not expect the BaS irregular condition to elicit a LAN effect in the Past Context experiment (Penke et al., 1997). Instead, we expected the misleading temporal information contained in the present tense allomorph to evoke a P600, if these were fully specified for tense. The expectations for the Present Context experiment were also governed by the requirements of the verbal paradigm. Considering the similarity of the weak and strong verb paradigms in the present tense, we expected the two BaS conditions to elicit similar violation-related brain responses, viz. a LAN effect, if the present tense allomorphs were fully specified for tense.

We hypothesized that only the past tense allomorph should be marked with the feature [+PRET], the present tense/basic allomorph being underspecified. For validation of our hypothesis, we expected the BaS irregular items to evoke N400 in both experiments. This prediction was based on the assumption that the temporal context imposed by the sentence should require a predicate carrying temporal characteristics. The BaS irregular items being underspecified for tense and lacking inflectional markers would thus trigger a conflict reflected in the amplitude of the N400 component. As we predicted, the BaS irregular condition consistently evoked an N400 effect in both experiments (Figure 24).

We considered several factors that could have contributed to the induction of the N400, such as (i) underspecification for the tense feature, (ii) the ability of the stem vowel to alternate in the 2nd and 3rd person singular could be marked in the present tense, and (iii) the imperative mood. The first factor has already been considered in the previous paragraph. According to factor (ii), the ability of the stem vowel to regularly alternate could have elicited an N400 effect. Twelve irregular verbs used in this study employed a regular stem vowel alternation to generate the 2nd and 3rd person singular forms in the present tense: *waschen* (wash) – *er wäscht* (he washes), *lesen* (read) – *er liest* (he reads). If both irregular allomorphs shared a lexical entry, the ability of the stem vowel to alternate could interfere with the processing of a bare stem. The deviant input could have triggered the repair process within the lexical entry with the subsequent semantic composition process (Koester et al., 2007). We subdivided the stimulus materials into two groups containing the verbs with vowel change (12 verbs) and those without vowel change (36 verbs). The repeated measures ANOVAs revealed no significant interactions with the stem vowel or main effects thereof within the experiments or between them[7]. Therefore, the assumption that the ability of a stem vowel to alternate could be marked was refuted.

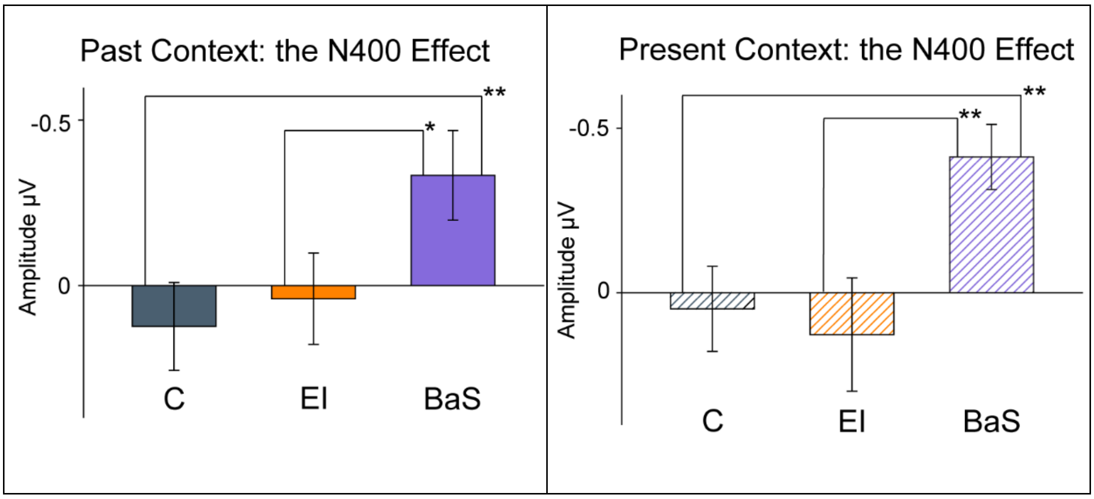

Figure 24. Strong Verbs: the N400 Effect

*Bar diagrams of mean amplitude values in the latency range and topography (Cz CPz Pz) of the N400 component. Standard error of mean is plotted in both directions. The left part of the plot illustrates mean amplitude values of the C, EI and BaS conditions in the Past Context experiment. The right part of the graph demonstrates mean amplitude values of the C, EI and BaS conditions in the Present Context experiment. Significant differences are marked with asterisks (** = p<0.01, * = p<0.05).*

The German imperative in the 2nd person singular is generated from the present stem morpheme in the 2nd person singular with the optional suffix {-e}: *gehen* (to go) – *geh!* (go!). If a verb undergoes umlaut to form the 2nd person singular, the imperative form of this verb is generated without umlaut. With the exception of six verbs employing the change of height to generate the 2nd and 3rd person singular (*lies!* – read!), the BaS items corresponded to the imperative form. Considering that imperative constructions in singular do not require a

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[7] The repeated measures ANOVA revealed a significant main effect of *Stem*: F(1.94,73.94)=6.3, p<0.01. The other main effects and interactions failed to reach significance: *Vowel* F(1,38)=0.0; *Vowel X Tense* F(1,38)=1.88; *Stem X Tense* F(1.94,73.94)=0.89; Vowel X Stem X Tense F(1.8,68.79)=0.61.

subject, the sentences used in the present study could be initially interpreted as an imperative. The clash of an imperative verb form with the presence of a subject immediately following the verb could have triggered the N400 observed in the present study. The fact that only BaS irregular items elicited an N400 effect while BaS regular condition evoked a LAN suggested that the imperative form of a strong verb be semantically marked in the mental lexicon entry of a strong verb.

Table 18. Summary of results of the Past & Present Context experiments

The results of the Past (second column) and Present (third column) Context experiments are subdivided into two parts: the first part (grey background color) illustrates the effects elicited by the strong verbs; the second part (against the white background) provides the effects evoked by the weak verbs.

	Past Context experiment	**Present Context experiment**
C irregular	ging _______	geh-t ______
EI	*ging-te LAN	*ging-t ______
BaS irregular	*geh N400	*geh N400
C regular	dreh-te _______	dreh-t ______
BaS regular	*dreh LAN	*dreh LAN

The working hypothesis of the second part of this thesis was that irregular stem allomorphs should be represented separately within a lexical entry based on underspecification of morphological features. We argued that the separate representation of the past and present tense allomorphs of strong verbs could be proven provided they triggered differential error-detection mechanisms. Another factor supporting our hypothesis would be the difference in the processing of the violated weak and strong verbs. The summary of the results is demonstrated in Table 18. The results of the Past and Present Context experiments provided evidence in favor of our hypothesis. The BaS conditions though structurally very similar triggered differential brain responses both topographically and temporally if elicited by irregular vs. regular items (Table 18, rows 4 & 6). The EI violation condition was also spatially and temporally significantly different from the rest of the violation conditions (Table 18, row 3). Based on the results of the present series of studies, we maintain that irregular stem allomorphs should be represented by separate mental representations within a mental lexicon entry.

Furthermore, we posit that only past tense allomorphs should be marked for tense.

A unified representation of irregular stem allomorphs would require a number of surface form templates [8] and a number of paradigmatic morphosyntactic rules associated with these surface forms. Considering the maintenance cost of a unified mental representation, lexical retrieval would take much time and effort. However, the previous research as well as research reported in the present thesis did not show delayed responses in the retrieval or in the processing of strong verbs as compared to weak ones (Fleischhauer, 2013; Marcus et al., 1995; Pinker, 1999; Pinker & Ullman, 2002). On the contrary, the latency of the LAN component elicited by the BaS regular items, viz. by the bare stems of weak verbs, was significantly delayed compared to the LAN effect elicited by the EI items in the Past Context experiment. The difference in the timing of the reported effects as well as in the topographic distribution thereof provided evidence supporting separate representation of irregular stem allomorphs. Separate representations within a lexical entry would simplify the lexical retrieval procedure and decrease the maintenance cost. The separate manner of representation would provide access to the specific paradigm structures accelerating the retrieval or the generation of the necessary inflectional form. Additionally, a hierarchical organization of the lexical entry could capture marked forms, viz. the past tense, the imperative, and the subjunctive. Moreover, the regular vowel alternations involved in the paradigm of a given allomorph could be captured within the separate representations.

We put forth a putative model for the mental representation of irregular stem allomorphs illustrated in Figure 25. The upper part of the graph shows a mental representation of a basic/present tense allomorph, while the lower part of the graph demonstrates a mental representation of a past tense allomorph marked for tense. The metal lexicon entry is thus organized hierarchically with the underspecified stem at the upper level and the marked stem at the lower level (Clahsen et al., 2001; Wunderlich, 1996; Wunderlich & Fabri, 1995).The upper part of the graph demonstrates the lexical retrieval process of the verb *wasche* (I wash). The DORSAL feature extracted from the acoustic signal activates the dorsal node at the level of morphophonological surface rules. The subsequent extraction of the suffix {-e} characteristics from the acoustic signal activates the

[8] Here, we cannot speak about morphophonological surface form rules as the ablaut patterns are impossible to generalize into a single rule.

corresponding node at the level of morphosyntactic rules. The resulting form is the 1st person singular. The lexical retrieval process of the verb *wusch* (I/he washed) is exemplified by means of purple nodes in the lower part of the figure. The strong verb *waschen* (to wash) requires umlaut to generate *Konjunktiv II* in the past tense and the 2nd and 3rd person singular forms in the present tense. On extracting the DORSAL feature from the acoustic signal, this feature gets activated at the level of morphophonological surface form rules. The zero-suffixed form of the 1st and 3rd person singular gets activated at the level of the morphosyntactic rules via the bidirectional node connecting two rule levels. The choice of the verb to demonstrate the function of the model was not random. This example provided the opportunity to capture (i) the representation of the irregular nature of the past and present tense allomorphs and (ii) the ability of the stem vowel of these allomorphs to regularly alternate according to the demands of the verbal paradigm.

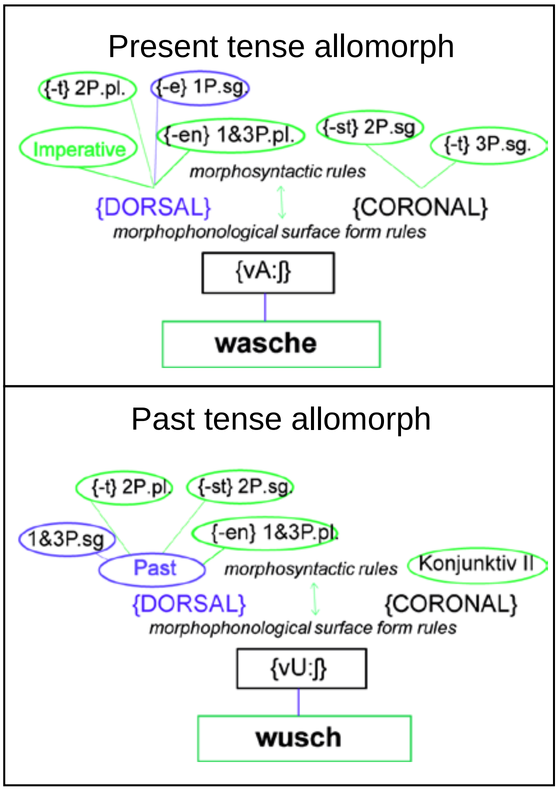

Figure 25. A speculative model for representation of irregular stem allomorphs

The upper part of the graph illustrates a mental representation of the basic/present tense allomorph wasch (wash). The lower part of the graph demonstrates a mental representation of the past tense allomorph wusch (washed). The graph reflects the hierarchy of the mental lexicon entry of the strong verb waschen (to wash): the underspecified entry is at the top, the marked entry is at the lower layer. The retrieval of the words wusch (I/he washed) and wasche (I wash) is shown by means of the purple color. Note that the imperative is marked in the present tense entry.

Figure 26 exemplifies the processing of the violation conditions employed with the strong verbs. Part A of the graph demonstrates the repair process of the EI items in the Past context experiment. According to the requirements of the temporal context and the subject in the 3rd person singular, the mental lexicon activates the entries for the past tense allomorphs. The allomorphs with the alternating stem vowels additionally activate the DORSAL feature at the level of morphophonological rules. The incoming signal is mapped onto the pre-activated DORSAL feature in the mental lexicon entry. The following acoustic input with the characteristics of the inflectional suffix {-te} cannot be matched to the inflectional forms associated with the past tense stem morpheme on the one hand, and on the other, it results in the violation of the subject-verb agreement. Both factors taken together, the EI violation in the Past context experiment evokes a LAN effect. The lack of the LAN effect for the EI condition in the Present context experiment is explained by the pre-activation of the suffix {-t} in the paradigms of strong and weak verbs. On extracting the features of the suffix {-t} from the auditory input, the suffix is successfully mapped onto the pre-activated inflection. Though temporally deviant, the past tense allomorphs carry the necessary inflectional information that formally meets the requirements of the syntactic context.

The explanation of the N400 elicited by the BaS irregular items is possible if we assume (i) the underspecification of the basic/present tense allomorphs for tense and (ii) the markedness of the imperative mood within the mental lexicon entry of a strong verb.

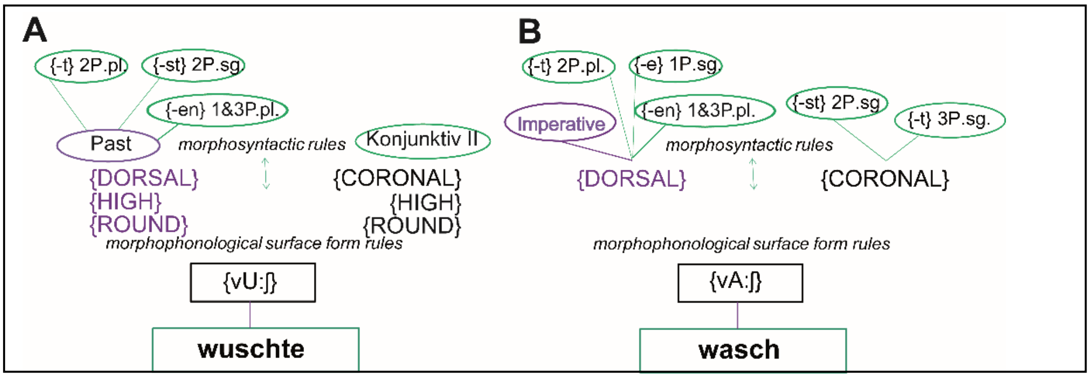

Figure 26. Results for the BaS irregular and EI conditions in the framework of the proposed model

*Part A illustrates the processing of the EI violation condition, e.g. *wuschte (washed-ed). The activation of the correct tense allomorph is shown with the purple nodes. The failure to find a corresponding suffix at the level of morphosyntactic rules results in the LAN effect. Part B demonstrates the N400 effect elicited by the BaS condition, e.g. *wasch (wash). The activation of the marked imperative blocks the morphosyntactic processing.*

The comparison of the BaS items revealed that only BaS irregular condition caused a semantic anomaly. We argued that the semantically deviant processing could be triggered by the underspecification of the basic stem morpheme and by the imperative interpretation of the BaS irregular stimuli.

Considering the lack of N400 effects in the BaS regular condition, we suggested that the imperative be semantically marked within the lexical entry of a strong verb. The factors in favor of the semantic markedness of the imperative would be (i) the change of the grammatical mood from real (indicative) to unreal (imperative), (ii) the command nature that requires a response or an action (Austin, 1962; Searle, 1969), and (iii) specific syntax. The markedness of the imperative node would block the activation of the inflectional nodes thus inhibiting the indicative interpretation of the syntactic structure (part B of Figure 26).

The imperative interpretation of the BaS items might be considered a confound, yet we regard it as an additional but valuable finding. To structurally separate the sources of the indicative vs. imperative mood, further research with implementation of the imaging techniques, viz. MEG or fMRI, is necessary. An option to dispose of the imperative confound could be the implementation of subordinate clauses. The structure of the German subordinate clause requires the finite verb in the final position. Thus, the violation conditions could be investigated sentence-finally with a biasing semantic, syntactic and pragmatic context.

Another proposition could be to conduct visual experiments with the same stimulus materials. The purpose of this design would be an attempt to dispose of the latency shifts of the LAN effect elicited by EI and BaS regular items. The visual modality, though secondary in acquisition, offers whole-word presentation, which is impossible in the auditory modality. The linear character of the auditory input suggests that a stimulus be perceived segment after segment as the signal unfolds. Both modalities have merits and drawbacks, the merit of the auditory modality for the present series of studies being the possibility of investigating the role of phonological structure in morphological processes. Having established the difference in the phonological processing of strong and weak verbs, the next step could be the exploration of the nature of the latency shifts with the whole-word presentation. If the difference in the latency of LAN effects perseveres it would mean that the processing cost involved in the calculation of the weak verb structure does not depend on modality. Rather it would provide additional evidence for the functional differentiation of the regular and irregular inflectional forms.

The differential processing of strong and weak verbs reported in the present series of studies provided evidence for differential representation of weak and strong verbs. While weak verbs are represented by a single underlying morpheme, irregular allomorphs of strong verbs have separate representations listed within a unified lexical entry hierarchically organized on the basis of underspecification (Lahiri & Reetz, 2010; Plank & Lahiri, 2015; Scharinger et al., 2009). The present results demonstrated that regular inflectional forms are indeed subject to morphological decomposition. Taken together, the results of the present series of studies validated our hypothesis that irregular stem allomorphs should be represented separately and only past tense allomorphs should be marked for the tense feature.

5 General Discussion

The present thesis was focused on the mental representation and processing of phonological stem variants of morphologically complex words. To investigate this topic, we used two word formation processes that employed stem vowel alternation: (i) derivation, involving TSS in English and umlaut in German, and (ii) past tense formation of German strong verbs, involving ablaut. The ERP technique was used to track the processing stages of violated vs. non-violated items in both word formation processes. The difference in the processing stages indexed by topographically and functionally distinct brain responses was associated with a differential manner of representation of phonological stem variants employed in (i) vs. (ii).

5.1 Representation of Regular Stem Allomorphy

The first part of the dissertation investigated derivation employing regular stem allomorphy in English and German. We conducted a series of word list and sentence context experiments with British and German subjects. The word list experiments investigated the processing of complex words and nonwords in isolation with a superimposed linguistic task (lexical decision task) or with a memory task. The sentence context experiments explored lexical retrieval and processing of complex words and nonwords in a biasing context. The series of studies was finalized with a pilot experiment conducted with low-proficient L2 learners of German. The pilot experiment investigated the acquisition of a morphosyntactic rule in line with Ullman's declarative/procedural model (Ullman, 2001a, 2001b, 2004). We planned to observe the transition from the reliance on the declarative memory in the application of a morphosyntactic rule to the reliance on the procedural memory.

The objective of the word list experiments was the determination of how regular stem allomorphs were listed in the English and German mental lexicons. We hypothesized that regular phonological stem variants shared a lexical entry. To test this hypothesis, we studied the error-detection mechanisms triggered by three violation conditions, viz. **ser[i:]nity/*Stärkung* (RD), **ser[aɪ]nity/*Sturkung* (UD), and **seromity/*Stögung* (NC), in comparison with the real word condition *serenity/ Stärkung* (W). We argued that a unified representation of regular stem allomorphs would allow the structural repair of the RD items that were made up by omitting TSS and umlaut. Therefore, the error-detection mechanisms triggered by the RD items should differ from those evoked by the complete/irreparable nonword conditions. Separate listing of the regular stem allomorphs would result in a similar brain response pattern for all violation conditions due to the impossibility of structural repair. The results of the word list experiments showed that RD items consistently elicited violation-related brain responses qualitatively distinct from the other conditions. Thus, the lexical decision task experiments in both groups revealed a graded N400 effect of the type W<RD<UD=NC. The violation of TSS in the British memory task experiment evoked a PMN effect in the early processing stages and LPN in the late processing stages. The violation of umlaut in the German memory task experiment elicited a LAN effect. The result pattern of the word list experiments presented supporting evidence for our hypothesis that regular stem allomorphs share a mental lexicon entry. The unique status of the RD items was based on the possibility of structural repair of these nonwords. We argued that the access to the shared representation enabled structural repair of the morphophonological or morphosyntactic rule violations. We proposed that a unified representation of the regular stem allomorphs should consist of an abstract morpheme with a set of morphophonological surface form rules and morphosyntactic combinatory rules

The structural repair process as revealed by the attenuated N400 effect, on the one hand, and PMN/LPN and LAN, on the other, demonstrated that transparent morphological relations were represented in the mental lexicon. This finding contradicted the proposition of the Full Listing Hypothesis (Butterworth, 1983) that relations between words and word forms should be represented by means of a fast associative network. Following the Full Listing Hypothesis, the phonological/orthographic overlap between the existing words and the RD and UD conditions would have elicited similar brain responses. Without the storage of morphological information it would have been impossible to assess the quality of deviation of the RD and UD items from the stored standard. Therefore, both – morphosyntactic and purely phonological – violation conditions would have been qualified as nonwords evoking similar brain responses. The present pattern of results demonstrated that full listing did not hold for the semantically and morphologically transparent complex words. Our findings also contradicted the Parallel-distributed processing models (Rumelhart & McClelland, 1986; Seidenberg & Gonnerman, 2000). We demonstrated that morphological relationship influenced the lexical retrieval process as revealed by the difference between reparable and irreparable conditions. In contrast, the PDP models assumed that the relationship between morphemes did not influence further processing steps.

In the present thesis we adopted the view that semantically and morphologically transparent complex words were subject to obligatory morphological decomposition (Taft & Forster, 1975, 1976). Contrary to the Full Listing Hypothesis and the PDP, the model by Taft and Forster (1975, 1976) required prelexical decomposition of all morphologically complex words. According to this model, the detection of an affix in an affixed word helps to identify the stem morpheme. Although the present results were in favor of the affix stripping, they were insufficient to provide supporting evidence for the full morphological decomposition regardless of the semantic transparency as proposed by Taft and Forster (1975, 1976).

According to the Parallel Dual-Route model proposed by Schreuder and Baayen (1995), high-frequency words were accessed directly as whole units, while low-frequency words were recognized via their morphemes. The authors claimed that morphological decomposition decelerated lexical retrieval and was resorted to only in case of novel or unknown words. The W condition of the present series of studies employed complex words with relatively high frequency of occurrence, while the nonword items had a zero frequency of occurrence. Nevertheless, we did not observe any latency shifts indicative of the acceleration or deceleration of lexical retrieval. Therefore, the present pattern of results could not be regarded as supporting the Parallel Dual-Route model. Dual-Mechanism models (Pinker, 1999; Clahsen, 1999; Friederici et al, 1993; Marslen-Wilson & Tyler, 1997, 1998, 2003, Ullman, 2001, Pinker and Ullman, 2002) posit that the mechanism of lexical access depends on the type of morphological composition. Regular inflection forms were subject to morphological decomposition, while irregular inflection forms and derived words were subject to full listing. The present pattern of results could support Dual-Mechanism models if the notion of regularity were extended to regular phonological alternations.

The present pattern of results supported the accounts by Marslen-Wilson et al. (1994), Wiese (1996) and Scharinger et al. (2009, 2010) having demonstrated that regular stem allomorphs should be represented by a single abstract morpheme with a set of morphophonological and morphosyntactic rules. Marslen-Wilson et al. (1994) and Scharinger et al. (2010) regarded the unified representation as based on the stem vowel underspecification. In contrast, Wiese (1996) considered umlaut as a phonological rule that was triggered only if a stem morpheme had a floating feature [FRONT]. Although we did not intend to validate

Marslen-Wilson et al.’s (1994), Wiese’s (1996) and Scharinger et al.’s (2009, 2010) accounts, the present results showed that regular stem vowel alternations should be governed by the intrinsic ability of the stem vowel to alternate.

Summarized, the results of the first part of the present thesis provided evidence for (i) the obligatory morphological decomposition of semantically transparent complex words (Taft & Forster, 1975, 1976; Taft & Hambly, 1985; Taft & Kougious, 2004); (ii) a unified representation of regular stem allomorphs; (iii) a similar representation of regular stem allomorphs in English and German (W.D. Marslen-Wilson et al., 1994; Scharinger, 2009; Scharinger et al., 2010). Though we demonstrated that semantically transparent complex words were morphologically segmented, we did not claim that all word forms regardless of their semantic and morphological transparency are stored in a decomposed manner.

5.2 Processing of Regular Stem Allomorphy in English and German

The lexical decision task experiments provided evidence for similar processing of regular stem allomorphs in English and German. The results of the memory task experiments, however, demonstrated differential violation-related brain responses in the nationality groups. While, during the lexical retrieval stage, the German group showed a LAN effect for the RD items, the British group failed to show any violation effects in this time window. We argued that the LAN effect in the German group and the lack thereof in the British group was triggered by the depth of derivation. Thus, the TSS rule employed in the present series of studies accompanied the attachment of the suffix {-ity}. Umlaut, on the other hand, was indicative of the first step of derivation that preceded the generation of a deverbal noun. In accord with our speculative model (Figure 16), the omission of TSS resulted in the violation of the morphophonological rules. The omission of umlaut, on the other hand, resulted in the violation of both – morphophonological and morphosyntactic – rules. The depth of derivation, viz. one step for trisyllabic shortened {-ity} nouns and two steps for umlauted deverbal nouns, was therefore indexed by differential error-detection mechanisms during the lexical retrieval stage.

The encoding differences between the languages were observed during the post-retrieval stage. Thus, a significant LPN effect was revealed for the RD items in the British group but not in the German group. German spelling being more transparent than British, the German RD items had to be memorized as a combination of an adjectival stem and the suffix {-ung}. In contrast, the British RD nonwords required the memorization of the surface structure of the item and the computation of the orthographic rendering of this structure: though phonetically different, the W and RD stem allomorphs had the same orthographic code. The maintenance of the RD items for the task performance was therefore influenced by the orthographic transparency.

Without a superimposed linguistic task, the processing of regular stem allomorphs in English and German was influenced by two factors: (i) the depth of derivation reflected in the error-detection mechanisms during the lexical retrieval stage and (ii) the phonological transparency of an orthographic form indexed by the LPN component during the post-retrieval stage.

5.3 Representation of Irregular Stem Allomorphy

The *second* part of the present thesis investigated the representation and processing of irregular stem allomorphy employed in the past tense formation of German strong verbs. We were also interested in finding out whether one tense form was prioritized of over the other. We hypothesized that irregular stem allomorphs should be stored separately due to the unpredictability of the stem vowel alternation. Furthermore, we argued that the mental lexicon entry of a strong verb should be organized hierarchically based on the underspecification of morphological features. Thus, the basic/ present tense stem allomorph underspecified for tense should be placed at the upper level. The past tense allomorph should be placed at the lower subnode inheriting the verbal features from the basic stem and adding a marked feature [+PRET]. We used German strong verbs because they generate past tense and past participle forms by means of a non-productive and unpredictable stem vowel alternation, viz. ablaut. The ablaut patterns could not be generalized into a single morphophonological rule. Therefore, the products of ablaut, i.e. the present tense, past tense and past participle forms of the strong verbs, should be represented separately. We tested our hypothesis in two ERP experiments conducted in the past and present tense context respectively. The temporal context was expected to activate the corresponding tense paradigms for strong and weak verbs. We compared the deviant processing of the violated strong verbs, i.e. excessively inflected (EI) items and bare stem irregular items (BaS irregular), to the normal processing of these verbs within and between the temporal contexts. To control for the processing of regular forms, we introduced the suffixation violation of the weak verbs, i.e. bare stem regular items (BaS regular). We argued that significant difference between the processing of the violated strong and weak verbs should be indicative of their differential representation.

The violated regular and irregular verbs elicited a differential brain response pattern in the Past Context experiment. The excessively inflected (EI) items (**wusch-te*) elicited a LAN effect, while the bare stem (BaS) irregular items (**wasch*) induced an N400. The BaS regular items (**tanz*) elicited a delayed LAN effect. The results of the Past Context experiment supported our hypothesis. Thus, the violation of the morphosyntactic rules – the subject-verb agreement in the EI condition and the omitted suffixation in the BaS regular items – elicited a LAN effect. The BaS irregular items, on the other hand, evoked an N400 reflecting difficulties in the semantic processing. The morphosyntactic violation effect elicited by weak verbs and the semantic violation effect evoked by the bare stem strong verbs were replicated in the present tense. Thus, the Present Context experiment revealed a LAN effect for the BaS regular items and an N400 for the BaS irregular ones.

We hypothesized that irregular stem allomorphs should be represented separately. We argued that separate representation of the past and present tense allomorphs of German strong verbs could be proven by differential error-detection mechanisms triggered by these items. Furthermore, distinct spatial-temporal violation related brain responses were expected to be indicative of morphological underspecification. We also expected the difference in the processing of the violated weak and strong verbs to be an additional factor supporting our hypothesis. The pertinacity of the LAN effect elicited by BaS regular items and the N400 effect evoked by BaS irregular items in the Past and Present Context experiments provided evidence in favor of our hypothesis. The BaS conditions were structurally identical. Yet they triggered topographically and temporally different brain responses if elicited by irregular (strong verbs) vs. regular (weak verbs) items. The difference in the brain responses to these conditions was caused by the underspecification for tense of the basic allomorphs of strong verbs, which was not the case in the weak verb condition. The EI violation condition was also spatially and temporally significantly different from the rest of the violation conditions. The difference in the topographic distribution and the latency of the reported effects provided supporting evidence for separate and underspecified representation of irregular stem allomorphs. Such manner of representation would (i) simplify the lexical retrieval process, (ii) decrease the maintenance cost, (iii) provide access to the specific paradigm structures. Additionally, separate hierarchically organized mental representations could capture not only marked forms as preterit, imperative, Konjunktiv II, but also the regular vowel alternations involved in the paradigm of a strong verb allomorph.

The topographic distribution and the latency of the N400 effects elicited by the BaS irregular items in both experiments could also point to the semantic markedness of this construction regardless of a given temporal context. We put forth the idea that this construction could be interpreted by the subjects as the imperative mood. Considering the pertinacity of the effect, the imperative interpretation of the BaS irregular items was independent of the temporal context. We proposed to conduct further research with implementation of the imaging techniques, viz. MEG or fMRI, to structurally separate the sources of the indicative vs. imperative mood.

The differential processing of violated strong and weak verbs refuted the Full Listing Hypothesis (Butterworth, 1983). Similar storage manner implies similar processing stages and error-detection mechanisms for words sharing a grammatical category. However, the present result pattern revealed distinct error-detection mechanisms employed in the processing of violated weak and strong verbs, indicating differential representation and processing thereof. Considering the pertinacity of the N400 effect in both temporal contexts and the presence of the LAN effect only in the past context, the influence of phonological associations proposed by the PDP models (Rumelhart & McClelland, 1986; Seidenberg & Gonnerman, 2000) could also be refuted. The brain responses elicited by the EI and the BaS regular conditions presented evidence in favor of the obligatory morphological decomposition model by Taft and Forster (1975, 1976). The difference in the latency of the LAN effects elicited by the EI and the BaS regular items could be also explained within the framework of Dual-Mechanism models (Pinker, 1999; Clahsen, 1999; Friederici et al, 1993; Marslen-Wilson & Tyler, 1997, 1998, 2003, Ullman, 2001, Pinker and Ullman, 2002). Dual-Mechanism models posit that regular inflection forms are subject to morphological decomposition, and they undergo the full parsing procedure, hence the delayed LAN for the BaS regular items. According to this model, irregular inflection forms and derived words are stored as full units, and therefore they are subject to full listing. However, German strong verbs combine ablaut patterns for the generation of, for example, past tense forms, on the one hand, and the attachment of inflectional suffixes for the generation of person and number forms, on the other. Therefore, German strong verbs could have a hybrid status as preterit forms are considered by the Dual-Mechanism models as fully decomposable, while past participles of these verbs are regarded as subject to full-listing (Pinker, 1999; Clahsen, 1999; Friederici et al, 1993; Marslen-Wilson & Tyler, 1997, 1998, 2003, Ullman, 2001, Pinker and Ullman, 2002; Clahsen et al., 2001). As we did not investigate the processing and representation of past participle forms, we cannot provide experimental evidence fully supporting the Dual-Mechanism models. Taken together, the results of the second part of the thesis validated our hypothesis that irregular stem allomorphs are represented separately within a lexical entry with the basic morpheme being underspecified for tense.

5.4 Conclusion

This thesis presented results from several ERP studies that focused on the representation and processing of phonological stem variants of complex words.

In the first part of the dissertation, we presented research on the representation and processing of regular stem allomorphy involved in derivation. More specifically, we investigated the cases of TSS in English and umlaut in German. The results of this series of studies provided experimental evidence in favor of unified representation of regular stem allomorphs. Experiments 1-4 demonstrated that allomorph misapplication in derivation could be structurally repaired as revealed in the attenuated N400 effect and LAN/LPN for RD items. We argued that the structural repair process of the RD items proceeded via access to the unified lexical entry. Experiments 5-6, however, showed that the character of deviation from the standard, viz. morphosyntactic vs. purely phonological, did not matter, as long as the deviant items were presented in a biasing context and had a significant overlap with the expected words. The pilot study (Experiment 7) showed that low-proficiency L2 learners of German relied on the declarative memory in the acquisition of morphosyntactic rules.

In the second part of the thesis, we analyzed the representation and processing of irregular stem allomorphy focusing on German strong verbs. Experiment 8 investigated the processing of excessively inflected and bare stem strong verbs in contrast to bare stem weak verbs in the past tense context.

Experiment 9 analyzed the processing of the same conditions in the present tense context. The results of these studies revealed differential representation of the weak and strong verbs. Furthermore, excessively inflected past tense allomorphs of strong verbs elicited violation effects only in the Past Context experiment. The bare stem strong verb condition, on the other hand, systematically triggered similar error-detection mechanisms independent of the temporal context. We argued that irregular stem allomorphs of German strong verbs were represented separately. Moreover, the bare present tense allomorphs were underspecified for tense, as reflected in the N400 effect. We also put forth the idea that bare stems could be perceived as the imperative mood. We suggested that the imperative mood should be semantically marked within the mental lexicon entry of the present tense allomorphs of strong verbs.

Based on the reported series of studies, two highly speculative models of representation of complex words were put forward. The first model (Figure 16) depicted a unified lexical entry for regular stem allomorphs that included a layer of morphophonological rules defining the surface form of an allomorph and a layer of morphosyntactic combinatory rules associated with a given surface form. The second model (Figure 25) demonstrated representation of irregular stem allomorphy. Thus, each irregular allomorph of a strong verb should be represented separately on different subnodes. The basic allomorph carrying only verbal characteristics and underspecified for tense should be placed at the top. The deeper subnodes should inherit the features from the upper nodes adding marked features. Therefore, the past tense allomorph should inherit the verbal characteristics from the basic stem and add the feature [+PRET]. Such manner of representation could capture regular stem vowel alternations that irregular stem allomorphs undergo within their paradigms (Figure 26). Furthermore, a present tense allomorph of a strong verb could contain a marked node for the imperative mood.

The findings of the present dissertation suggested directions for future research on the representation and processing of complex words. Thus, the notion of regularity should be revised and possibly extended to the domain of derivational morphology. A hybrid status of German strong verbs should be considered and accounted for by further studies. To validate the results of the present studies for a broader variety of regular processes, different derivational paradigms should be tested in both English and German. For example, the cases of immediate derivation involving a regular phonological change, such as *tone/tonic* and *stark/Stärke* (strong/strength), could be compared. It would also be interesting to replicate the reported findings in the visual modality in order to control for the acoustically vs. cognitively triggered latency shifts. Further research is also necessary to explore the influence of context, both structural and semantic, on the processing of deviant input. We hope that the research reported in this thesis will provide a better understanding of the mental representation of language and of the mechanisms underlying natural speech processing.

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Appendices

Appendix A: Stimuli used in Experiments 1, 2, 6

W – Word: Derived stem {C***V***C}+{-ity}	**RD** – related derived: Existing stem illegal in the combination {C$\boldsymbol{V_1}$C}+{-ity}	**UD** – unrelated derived: Non-existing stem {C$\boldsymbol{V_2}$C}+{-ity}	**NC** – nonce com-plete: Non-existing stem {C$\boldsymbol{V_3}$$\mathbf{C_1}$}+{-ity}
austerity	*aust[iɛ]rity	*aust[ai]rity	*auspority
brevity	*br[i:]vity	*br[u:]vity	*broshity
chastity	*ch[ei]stity	*ch[ou]stity	*chevity
clarity	*cl[iɛ]rity	*cl[ai]rity	*clowrity
concavity	*conc[ei]vity	*conc[i:]vity	*condubity
divinity	*div[ai]nity	*div[ei]nity	*divudity
extremity	*extr[i:]mity	*extr[u:]mity	*explomity
gravity	*gr[ei]vity	*gr[i:]vity	*grudity
humanity	*hum[ei]nity	*hum[ai]nity	*hulonity
inanity	*in[ei]nity	*in[i:]nity	*inokity
insanity	*ins[ei]nity	*ins[ou]nity	*insupity
insincerity	*insinc[iɛ]rity	*insinc[u:]rity	*insantority
mediocrity	*medi[ou]crity	*medi[ei]crity	*mediucity
obscenity	*obsc[i:]nity	*obsc[u:]nity	*obrentity
opacity	*op[ei]city	*op[i:]city	*opudity
parity	*p[a:]rity	*p[ai]rity	*peshity
profanity	*prof[ei]nity	*prof[i:]nity	*progunity
profundity	*prof[au]ndity	*prof[i:]ndity	*prefendity
sanity	*s[ei]nity	*s[ou]nity	*saibity
serenity	*ser[i:]nity	*ser[ai]nity	*seromity
severity	*sev[iɛ]rity	*sev[ai]rity	*sesherity
sincerity	*sinc[iɛ]rity	*sinc[o:]rity	*simpority
vanity	*v[ei]nity	*v[i:]nity	*vabity

Appendix B: Stimuli used in Experiments 3-5, 7

W – Word: Derived stem {C***V***C}+{-ung}	**RD** – related derived: Existing stem illegal in the combination {C***V₁***C}+{-ung}	**UD** – unrelated derived: Non-existing stem {C***V₂***C}+{-ung}	**NC** – nonce com-plete: Non-existing stem {C***V₃C₁***}+{-ung}
Änderung	*Anderung	*Onderung	*Änkurung
Bräunung	*Braunung	*Brünung	*Brastung
Fälschung	*Falschung	*Filschung	*Fänkung
Glättung	*Glattung	*Glottung	*Glöppung
Härtung	*Hartung	*Hirtung	*Hurmung
Klärung	*Klarung	*Klörung	*Klochung
Kränkung	*Krankung	*Krinkung	*Krolkung
Krümmung	*Krummumg	*Krämmung	*Krolnung
Kürzung	*Kurzung	*Karzung	*Kilzung
Lähmung	*Lahmung	*Lohmung	*Lurung
Näherung	*Naherung	*Noherung	*Noserung
Öffnung	*Offnung	*Eiffnung	*Öpplung
Rötung	*Rotung	*Rietung	*Rontung
Säuberung	*Sauberung	*Sehberung	*Süperung
Schärfung	*Scharfung	*Schurfung	*Schurchung
Schmälerung	*Scmalerung	*Schmielerung	*Schnäferung
Schwächung	*Schwachung	*Schwochung	*Schwickung
Schwärzung	*Schwarzung	*Schwirzung	*Schwesung
Stärkung	*Starkung	*Sturkung	*Stögung
Tötung	*Totung	*Tutung	*Tisung
Zähmung	*Zahmung	*Zaimung	*Zaulung

Appendix C: Stimuli used in Experiment 8

C – control: The Past form of a strong verb in 3rd Pers. Sg.: {Past}	**EI** – excessive inflection: The Past form of a strong verb in 3rd Pers. Sg. and the suffix of the Past 3rd Pers. Sg.: {Past}+{-te}	**BaS** – basic stem: The Present form of a strong verb without affixes: {Present}
ging Gestern ***ging*** er zur Arbeit zu Fuß. Yesterday – ***went*** – he to work on foot.	*gingte Gestern ***gingte*** er zur Arbeit zu Fuß. Yesterday – ***went(ed)*** – he to work on foot.	*geh Gestern ***geh*** er zur Arbeit zu Fuß. Yesterday – ***go*** – he to work on foot.
biss	biss-te	beiß
barg	barg-te	berg
band	bande-te	bind
drang	drang-te	dring
aß	aß-te	ess
fing	fing-te	fang
floh	floh-te	flieh
floss	floss-te	fließ
fraß	fraß-te	fress
glich	glich-te	gleich
glitt	glitte-te	gleit
hing	hing-te	häng
half	half-te	helf
klang	klang-te	kling
lud	lude-te	lad
litt	litte-te	leid
las	las-te	les
mied	miede-te	meid
maß	maß-te	mess
pfiff	pfiff-te	pfeif
riet	riete-te	rat
rieb	rieb-te	reib
riss	riss-te	reiß
ritt	ritte-te	reit
roch	roch-te	riech
rang	rang-te	ring
schuf	schuf-te	schaff
schob	schob-te	schieb
schlief	schlief-te	schlaf
schnitt	schnitte-te	schneid
schrie	schrie-te	schrei
schwieg	schwieg-te	schweig
schwamm	schwamm-te	schwimm
sang	sang-te	sing

C – control: The Past form of a strong verb in 3rd Pers. Sg.: {Past}	**EI** – excessive inflection: The Past form of a strong verb in 3rd Pers. Sg. and the suffix of the Past 3rd Pers. Sg.: {Past}+{-te}	**BaS** – basic stem: The Present form of a strong verb without affixes: {Present}
ging Gestern ***ging*** er zur Arbeit zu Fuß. Yesterday – ***went*** – he to work on foot.	*gingte Gestern ***gingte*** er zur Arbeit zu Fuß. Yesterday – ***went(ed)*** – he to work on foot.	*geh Gestern ***geh*** er zur Arbeit zu Fuß. Yesterday – ***go*** – he to work on foot.
stahl	stahl-te	stehl
strich	strich-te	streich
stritt	stritte-te	streit
trank	trank-te	trink
wusch	wusch-te	wasch
wich	wich-te	weich
wog	wog-te	wieg
zwang	zwang-te	zwing

Appendix D: Stimuli used in Experiment 9

C – control: The Present form of a strong verb in 3rd Pers. Sg.: {Present}+{-t}	**EI** – excessive inflection: The Past form of a strong verb in 3rd Pers. Sg. and the suffix of the Present 3rd Pers. Sg.: {Past}+{-t}	**BaS** – basic stem: The Present form of a strong verb without affixes: {Present}
geht Normalerweise ***geht*** er zur Arbeit zu Fuß. Normally – ***goes*** – he to work on foot.	*gingt Normalerweise ***gingt*** er zur Arbeit zu Fuß. Normally – ***went(s)*** – he to work on foot.	*geh Normalerweise ***geh*** er zur Arbeit zu Fuß. Normally – ***go*** – he to work on foot.
beißt	biss-t	beiß
birgt	barg-t	berg
bindet	bande-t	bind
dringt	drang-t	dring
isst	aß-t	ess
fängt	fing-t	fang
flieht	floh-t	flieh
fließt	floss-t	fließ
frisst	fraß-t	fress
gleicht	glich-t	gleich
gleitet	glitte-t	gleit
hängt	hing-t	häng
hilft	half-t	helf
klingt	klang-t	kling
lädt	lude-t	lad
leidet	litte-t	leid
liest	las-t	les
meidet	miede-t	meid
misst	maß-t	mess
pfeift	pfiff-t	pfeif
rät	riete-t	rat
reibt	rieb-t	reib
reißt	riss-t	reiß
reitet	ritte-t	reit
riech	roch-t	riech
ringt	rang-t	ring
schafft	schuf-t	schaff
schiebt	schob-t	schieb
schläft	schlief-t	schlaf
schneidet	schnitte-t	schneid
schreit	schrie-t	schrei
schweigt	schwieg-t	schweig
schwimmt	schwamm-t	schwimm
singt	sang-t	sing
stiehlt	stahl-t	stehl

C – control: The Present form of a strong verb in 3rd Pers. Sg.: {Present}+{-t}	**EI** – excessive inflection: The Past form of a strong verb in 3rd Pers. Sg. and the suffix of the Present 3rd Pers. Sg.: {Past}+{-t}	**BaS** – basic stem: The Present form of a strong verb without affixes: {Present}
geht Normalerweise ***geht*** er zur Arbeit zu Fuß. Normally – ***goes*** – he to work on foot.	*gingt Normalerweise ***gingt*** er zur Arbeit zu Fuß. Normally – ***went(s)*** – he to work on foot.	*geh Normalerweise ***geh*** er zur Arbeit zu Fuß. Normally – ***go*** – he to work on foot.
streicht	strich-t	streich
streitet	stritte-t	streit
trinkt	trank-t	trink
wäscht	wusch-t	wasch
weicht	wich-t	weich
wiegt	wog-t	wieg
zwingt	zwang-t	zwing

Appendix E: Stimuli used in Experiments 8 and 9

Past		Present	
C – control: {stem}+{-te}	**BaS** – basic stem: {stem}	**C** – control: {stem}+{-t}	**BaS** – basic stem: {stem}
<u>drehte</u> *Gestern **drehte** der Sender einen Beitrag über den Frauentag.* *Yesterday – **shot** – the channel a report about the Women's day*	*<u>dreh</u> *Gestern **dreh** der Sender einen Beitrag über den Frauentag.* *Yesterday – **shoot** – the channel a report about the Women's day.*	<u>dreht</u> *Seit dem Erdbeben in Japan **dreht** sich die Erde schneller.* *Since the earth-quake in Japan – **rotates** – refl.pron. the Earth faster.*	*<u>dreh</u> *Seit dem Erdbeben in Japan **dreh** sich die Erde schneller.* *Since the earth-quake in Japan – **rotate** – refl.pron. the Earth faster.*
dank-te	dank	dank-t	dank
dräng-te	dräng	dräng-t	dräng
dreh-te	dreh	dreh-t	dreh
droh-te	droh	droh-t	droh
drueck-te	drueck	drueck-t	drueck
ende-te	end	ende-t	end
förder-te	förder	förder-t	förder
fürchte-te	fürcht	fürchte-t	fürcht
gründe-te	gründ	gründe-t	gründ
herrsch-te	herrsch	herrsch-t	herrsch
koste-te	kost	koste-t	kost
lächel-te	lächel	lächel-t	lächel
lieb-te	lieb	lieb-t	lieb
liefer-te	liefer	liefer-t	liefer
nick-te	nick	nick-t	nick
pfleg-te	pfleg	pfleg-t	pfleg
plan-te	plan	plan-t	plan
prüf-te	prüf	prüf-t	prüf
rette-te	rett	rette-t	rett
sammel-te	sammel	sammel-t	sammel
schätz-te	schätz	schätz-t	schätz
schenk-te	schenk	schenk-t	schenk
schick-te	schick	schick-t	schick
schilder-te	schilder	schilder-t	schilder
schüttel-te	schüttel	schüttel-t	schüttel
schütz-te	schütz	schütz-t	schütz
sieg-te	sieg	sieg-t	sieg
sorg-te	sorg	sorg-t	sorg
spür-te	spür	spür-t	spür
stamm-te	stamm	stamm-t	stamm
starte-te	start	starte-t	start
steiger-te	steiger	steiger-t	steiger
stör-te	stör	stör-t	stör

Past		Present	
C – control: {stem}+{-te}	**BaS** – basic stem: {stem}	**C** – control: {stem}+{-t}	**BaS** – basic stem: {stem}
drehte *Gestern **drehte** der Sender einen Beitrag über den Frauentag.* *Yesterday – **shot** – the channel a report about the Women's day*	*dreh *Gestern **dreh** der Sender einen Beitrag über den Frauentag.* *Yesterday – **shoot** – the channel a report about the Women's day.*	dreht *Seit dem Erdbeben in Japan **dreht** sich die Erde schneller.* *Since the earth-quake in Japan – **rotates** – refl.pron. the Earth faster.*	*dreh *Seit dem Erdbeben in Japan **dreh** sich die Erde schneller.* *Since the earth-quake in Japan – **rotate** – refl.pron. the Earth faster.*
töte-te	töt	töte-t	töt
trenn-te	trenn	trenn-t	trenn
üb-te	üb	üb-t	üb
warn-te	warn	warn-t	warn
wechsel-te	wechsel	wechsel-t	wechsel
widme-te	widme	widme-t	widme
wohn-te	wohn	wohn-t	wohn
zähl-te	zähl	zähl-t	zähl
zahl-te	zahl	zahl-t	zahl