Looking at feet.

A neurolinguistic and constraint-based analysis of German word stress

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Zusammenfassung

Diese Dissertation beschäftigt sich mit der Rolle des prosodischen Fußes für den Wortakzent des Deutschen im Hinblick auf Erkenntnisse aus neurolinguistischen Studien zur Wortakzentverarbeitung. Dieser relativ neue methodische Ansatz erlaubt es, unter Verwendung von (zeitlich) hochauflösenden EEG-Messungen Verarbeitungseffekte aufzuzeigen und daraus Generalisierungen über prosodische Strukturen abzuleiten, die mit bisherigen Methoden wie sprachtypologischen Vergleichen und Korpusstudien nicht möglich waren.

In einem einleitenden Kapitel gebe ich einen kurzen Überblick über die wichtigsten theoretischen Arbeiten zum prosodischen Fuß. Die Optimalitätstheorie (OT) nimmt hierbei eine besondere Stellung ein, da sie sich schon seit ihrem Entstehen Anfang der 90er Jahre des vergangenen Jahrhunderts mit der Analyse von Wortakzent in verschiedenen Sprachen beschäftigt hat und zahlreiche neuere Arbeiten zum Wortakzent dieses Modell nutzen.

Kapitel 2 stellt die wichtigsten Ergebnisse aus Publikationen, die ich mit meinen Koautoren veröffentlicht habe, dar. Knaus et al. (2007) untersuchten verschiedene experimentelle Designs im Hinblick darauf, wie sensitiv sie für Wortakzentverletzungen sind. Knaus und Domahs (2009) entwickelten auf Basis dieser experimentellen Ergebnisse ein optimalitätstheoretisches Modell für die Zuweisung des Hauptakzents im Deutschen.

Im dritten Kapitel erweitere ich die in Knaus et al. (2007) und Knaus und Domahs (2009) entwickelten Methoden und Modelle und erstelle eine experimentelle Analyse des Sekundärakzents im Deutschen. Anhand dessen diskutiere ich die modelltheoretischen Konsequenzen.

Anschließend werden zwei weitere Publikationen, die den Einfluss von Parametern höherer prosodischer Ebenen behandeln und deren Ergebnisse beschrieben (Domahs, Wiese und Knaus, im Erscheinen; Knaus, Wiese und Domahs, 2011).

Im letzten Kapitel der Arbeit stelle ich die in den vorangehenden Kapiteln beschriebenen experimentellen Ergebnisse zwei optimalitätstheoretischen Ansätzen gegenüber. Darüber hinaus vergleiche ich die Ergebnisse von methodisch ähnlichen EKP-Studien zum Wortakzent im Polnischen und Türkischen mit den Ergebnissen zum deutschen Wortakzent. Während wortinterne prosodische Strukturen für die Wortakzentverarbeitung in anderen Sprachen eine geringere Rolle spielen, lässt sich die Verteilung und Verarbeitung des Wortakzents im Deutschen nur mit Hilfe des prosodischen Fußes verstehen.

Contents

Introduction

In this dissertation, I examine the role of the foot in the assignment of word stress in German in light of results from recent neurolinguistic studies on word stress processing. This relatively new method is used to detect processing effects and support generalizations concerning prosodic structure. In particular, the use of sensitive, (temporally) high-resolution techniques reveals some details that cannot be shown by typological corpus studies alone.

Over several chapters, the reader is guided through the topics that were investigated with the ERP method and the published studies are presented in summarized form.

Chapter 1 gives a brief overview of linguistic literature on the foot, focusing only on the most influential works. It is divided into two parts which can be roughly described as pre-OT and OT works on the prosodic foot.

Chapter 2 summarizes the publications Knaus et al. (2007) and Knaus and Domahs (2009), which deal with the experimental design of the EEG studies on main stress in German and how their results can be analyzed in a constraint based model.

In chapter 3, I extend the methods and models developed in Knaus et al. (2007) and Knaus and Domahs (2009) to an investigation of secondary stress in pentasyllabic words of German. Consequences for an optimality theoretic account are discussed.

Crossing the boundaries of the prosodic word to examine the relations of word stress to conflicting demands of higher prosodic levels is the topic of chapter 4. Here I summarize and discuss the findings of Domahs et al. (to appear) and Knaus et al. (2011).

The last chapter presents an outlook and widens the focus of investigation to other languages. Two additional modern theoretical perspectives are examined in view of the experimental evidence presented in previous chapters. These concluding remarks highlight a central theme of this dissertation: the utility and even necessity of empirical data, especially from neuro- and psycholinguistic methods, for the development of a sound linguistic theory of phonological structure and processing.

1 The foot in prosodic phonology

In this chapter, the foundational concepts of the prosodic unit foot will be introduced and discussed. The term "foot" was adopted by prosodic phonology from poetic meter where it denotes the smallest structural unit that subdivides a verse (carrying a specific name according to its internal prominence relation, e.g., trochee, iamb, dactyl, anapaest, etc.). In poetics, a foot is formed by minimally two syllables (Drabble et al., 2007). In prosodic phonology, however, also unary feet consisting of just a single syllable are assumed. Besides the obvious analogy to use the notion as a unit of word stress assignment the foot receives evidence from other (morpho)phonological phenomena as well. These aspects of the foot in "classic" prosodic phonology will be outlined in the first section of this chapter. In a second section, the reception and treatment of the foot in Optimality Theory is discussed.

1.1 The foot as a prosodic unit and evidence for the foot

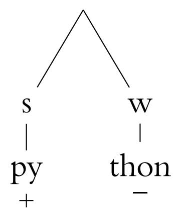
The primary application of the foot in prosodic phonology is the analysis of word stress. However, this has not always been the case. Neither the term foot nor its application to word stress were treated uniformly. In early approaches, word stress was seen as a purely phonetic phenomenon expressed by duration, intensity, pitch, and quality of a vowel (Fry, 1958; Morton and Jassem, 1965). Phonological theory looked for a model to describe and predict which syllable of a word receives stress. This model should as well be capable to explain which syllable receives main stress and which one secondary stress in cases with more than one stressed syllable in a word. To this end many researchers rely on the term foot. However there are very different concepts of what a foot is.

Abercrombie (1964) uses the term foot for analysing rhythm, the sequence of prominent positions, i.e., of stressed syllables in an utterance. In his definition a foot denotes the distance from one stress to the next. There is an "isochronous stress pulse" that divides an utterance into feet of "even length" (Abercrombie, 1964: 217). Abercrombie (1964: 217-218) mentions monosyllabic, disyllabic and trisyllabic feet for English. The length of the syllables is adjusted to achieve even length of a foot, i.e., syllables in monosyllabic feet are longest, while the shortest syllable is always found in a trisyllabic foot. For English syllables, a tripartite length distinction is assumed. Short syllables bear one time unit, syllables of medium length bear one and a half and long syllables bear two time units (Abercrombie, 1964: 219). As the foot only makes reference to the stress pulse it is independent of word boundaries and can extend over a word boundary (Abercrombie, 1964: 217). This essentially is a top-down view of stress assignment. Stresses are given by the stress pulse and the shape of the prosodic unit foot is shaped accordingly.

Linear models like that of Chomsky and Halle (1968) describe phonological structure as a linear sequence of segments formed by unordered feature bundles. They treat word stress as a special phonological feature of vowels [n stress], which take the stress level as featural value. There is no *a priori* restriction on the number of stress levels that a vowel can take. Stresses are assigned by rules in a cyclic way (Chomsky and Halle, 1968: 15-24). With rules stated by linear models it is possible to describe the binary alternating patterns of stressed and unstressed syllables found in many languages. However, there is no restriction within these models to produce only the attested patterns and therefore rules cannot explain why there is this similarity across languages. In fact, as Chomsky and Halle (1968: 400) themselves note, linear models could describe any kind of non-existent patterns as well. This descriptive inadequacy was one of the reasons that led to the development of the notion foot (see below). Furthermore, linear models fail to express the relational property of word stress. A segmental feature can only indicate that a syllable is stressed or not but it cannot express that this syllable is stressed in respect to other adjacent syllables (cf. Selkirk, 1984: 18).

With the advent of non-linear models, the view of word stress changed. Stress was now described as a relational value, i.e.,a syllable is only perceived as stressed if there is an adjacent syllable which is not (or at least less) stressed. The work of Liberman and Prince (1977) was one of the pioneering works in this respect. Liberman and Prince (1977) take stress as a strictly binary feature and deduce the stress levels from tree structures with binary branching nodes where one branch is weak (w) and the other is strong (s). An example is shown in figure 1.1.

Figure 1.1: Tree structure of the word *python*



These tree structures are applied to words, phrases, and compounds in similar fashion. While phrases always are left branching and phrasal stress accordingly is on the left, stress positions in compounds vary depending on the internal branching structure (left or right strong). Word internally the feature [±stress] is assigned to vowels by an iterating rule. Upon these featural values metrical trees are built up where [+stress] corresponds to a strong node and [−stress] to a weak node. By relying on binary branching of the trees "the structure and labelling of the sequences is uniquely determined" (Liberman and Prince, 1977: 266). These subtrees in turn are incorporated into higher level trees whose nodes are strong if they branch on lower level. Thus, Liberman and Prince already anticipate the concept which was used in later works on the foot by assuming tree structures below the word level.[1]

The concept of the foot as a separate, parametric unit of word stress was developed starting in the late 1970's and 1980's with the works of McCarthy (1979a), Selkirk (1980, 1984), Halle and Vergnaud (1987), Hayes (1981, 1995) among others. Selkirk defines the term foot as the prosodic category "mediating between the syllable and the prosodic word" (1980: 570). As this view of the foot is a very different one from that of Abercrombie (see on page 4), Selkirk calls it *stress foot*. Its position in the prosodic hierarchy is outlined in Nespor and Vogel (1986) as shown in figure 1.2.

Figure 1.2: The prosodic hierarchy

phonological utterance (U)
|
intonational phrase (I)
|
phonological phrase (Φ)
|
clitic group (C)
|
phonological word (ω)
|
foot (Σ)
|
syllable (σ)

For the prosodic hierarchy, the so called "Strict Layer Hypothesis" has been proposed (Selkirk, 1984; Nespor and Vogel, 1986) which constrains the way how prosodic constituents can be positioned and nested within the tree. The

[1] Although the term 'foot' is in fact used repeatedly by Liberman and Prince (1977) it is treated more as a possible alternative or accompanying description to the metrical tree which needs to be explored further and not yet as a discrete prosodic unit or category as in later works on the topic (cf. discussion in Selkirk, 1980: 568).

Strict Layer Hypothesis consists of two principles shown in 1.1, which both go back to (Selkirk, 1981).

(1.1) The Strict Layer Hypothesis

a. A category of level *i* in the prosodic hierarchy immediately dominates one or more categories of level *i−1* (Selkirk, 1981: 382).

b. The lower category is exhaustively contained in the higher category which it is part of (Selkirk, 1981: 383).

As consequence of 1.1.a., recursion of prosodic structure is nearly totally blocked. However, Selkirk herself already circumvented the strict layering by assuming nodes in the tree that do not have a category[2] label (and are named *s* only). In this regard, the Strict Layer Hypothesis also bears conflicts with the often proposed foot binarity (see below). It is at least problematic to maintain both restrictions on prosodic structure in a number of analyses, e.g., in words that consist of an odd number of syllables. If feet are maximally binary, then there is always one surplus syllable which either forms a foot by itself (heavy or degenerate foot) or remains unfooted. The latter is obviously a violation of strict layering. The prevailing view in the literature is that especially the first part of the Strict Layer Hypothesis is not to be interpreted in this most rigorous sense. In more recent approaches which make use of constraint-based models like Optimality Theory (see next section) it has been proposed to split up the Strict Layer Hypothesis into several single violable constraints (Selkirk, 1995; Peperkamp, 1997; Itô and Mester, 2003, among others). Thus, the generalization that complex prosodic structures are costly/dispreferred (e.g., unparsed syllables which are incorporated into prosodic words at a later stage etc.) is maintained, however not in the sense of an invariable rule but a gradient restriction which is influenced by other prosodic wellformedness requirements.

The second part of the Strict Layer Hypothesis blocks a subordinate category from spanning over a higher level categories' border. Thus, feet cannot cross word boundaries (cf. Nespor and Vogel, 1986: 109). This second part

[2] The term "category" is used in analogy to syntactic categories (Selkirk, 1981: 381).

is less controversial although there are independently motivated optimality theoretic constraints which conflict with this exhaustivity claim (e.g., Hyde 2002). A discussion in the light of experimental findings will be presented in chapter 2 and chapter 3.

The idea of the stress foot was developed into a parametrized theory of the foot by Hayes (1981, 1995). He characterizes feet along the parameters headedness, boundedness, directionality, iterativity and quantity sensitivity. Headedness describes the position of the prominent syllable within a foot. A foot can either be right headed (iambic) or left headed (trochaic) (Hayes, 1981: 107). This categorization is founded on a number of perception experiments (see Hayes (1995: 79) for a listing) where participants were presented with a sequence of segmentally equal syllables (e.g., *ta-ta-ta…*) where every second sound was more pronounced than its precursor. If stressing was done by lengthening the particular syllable, participants formed binary groupings with final stress. If the emphasis was obtained by playing the syllable louder, participants formed binary groupings with initial stress. Based on these experimental findings Hayes formulated the "Iambic/Trochaic Law".

(1.2) The Iambic/Trochaic Law (Hayes, 1995: 80)

a. Elements contrasting in intensity naturally form groupings with initial prominence.

b. Elements contrasting in duration naturally form groupings with final prominence.

This principle is inherently related to the headedness parameter and is (directly or indirectly) influential for later analyses within the framework of Optimality Theory as well (e.g., Alber 1997b).

The parameter boundedness differentiates between languages that have bounded stress, where stresses bear a fixed relation to a word boundary or another stressed syllable and unbounded stress systems, which do not show any of these sequential or distance relationships (Hayes, 1995: 31). Boundedness is inherently related to foot binarity. Thus, the above definition can just as well be expressed by stating that languages with bounded stress have maximally binary branching trees. This is a result of the rules governing tree structure. In languages with bounded stress there are no "dominant" (i.e., strong) nodes higher up in the tree, they only appear at vertically final, terminal position. Due to this restriction, no further branching is possible since "recessive" (i.e., weak) nodes by definition cannot branch (Hayes, 1981: 47). Thus, feet cannot grow larger than two syllables. Unbounded stress systems do not have these restrictions (the position of dominant nodes is completely free) (Hayes, 1981: 47). To account for stress patterns that deviate from strict binarity, Hayes applies the concept of extrametricality (Hayes 1981: 66–82, Hayes 1995: 56–60, 105–108), which implies that a prosodic unit (mora, syllable, foot, ...) at an edge (e.g., of the prosodic word) is ignored by the parser. The minimum foot size is a single syllable. In case this syllable is a light one (see below for the definition of syllable weight) this foot is called degenerate (Hayes, 1995: 102). The occurrence of degenerate feet is either restricted to specific contexts or is prohibited completely (Hayes, 1995: 86–105).

There are two parameters that affect parsing, directionality and iterativity (Hayes, 1995: 113). Directionality specifies the orientation of foot construction; either footing starts at the right or the left word edge. Iterativity determines whether foot construction algorithms are applied iteratively or not.[3]

Finally, Hayes distinguishes between languages in the way they treat syllable weight (1981: 11–15). Some languages show a preference for stressing heavy syllables, while other languages do not. Depending on the theoretical model followed, these are defined as syllables with a branching rhyme as proposed e.g., by McCarthy (1979a,b) (or with a branching nucleus only, if only syllables with long vowels count as heavy) or as syllables with more than one mora in moraic theory (Hayes, 1989), where weight is decoded directly into segmental structure inside the subsyllabic prosodic unit mora. All other syllables are regarded as light. Languages which draw a distinction between heavy and light syllables are called quantity-sensitive, whereas languages that treat both syllable types alike are called quantity-insensitive.

[3] This parameter obviously plays a lesser role in theoretical frameworks like Optimality Theory which make use of parallel evaluation.

Along the mentioned parameters Hayes (1995: 71) assumes three basic bounded foot types, syllabic trochee (ˈσσ), moraic trochee (ˈμμ) and iamb (σˈσ), which he establishes on the basis of typological distributions. Foot types are distributed asymmetrically across languages. According to Hayes, there are no iambic quantity-insensitive languages. Although this typological gap might not be absolute, Hayes proposes to analyze the rare counterexamples exhibiting superficially an iambic quantity-insensitive pattern to just have no heavy syllables underlyingly (1995: 266–268). The asymmetry in distribution of foot types is summarized in table 1.1.

Table 1.1: Trochaic and iambic systems in comparison

trochee	iamb
leftheaded	rightheaded
quantity-sensitive or quantity-insensitive	quantity-sensitive
right to left and left to right foot parsing	left to right foot parsing[4]
optimal with equal quantities	intensifying quantity-contrast

The described asymmetry shows up in foot based phonological phenomena such as iambic lengthening and trochaic shortening. Syllables which group into iambs tend to be of unequal length. In many languages this is accomplished by iambic lengthening, i.e., a lengthening of the foot final syllable (Hayes, 1995: 83). Trochees are preferably of equal length, and there are shortening processes in trochaic languages (e.g., trisyllabic shortening in English) to achieve this (Hayes, 1995: 145–149).

Apart from the tree model of stress relations described above, an alternative notation for the description of rhythmical stress was proposed by Prince (1983) with its foundations already laid in the second half of Liberman and Prince (1977: 309ff.) where numbered grid marks are used to describe stress relations within phrases. This so called metrical grid is build upon observations of clash phenomena, i.e., structures with adjacent stressed syllables.

[4] Hayes (1995: 262–266) discusses a number of iambic languages where some analyses assume right to left parsing of feet and gives convincing alternative analyses for applying only left to right parsing in these languages.

Such clashes are generally dispreferred and often repaired by shifting one of the clashing stresses onto a non-adjacent syllable. Notationally, Prince (1983) replaces the numbered marks by simple crosses. Instead of deriving stresses by tree structure – Liberman and Prince (1977) still assume this connection – he derives them directly from the syllable, more precisely from its sonority structure (Prince, 1983: 97). The core of Prince's theory is made up by rules of the following types:

a. The "End Rule", which requires the left- or rightmost grid mark entry at one prosodic level receives a grid mark at the next higher level (Prince, 1983: 28)

b. Extrametricality rules, which may apply at different prosodic levels

c. "Perfect Grid Construction (PG), which establishes a perfect grid, maximally organized up to a certain level and clash-free" (Prince, 1983: 97) starting with a peak (i.e., a grid mark) or a trough (no grid mark) moving left or right

d. "Move *x*, which reorganizes otherwise unavoidable clashes" (Prince, 1983: 97) by moving a grid mark to another adjacent position on the same level

e. Rules regarding quantity restrictions (treatment of heavy syllables and moras) (Prince, 1983: 97)

The interplay of some of these rules can be shown using the word *parachute* as an example, see figure 1.3. At lowest level every syllable receives a grid mark. A PG rule and an End Rule (rightmost) create the grid marks at the second (foot) level. At the same level an extrametricality rule renders the rightmost grid mark invisible (indicated by parentheses) for the End Rule (rightmost) which is applied again to create the grid mark on word level.

The crucial difference between theories using only tree structures and the metrical grid is that the latter is "a constituent-free hierarchy" (Prince, 1983: 96). Prince uses the prosodic constituent names to denote the grid levels,

Figure 1.3: Grid structure for the word *parachute*

ω:	x		
Σ:	x		(x)
σ:	x	x	x
	pa	ra	chute

but these are just labels. Especially, this has consequences for the foot as the prosodic unit relevant for stress assignment. Feet are seen just as an epiphenomenon (Prince, 1983: 88). This assumption was continued by Selkirk (1984) which proposes a grid-only model as well which discards feet, words and phrases as constituents of the prosodic hierarchy (Selkirk, 1984: 31). However, these extreme positions have received some criticisms. Hayes (1995: 46-47) argues against a grid-only model by showing that in languages (e.g., Lenakel) which exhibit a stress pattern with right directionality in one paradigm but left directionality in another a grid-only model misses to point out an important generalization. As is shown in example 1.3, a pure grid model would analyze a left-to-right paradigm as peak first (a.), the other one as trough first (b.) while a model which assumes feet as prosodic constituents can assume a single foot type for both paradigms. Thus the grid-only model has to assume two parameter switches while the model with feet assumes a switch in directionality only. Furthermore, assuming foot constituents allows to analyze languages of this kind to have a single foot template which forms a "predicted natural class" (Hayes, 1995: 45).

(1.3) Differences of grid-only models and models assuming feet

a.	Pattern	# ˈσσ ˈσσ…
	Directionality	→
	Grid-only model	x . x .
	Model with feet	(x .)(x .)

b.	Pattern	…ˈσσ ˈσσ #
	Directionality	←
	Grid-only model	x . x .
	Model with feet	(x .)(x .)

Wiese (1988: 14–17) points out that a pure grid model cannot describe that German speakers intuitively group together the first and second syllable (as well as the third and fourth) but not the second and the third syllable in German words like *Abenteuer* or *Propaganda*. This relational aspect is expressed naturally by a model that assumes feet as prosodic constituents.

On the whole it should be noted that apart from the discussion of constituency of several elements of the prosodic hierarchy both models, grid and tree are largely compatible. Many approaches combine both of them in a single notation often called bracketed grid (e.g., Halle and Vergnaud, 1987; Hayes, 1995, among others), with variations in bracket notation (single or paired brackets) and in notation of the lowest grid line (grid marks and dots) which are not discussed here.

Apart from its role as prosodic unit involved in word stress assignment the foot has received independent evidence in other areas of phonology as well. Table 1.2 on the next page gives a non-exclusive selection of examples.

All these phenomena are described adequately by rules that apply on the foot domain. This way, it is possible to formulate general rules without the need to make reference to foot form itself and thus it allows to abstract away from the language specific foot construction rules (Nespor and Vogel, 1986: 100). Without assuming feet one would be obliged to define similar contexts of rule appliances separately. To sum up, the prosodic category foot allows for simpler rules which identify core generalizations behind superficially different phonological processes. The foot is thus independently motivated by numerous non-stress phenomena as well.

Table 1.2: Phonological processes applying at foot domain

Language	Phenomenon	Source
Applecross Gaelic	Nasalization applies only foot internally	van der Hulst and Smith (1982: 317–322), Nespor and Vogel (1986: 98–99)
Amoy	Stop-voicing and gemination inside a foot only	Yip (1980: 161), Nespor and Vogel (1986: 95–97)
Mandarin	One fully toned syllable per foot	Yip (1980: 148), Nespor and Vogel (1986: 95–97)
English	Aspiration applies only to the foot initial segment (no matter if that foot contains a stressed syllable or not)	Nespor and Vogel (1986: 91)
English	Obligatory *n*-Velarization and Mutual *k*-*r*-Assimilation	Kiparsky (1979: 439–440), Nespor and Vogel (1986: 94)
English	*l*-Devoicing and Diphtong Shortening	Kiparsky (1979: 440), Nespor and Vogel (1986: 93)
Dutch	ə-Insertion and Pre-*r*-Lengthening	Gussenhoven (1993: 48–50), Gussenhoven and Jacobs (1998: 228)
German	Foot initial ʔ-insertion before onsets without consonants	Wiese (2000: 58–59)
German	Plural forms all take (apart from the *s*-plural) a final ə after a preceding stressed syllable, i.e., these plurals end in a bisyllabic foot	Wiese (2000: 61–62)
German	Hypochoristics (*-i* and *-o* short forms) are all formed by bisyllabic feet only or end in a final bisyllabic foot	Wiese (2000: 62–64)
German	In reduplications (*Hokuspokus*) the main part of a foot is taken as reduplicant	Wiese (2000: 64)
Manam	Reduplication, reduplicative morpheme is a bisyllabic foot	McCarthy and Prince (1996: 30–31), Alber (2005b: 543)
English	Position of expletive infixation (*Cali-fuckin'-fornia*)	McCarthy (1982)
Lardil	Minimal word effects, words must at least consist at least of one foot	Prince and Smolensky (1993/2002: 124), Alber (2005b: 543–544)
English	Trisyllabic Shortening (Trochaic Shortening)	Prince (1990: 13–15), Alber (2005b: 544)

1.2 The foot in Optimality Theory

The approaches to word stress described in the previous section laid the ground for many constraints used in Optimality Theory which is since its beginnings concerned with analyzing word stress. In the constitutive work of this theoretical framework, Prince and Smolensky (2004) develop a basic set of constraints which is used in OT when dealing with word stress.

1.2.1 Basic Optimality Theory

To capture the distribution of main stress in unbounded, prominence-driven stress systems, Prince and Smolensky introduce the constraints PEAK-PROMINENCE and EDGEMOST. PEAK-PROMINENCE describes that the preferred position for (main) stress in a string of syllables is the syllable with the highest "intrinsic prominence".[5]

(1.4) PEAK-PROMINENCE (PK-PROM)
Peak(x) ≻ Peak(y) if $|x| > |y|$.
"By PEAK-PROMINENCE, the element x is a better peak than y if the intrinsic prominence of x is greater than that of y."
(Prince and Smolensky, 2004: 46)

PEAK-PROMINENCE is founded on the Heaviness Scale (1.5) the syllable weight distinction suggested by Hayes (1981) (see page 9). Syllables with a complex branching rhyme (i.e., long vowel plus consonant or vowel plus consonant cluster) are placed at the top, followed by syllables with a branching rhyme, while simple open syllables form the endpoint of the scale. Quantity sensitive languages may vary on the effective number of gradations of heaviness but the

[5] There is an extensive discussion in the literature on how this "intrinsic prominence" is actually to be captured, cf. references given in Prince and Smolensky (2004: 46). I will follow here the more general conception of the prominence principle "Quantity/Prominence Homology" defined in McCarthy and Prince (1996).

overall generalization that the more segmental material is in the rhyme the heavier the syllable is valid for all languages.

(1.5) Heaviness Scale (Prince and Smolensky, 2004: 48)
|CVVC, CVCC| > |CVV, CVC| > |CV|

EDGEMOST determines the favored position of the prominence peak, i.e., the main stress position:

(1.6) EDGEMOST(pk;L|R; Word)
A peak of prominence lies at the L|R edge of the Word.
(Prince and Smolensky, 2004: 46)

If EDGEMOST is ranked highest, main stress falls strictly on the first or the last syllable in a word. With PK-PROM ranked above EDGEMOST main stress falls on the rightmost or leftmost heavy syllable (Prince and Smolensky, 2004: 47).

In many languages stress on word final syllables is avoided. Prince and Smolensky formulate this in a single constraint NONFINALITY. With the help of this constraint, various except-when rules describing extrametricality, stress shift or destressing and the like can be subsumed as instances of a single phenomenon. The definition of NONFINALITY slightly varies though in the line of reasoning. Prince and Smolensky provide a preliminary definition, and then develop the constraint in the course of their analyses of various stress related phenomena. This results in three different constraint definitions:

(1.7) NONFINALITY

a. The prosodic head of the word does not fall on the word-final syllable.
(Prince and Smolensky, 2004: 48)

b. The head *foot* of the PrWd must not be final.
(Prince and Smolensky, 2004: 51)

c. No head of PrWd is final in PrWd.
(Prince and Smolensky, 2004: 62, 68)

All these constraint definitions have in common the non-final placement of a prosodic head within the prosodic word (PrWd). The differences are in the conception of recursivity of prosodic heads. Either the prosodic head is the head foot, i.e., the foot carrying main stress (1.7 b.), or "prosodic head" denotes only the main-stressed syllable (1.7 a.) or a combination of both (1.7 c.). Definitions a. and b. rate candidates differently. A critical case is for example a word of the syllabic structure LH in a trochaic system. If this syllabic string is parsed as (ˈLH) it would not violate NONFINALITY as defined in a., as main-stressed L is not the final syllable, while it receives a violation mark with the constraint definition b., as the head foot is clearly the final one here. Nevertheless Prince and Smolensky (2004: 62, 64, 69) show in their analysis of Latin word stress that both forms of NONFINALITY are needed, to correctly analyse stress in words of the LH-type on the one hand, e.g., [(ˈa.moː)] and not *[a(ˈmoː)], and in LLL-words, e.g., [(ˈspa.tu)la] and not *[spa(ˈtu.la)] on the other hand. To meet both requirements the constraint can be defined as in (c.), meaning that [(ˈa.moː)] receives a violation mark due to its final (head) foot but still behaves better than *[a(ˈmoː)] which receives two violation marks, one for the final head foot and one for the final stressed syllable. "NONFINALITY is violated when *either* abuts the trailing edge of the PrWd; we assume that each violation counts separately" (Prince and Smolensky, 2004: 62). In sum, extrametrical syllables are treated differently in OT than in rule based accounts. Extrametricality is seen as an effect of EDGEMOST interacting with other prosodic wellformedness constraints (Prince and Smolensky, 2004: 45). NONFINALITY is one of these constraints. In contrast to extrametricality rules it does not describe the unparsed status of the final syllable but a wellformedness requirement of a stress peak. Thus, it is firmly related to stress (Prince and Smolensky, 2004: 48).

A further constraint introduced by Prince and Smolensky is LX≈PR (*MCat*). It demands that any morphological category, e.g., a root, a stem or a word, corresponds to a phonological category (the prosodic word as domain of word stress which consists of feet and syllables), i.e., a lexical word must also be a prosodic word (Prince and Smolensky, 2004: 51).

(1.8) Lx≈Pr (*MCat*)
A member of the morphological category *MCat* corresponds to a PrWd. (Prince and Smolensky, 2004: 51)

This constraint ensures that monosyllabic content words are parsed into prosodic structure, i.e., they are footed and form a prosodic word. It is not an option to leave the prosodic content of these words unparsed. Lx≈Pr (*MCat*) thus is an antagonist to NonFinality.

Prince and Smolensky put the prosodic hierarchy in the center of their analyses. A prosodic word "must contain at least one foot; a foot will contain at least two moras" (Prince and Smolensky, 2004: 56). This principle is transcribed into the constraint FtBin.

(1.9) Foot Binarity (FtBin)
Feet are binary at some level of analysis (μ, σ).

FtBin can be vacuously fulfilled by the so called *Null Parse*. This is a candidate that lacks all prosodic structure, as its syllables are not parsed into feet. If this candidate becomes optimal the resulting output is uninterpretable and therefore silent. Although this is rarely the case, a possible occurrence of the Null Parse is for example the English comparative: The suffix <-er> is only realized if the base is a minimal (single foot) word. So an input like /violet + er/ will not end up in an output *[violeter], instead, the suffix undergoes a morphological Null Parse (Prince and Smolensky, 2004: 58).

An additional constraint dealing with the formation of prosodic structure itself is Parse-σ. This constraint encodes the "principle of exhaustive metrical analysis familiar from the earliest work in the area (Liberman 1975)" (Prince and Smolensky, 2004: 69). Parse-σ is directly militating against a possible Null Parse. Any Null Parse necessarily violates this constraint.

(1.10) Parse-σ
Syllables are parsed into feet. (Prince and Smolensky, 2004: 69)

The effect of Parse-σ in a ranking is similar to that of Lx≈Pr although they denote different generalizations about prosodic structure. Lx≈Pr initiates the creation of prosodic structure itself, i.e., footing and stressing. It is satisfied if there is at least some prosodic structure at all. Parse-σ instead, demands that all syllables in a word must be incorporated in the next higher prosodic level, i.e., in a foot. The difference between the two constraints becomes visible if one considers a bisyllabic word consisting of two heavy syllables in a mora counting/quantity sensitive language. While Lx≈Pr is already satisfied by an output candidate (H)H or H(H) a complete satisfaction of Parse-σ is only achieved by an exhaustive parse (H)(H) or (HH) (Prince and Smolensky, 2004: 69). Thus, Parse-σ is more specific in its demands on prosodic structure than Lx≈Pr.

Besides FtBin there are a few more constraints determining the form of a prosodic foot. The distinction between languages with a trochaic or a iambic rhythm is couched in the constraint RhType=I/T.

(1.11) RhType=I/T
Feet have final/initial prominence.
(Prince and Smolensky, 2004: 63; Kager, 1999a: 172)

A high ranked RhType=I prefers iambic footing of syllables (σˈσ) while trochaic feet (ˈσσ) are the preferred outcome with a high ranked RhType=T.

In many languages syllable weight influences the construction of feet. Stress falls preferably on heavy syllables in these languages. This aspect of quantity sensitivity is expressed by the constraint Weight-to-Stress Principle which itself relies on earlier work by Prince (1983, 1990).

(1.12) Weight-to-Stress Principle (WSP)
Heavy syllables are prominent in foot structure and on the grid.
(Prince and Smolensky, 2004: 63)

WSP militates against heavy syllables in weak branches of a foot. Accordingly, a trochee like (ˈLH) violates WSP. Compared to the constraint Pk-Prom (1.4) WSP is limited to foot level. "The WSP goes from weight to stress: 'if heavy then stressed' (equivalently, 'if unstressed then light'). Pk-Prom essentially goes the other way: 'if stressed then heavy' (contrapositively and equivalently: 'if light then unstressed')" (Prince and Smolensky, 2004: 74). Pk-Prom "deals only with main stress" (Prince and Smolensky, 2004: 73, Fn. 41) and states that a light syllable cannot be stressed if there is a heavy one in a string of syllables. WSP instead only says something about the position of a heavy syllable in a foot. It does not deal with light syllables.

A last constraint introduced by Prince and Smolensky is a restriction on the structure of trochaic feet.

(1.13) Rhythmic Harmony (RhHrm)
*(HL)
(Prince and Smolensky, 2004: 70–71)

(ˈHL)-feet are "marked or even absent in trochaic systems" (Prince and Smolensky, 2004: 70; referring to Prince, 1990 among others).

These trochees are not harmonic with regard to rhythmic structure, "which favors length at the end of constituents" (Prince and Smolensky, 2004: 70). This constraint refers to the markedness scale of feet introduced by Prince (1990).

(1.14) Markedness scale of foot structure (cf. Prince, 1990: 360, 363)

Iambic	(LˈH)	≻	(LˈL), (ˈH)	≻	(ˈL)
Trochaic	(ˈLL), (ˈH)	≻	(ˈHL)	≻	(ˈL)

In the literature several similar constraints can be found essentially capturing this markedness scale, e.g., Kager's (1999a: 174) Rh-Contour "A foot must end in a strong–weak contour at the moraic level" ruling out dispreferred (HL)-trochees and (LL)-iambs and the even more general Iambic-Trochaic-Law (ITL) "The components of a trochaic foot must be equal, the elements of an iambic foot must contrast in quantity" (Alber, 1997b: 6) which bans (LH)- and (HL)-trochees as well as (LL)-iambs. The latter expresses the prominence contrasts of Hayes (1995) (see page 8 above) which themselves form the basis for Prince's (1990) markedness scale. Nevertheless at least some languages exist where processes are at work which produce exactly these (ˈHL)-feet (cf. Mellander, 2003).

1.2.2 Generalized Alignment

Optimality theory captures directionality of foot parsing by using Alignment constraints (McCarthy and Prince, 1993). The theory of alignment formulates constraints on the relation of edges of constituents to each other. Constituents may be of prosodic or morphological nature. McCarthy and Prince integrate all prosodic and morphological processes with reference to edges in a single definition named *Generalized Alignment* which describes a family of wellformedness constraints.

(1.15) Generalized Alignment
Align(Cat1, Edge1, Cat2, Edge2) $=_{def}$
$\forall$ Cat1 $\exists$ Cat2 such that Edge1 of Cat1 and Edge2 of Cat2 coincide.
Where
Cat1, Cat2 $\in$ PCat $\cup$ GCat
Edge1, Edge2 $\in$ {Right, Left}
(McCarthy and Prince, 1993: 80)

Definition 1.15 shows how alignment constraints are made up: An edge, i.e., the beginning or the end of a linguistic category shall coincide with the edge of another category. More precisely, the first category is subject to the universal quantifier ($\forall$) while the second category underlies the existential quantifier ($\exists$), meaning that *every* member of the first category is aligned with *at least one* member of the second category. Effects of the different quantifiers become visible when looking at alignment of prosodic edges with each other (see below).

Alignment constraints on prosodic edges allow to discern different distances of several prosodic categories, e.g., between edges of feet and the edge of a prosodic word. These constraints, introduced by McCarthy and Prince, are based on the standard conception of the prosodic hierarchy (cf. Selkirk, 1980).

They assume that the prosodic word is recursive, while the categories foot and syllable are not.

> Through their various principles, foot theory and syllable theory license a very limited set of expansions of foot and syllable, and recursion is simply not among these options. There is no theory placing comparable limits on the expansion of PrWd, and indeed there could not be, if only because there is no upper bound on the length of a PrWd. (McCarthy and Prince, 1993: 85)

Primary examples for prosodic alignment constraints given by McCarthy and Prince are the left oriented ALIGN-PRWD, which demands that any prosodic word's left edge coincides with that of a foot, and the right oriented ALIGN-FT which is satisfied if any right foot edge is aligned with the right edge of a word.

(1.16) ALIGN-PRWD (McCarthy and Prince, 1993: 95)
ALIGN(PrWd, L, Ft, L)
Any $[_{\text{PrWd}}$ is aligned with a $(_{\text{Ft}}$.

(1.17) ALIGN-FT (McCarthy and Prince, 1993: 95)
ALIGN(Ft, R, PrWd, R)
Any $)_{\text{Ft}}$ is aligned with a $]_{\text{PrWd}}$.

The last-mentioned constraint ALIGN(Ft, R, PrWd, R), as well as its directional counterpart ALIGN(Ft, L, PrWd, L) also have an alternative naming. They are often called ALLFEET-R and ALLFEET-L (cf. Kager, 1999a; Alber, 1998; Knaus and Domahs, 2009; i.a.), which is just a rewording in plain language of what the constraints demand.

Constraint 1.16 is a reformulation of Prince and Smolensky's (1993/2002) constraint EDGEMOST(see 1.6 on page 16) in terms of Generalized Alignment. EDGEMOST(F; L; PrWd) has the same effect as ALIGN(PrWd, L, Ft, L). The same is true for the directional mirror images ALIGN(PrWd, R, Ft, R). Both constraints – like EDGEMOST in Prince and Smolensky (1993/2002) – also have variants that align the head foot, i.e., the strongest foot in the word, with the prosodic word and thus are evaluating main stress placement. McCarthy and Prince (1993: 98) called these constraints ALIGN-HEAD-R/L, in the OT literature, however, these constraints are commonly referred to as LEFTMOST and RIGHTMOST.

(1.18) LEFTMOST (McCarthy and Prince, 1993: 98; Kager, 1999a: 167)
ALIGN(PrWd, L, Hd-Ft, L)
Any $[_{\text{PrWd}}$ is aligned with a $(_{\text{Hd-Ft}}$.

(1.19) RIGHTMOST (McCarthy and Prince, 1993: 98; Alber, 1997b: 10; Kager, 1999a: 167)
ALIGN(PrWd, R, Hd-Ft, R)
Any $]_{\text{PrWd}}$ is aligned with a $)_{\text{Hd-Ft}}$.

Just as with the variants of NONFINALITY (1.7) above, there are slightly different versions of LEFT- or RIGHTMOST according to the definition of what a "head" is. McCarthy and Prince (1993: 98-99) originally just stated "H(PrWd)" as category which the PrWd is aligned with but obviously refer to the head foot in the immediately following example on English word stress. Alber (1997b: 10, 17; 1998: 24) takes the same definition for RIGHTMOST in her analysis of German word stress but refers to the stressed syllable of the head foot (e.g., the candidate (ˈσ.σ) violates RIGHTMOST while (σ.ˈσ) does not). Furthermore, the order of the aligned categories varies between authors. McCarthy and Prince (1993) and Alber (1997b) align prosodic words with a head foot while Kager (1999a: 167) aligns head feet with a prosodic word (ALIGN(Hd-Ft, L/R, PrWd, L/R)). The difference in the scope of the quantifiers has no effect though, as both categories are unique within a prosodic word.

Though equal in effect to EDGEMOST of Prince and Smolensky (1993/2002), the Generalized Alignment variant is based on a more general conception: "it does not restrict the hierarchical relation" of the two prosodic categories nor does it "require the sameness of the shared edge" (McCarthy and Prince, 1993:

94). Going further, Generalized Alignment allows it to reformulate other prosodic OT-constraints as well. RhType can be expressed in alignment-terms. RhType=Tr is equivalent to Align(Ft, L, H(Ft), L), "where H(Ft) = 'head of foot' = strongest syllable-daughter of F" (McCarthy and Prince, 1993: Fn.6). Again, the same holds for the directional counterparts RhType=I and Align(Ft, R, H(Ft), R).

Considering again the constraints 1.16 and 1.17 which refer to the prosodic word, Generalized Alignment can also be used to explain directionality effects in foot parsing. By aligning feet with the prosodic word different trochaic stress patterns can be obtained which can all be confirmed by existing languages.[6]

Table 1.3: Analysis of trochaic stress patterns by using alignment constraints (McCarthy and Prince, 1993: 91-92, 97)

Stress pattern	Ranking of alignment constraints	Language
L→R [('σσ)('σσ)('σσ)σ]	Align(Ft, L, PrWd, L) $\gg$ Align(PrWd, R, Ft, R)	Wankumara
R→L [σ('σσ)('σσ)('σσ)]	Align(Ft, R, PrWd, R) $\gg$ Align(PrWd, L, Ft, L)	Warao
initial trochee + R→L ("initial dactyl") [('σσ)σ('σσ)('σσ)]	Align(PrWd, L, Ft, L) $\gg$ Align(Ft, R, PrWd, R)	Garawa
L→R + final trochee [('σσ)('σσ)σ('σσ)]	Align(PrWd, R, Ft, R) $\gg$ Align(Ft, L, PrWd, L)	Polish

In words with an odd number of syllables various trochaic stress patterns are possible. There is always one syllable which cannot be incorporated in a well-formed disyllabic trochee. Where in a word this odd syllable occurs, depends on the relative ranking of alignment constraints, see table 1.3. If Align(Ft, L,

[6] McCarthy and Prince (1993) do not treat iambic systems. They argue that no (overt) specification of directionality in iambic systems is needed, as NonFinality (see definition 1.7) ranked above all alignment constraints provides all possible iambic stress patterns (McCarthy and Prince, 1993: Fn. 7).

PrWd, L) is ranked above Align(PrWd, R, Ft, R), the odd syllable will occur at the end of the prosodic word like in Wankumara. As the high ranked alignment constraint demands that every left foot edge should coincide with the left edge of a prosodic word, the optimal candidate will always have directly subsequent trochees starting from the left word edge without any intermittent unparsed syllables. In a language like Warao where the odd syllable occurs at the beginning of the word all right edges of feet are aligned with the right edge of the encompassing prosodic word. This is formalized by a high ranked Align(Ft, R, PrWd, R). Some languages show a stress pattern which is – based on the superficial look of stress placement here – often called an initial dactyl (following Prince, 1983: 49), i.e., at the beginning of the word a stressed syllable is followed by two unstressed ones while all following syllables fit in a regular disyllabic trochee pattern. As McCarthy and Prince assume strictly binary feet, an initial ternary foot is not an option for a language like this, such as Garawa. They show that in terms of Generalized Alignment there is an even more elegant solution which is congruent with those of the other languages shown in table 1.3 and makes use only of binary feet. A simple reranking solves this issue. If the alignment constraint which puts the prosodic word into the scope of the universal quantifier is high ranked (Align(PrWd, L, Ft, L)) it is most important to align *every* left edge of a prosodic word (which is trivially here, as there is only one) with the left edge of exactly *one* foot. A trochee at the beginning of a word satisfies this requirement. By pressure of the now lower ranked Align(Ft, R, PrWd, R) all other feet are aligned to the right edge of the prosodic word. Hence the third syllable is not incorporated in any foot which results in the dactylic look of the prosodic word. A structurally similar pattern which is only directionally reversed occurs e.g. in Polish, where every prosodic word's right edge should coincide with a right foot edge, as Align(PrWd, R, Ft, R) calls for. This constraint is ranked above Align(Ft, L, PrWd, L) which in turn ensures that all feet – with exception of the one needed for the satisfaction of Align(PrWd, R, Ft,R) – are oriented to the left.

The described reranking procedures show that Generalized Alignment provides a framework to describe seemingly very different stress systems in a coherent and principled manner. Not least because of this property, Generalized Alignment has quickly become the standard tool to analyze stress in Optimality Theory. Nevertheless, it has some shortcomings, especially when looking at typological descriptive adequacy, as was revealed in a number of recent works on this respect (McCarthy, 2003b; Kager, 2005; Alber, 2005a; Buckley, 2009). All these proposals offer different solutions to overcome some of Generalized Alignment's limitations.

1.2.3 Beyond Generalized Alignment

In the remainder of this chapter I will focus on the proposals of Kager and Alber as these introduce and use a number of constraints that are commonly used in more recent analyses of word stress. Both give a more prominent role to rhythmic factors that influence word stress which for example were previously described by the Principle of Rhythmic Alternation (Selkirk, 1984: 12, 19, 37). This principle describes the general preference for binary alternating patterns of weak and strong beats (see below). The new rhythmic constraints introduced interact with alignment constraints. However, some of the alignment constraints are dispensed with.

Kager (2001, 2005, 2007) concentrates on two typological gaps which cannot be captured by classical alignment theory. Both deal with directionality asymmetries.

One of these asymmetries occurs in languages that show a "strictly binary uni-directional" (Kager, 2007: 218) foot pattern. These languages do not allow for unary feet or rather allow for disyllabic feet only. In OT terms, this presupposes that the constraints PARSE-σ and FOOTBINARITY dominate the ranking hierarchy for these languages, with the latter constraint ranked highest. Consequently, in words with an odd number of syllables the optimal candidate can have only one single unfooted syllable. In 'classical' Generalized Alignment the position of this unfooted syllable is determined by the relative ranking of the alignment constraints AllFeet-L/R and AlignPrWd-L/R. The three tableaux 1.1, 1.2, and 1.3 show example rankings for words with five syllables, abstracting away from foot types.

Tableau 1.1: A strictly binary language with a final unparsed syllable

/σσσσσ/	FootBin	Parse-σ	AllFeet-L	AlignPrWd-L	AllFeet-R	AlignPrWd-R
(a) ☞ (σσ)(σσ)σ		⋆	⋆⋆		⋆⋆⋆⋆	⋆
(b) σ(σσ)(σσ)		⋆	⋆⋆⋆⋆	⋆	⋆⋆	
(c) (σσ)σ(σσ)		⋆	⋆⋆⋆		⋆⋆⋆	

Obviously, with the alignment constraints provided by Generalized Alignment, languages with an initial unparsed syllable (tableau 1.2), with a final unparsed (tableau 1.1) or a medial unparsed syllable (tableau 1.3) are possible. If AllFeet-L is ranked above AllFeet-R like in tableau 1.1, the optimal candidate has a final unfooted syllable. With the reversed ranking AllFeet-R above AllFeet-L the output will be the candidate with the initial unfooted syllable (1.2).

Tableau 1.2: A strictly binary language with an initial unparsed syllable

/σσσσσ/	FootBin	Parse-σ	AllFeet-R	AlignPrWd-R	AllFeet-L	AlignPrWd-L
(a) (σσ)(σσ)σ		⋆	⋆⋆⋆⋆	⋆	⋆⋆	
(b) ☞ σ(σσ)(σσ)		⋆	⋆⋆		⋆⋆⋆⋆	⋆
(c) (σσ)σ(σσ)		⋆	⋆⋆⋆		⋆⋆⋆	

With both AlignPrWd constraints ranked above the AllFeet constraints (tableau 1.3) the pentasyllabic word with the medial unparsed syllable will be the optimal form.

Tableau 1.3: A strictly binary language with a medial unparsed syllable

	/σσσσσ/	FootBin	Parse-σ	AlignPrWd-L	AlignPrWd-R	AllFeet-L	AllFeet-R
(a)	(σσ)(σσ)σ		⋆		⋆	⋆⋆	⋆⋆⋆⋆
(b)	σ(σσ)(σσ)		⋆	⋆		⋆⋆⋆⋆	⋆⋆
(c) ☞	(σσ)σ(σσ)		⋆			⋆⋆⋆	⋆⋆⋆

Note that the three tableaux demonstrate only some of all possible rerankings. It could for example be the case that in tableau 1.1 AlignPrWd-R and AlignPrWd-L change their place in the ranking. As long as AllFeet-L remains ranked above AlignPrWd-R this would not change the outcome. The interdependencies here are more complex than it can be shown in the linear fashion of a tableau. However, the point to be made here is that with Generalized Alignment all three patterns are possible.

Based on the results of these reranking procedures, Kager argues that if we look at uni-directional systems only – and thus exclude languages that have both AlignPrWd constraints ranked above the AllFeet constraints like in tableau 1.3 – Generalized Alignment predicts exactly four patterns, two iambic and two trochaic ones, but only three are attested (Kager, 2007: 209, 218-219). There are no iambic languages that are parsed from right to left, i.e., iambic languages with initial unparsed syllables (the pattern shown in tableau 1.2) do not exist. Kager (2001, 2005) analyses this typological gap as a rhythmically determined one. These iambic languages would suffer from a rhythmic lapse, i.e., two unstressed syllables, one immediately following the other.

The second typological gap is an issue that Generalized Alignment has with bidirectional systems, where one foot occurs fixed at one edge while all others are build up starting from the opposite edge of the word. Crucially, there are no languages where secondary stresses are not built up in direction to the fixed primary stress. (Kager, 2001: 2–3; 2007: 220)

Kager proposes a theory of "Rhythmic Licensing" to overcome these problems. The idea is to abandon some of the alignment constraints proposed by McCarthy and Prince (1993) in favour of a family of constraints that evaluate the occurrence of clashes and lapses in relation to stresses and prosodic edges. The general design of Rhythmic Licensing constraints is given in 1.20.

(1.20) Rhythmic Licensing (Kager, 2001: 11)
License a rhythmic configuration X (a clash or a lapse) in the immediate context of element Y (a peak or an edge).

The particular constraints Kager proposes are called LAPSE-AT-END and LAPSE-AT-PEAK. Word initial lapses (the first typological gap) are addressed by LAPSE-AT-END while LAPSE-AT-PEAK is used to amend descriptive adequacy of bidirectional stress systems (the second gap).

(1.21) LAPSE-AT-END (Kager, 2001: 4; 2005: 8; 2007: 219)
Lapse must be adjacent to the right edge.

(1.22) LAPSE-AT-PEAK (Kager, 2001: 4; 2005: 10; 2007: 220)
Lapse must be adjacent to the peak.

The two constraints evaluate if a lapse, i.e., a sequence of two adjacent weak syllables, is adjacent to the prosodic context (stress peak or end of word). If this is not the case, a violation mark is assigned.

These licensing constraints are accompanied by the rhythmic markedness constraint 1.23 which bans sequences of unstressed syllables.

(1.23) *LAPSE (Kager, 2001: 5; 2005: 7)
No two adjacent unstressed syllables.

*LAPSE is founded on Selkirk's Principle of Rhythmic Alternation.

(1.24) The Principle of Rhythmic Alternation (Selkirk, 1984: 52)

a. Every strong position on a metrical level *n* should be followed by at least one weak position on that level.

b. Any weak position on a metrical level *n* may be preceded by at most one weak position on that level.

Kager replaces the ALLFEET-L/R-constraints (i.e., 1.17 ALIGN-FT, McCarthy and Prince, 1993) by the rhythmic licensing constraints 1.21 and 1.22. With this group of constraints the two typological gaps can be correctly predicted. A further advantage pointed out by Kager is that Rhythmic Licensing provides constraints that count violations more local than those provided by Generalized Alignment. Constraints like 1.21 and 1.21 evaluate the strict adjacency to an edge or a stress peak (Kager, 2001: 4).

To address languages that allow for unary feet as well, Kager (2001: 8-11) makes use of a rhythmic markedness constraint that works against clashes, i.e., adjacent prominent positions.

(1.25) *CLASH (Kager, 1999a: 165; Kager, 2001: 9)
No two adjacent stressed syllables.

In languages with unary feet clashes may occur easily, e.g., (ˈσ)(ˈσσ). This is however a generally dispreferred pattern (Liberman and Prince, 1977; Prince, 1983; Selkirk, 1984, see 1.24 above). Again, in Kager's (2001) complete analysis this constraint is accompanied by further constraints which either disfavour clashes in the context of main stress (*CLASH-AT-PEAK) or license it at word edges (CLASH-AT-EDGE).

A different approach is taken by Alber (2005a), who abandons ALL-FT-R but retains ALL-FT-L. The latter constraint is ranked high in languages where feet are left aligned. The mirror image – right alignment – however, is not achieved by an alignment constraint but is an effect of high ranked rhythmic markedness constraints *CLASH and *LAPSE. Alber shows convincingly that an analysis in terms of this asymmetric alignment approach yields the correct results in strictly binary systems that leave single odd-numbered syllables unparsed (*LAPSE plays a crucial role in this respect) as well as in systems allowing for degenerate feet (here the crucial constraint is *CLASH) and quantity sensitive languages. Moreover, the typological predictions made by the set of constraints used by Alber are correct. Not only are the attested stress systems predicted but it is also shown which systems do not exist and why these patterns – e.g., right aligning iambic systems, initial dactyl systems – cannot be generated.

The general conception of the two approaches by Kager and Alber bear essential differences. Alber models the asymmetric foot inventory already proposed by Hayes (1981; 1995, see page 10 above) more accurately than Generalized Alignment. Kager on the other hand puts a stronger emphasis on general rhythmical patterns like the Principle of Rhythmic Alternation. Thus, Alber stresses the role of the foot as metrical constituent and the directionality of foot parsing while Kager's approach weakens the role of these parameters.

While Kager raises the typological adequacy by separating out some aspects of rhythmic constraints that have a negative definition (e.g., *LAPSE) and reformulating them in positive, licensing constraints (e.g., LAPSE-AT-PEAK), Alber reaches the same goal by letting general rhythmic requirements and directionality compete with each other. She achieves this by just replacing one generalized alignment constraint (ALL-FT-R) with two rhythmic markedness constraints while Kager's approach demands a whole group of various rhythmic markedness and licensing constraints. Yet, this larger set of constraints might weaken the descriptive adequacy by overgenerating patterns that are not attested. The factorial typologies presented in Kager (2005: 28,29) still state a number of patterns whose existence is unclear.

In sum, recent developments in Optimality Theory aimed at reaching the best typological adequacy possible by proposing different constraint sets. Alber's and Kager's approaches are by far not the only ones in this respect. McCarthy (2003a) proposes to dismiss gradient alignment at all and to assume only constraints that are violated categorically. An advantage of this approach might be in the co-effect of a more local evaluation of the violations which in turn is desirable from a computational perspective (cf. Eisner, 1999, 2000; Bíró, 2003). Buckley (2009) picks up the proposals of Kager (2005) and McCarthy (2003a) and develops an account that uses strictly local constraint formulations and an "increased reference to foot structure" (Buckley, 2009: 389), although the latter does not become clear in his model. He focuses on rare cases of initial extrametricality, which are exemplified by Kashaya, a Hokan language spoken in California (1994: 45 Speakers, nearly extinct, c.f. Lewis, 2009). According to Kager (and Alber) such iambic languages should not exist. Buckley tries to solve this problem by giving a greater reference to prosodic constituents that the *Lapse-constraints of Kager cannot provide. However, he generally assigns possible deviations from strict locality to factors outside prosody ("typological generalisations that cannot be expressed in a local way must find their explanation in extragrammatical pressures", Buckley, 2009: 429).

My own approach outlined in this dissertation tries to take a step away from these purely typological considerations. All mentioned analyses have a quite accurate descriptive adequacy. Discussions arise mainly about the details in which these proposals really differ, what the real exceptions are and how to deal with these. It is often problematic, however, to make definite statements here, as the mere amount of descriptive data for many of the languages that exhibit a single questionable stress pattern is sparse. If one takes into account how many different proposals exist for well studied languages with a rich amount of data, corpora etc., this situation often leaves doubts. Therefore, I propose to elaborate on a well studied language, German, and to take into account data collected with recent neurolinguistic methods. This way, it is possible to carefully review existing assumptions and constraints with these "hard" data and to shed new light on theoretical issues in the analysis of word stress systems.

2 German word stress – from experiments to parsing algorithms

2.1 A short survey of ERP studies on trisyllabic words

The event related potentials (ERP) method takes electroencephalogram (EEG) recordings in which the occurrence of stimuli is marked by triggers and applies several averaging steps, e.g., by stimulus condition within the EEG of one participant and subsequently by stimulus condition within all single subject averages. As a result of these averaging procedures, brain responses that are correlated with the presentation of a stimulus are emphasized while unspecific brain responses (noise) are averaged out. The ERP derives its name from these brain potentials that are related to a stimulus event. Potentials are named according to their polarity and their occurrence in time (e.g., N400, a negative deflection at 400 ms). Potentials that are "generated in a given neuroanatomical module when a specific computational operation is performed" (Luck, 2005: 59) are called components. The high temporal resolution of ERPs makes them an excellent tool to investigate neuronal activity that occurs with word stress related processing.

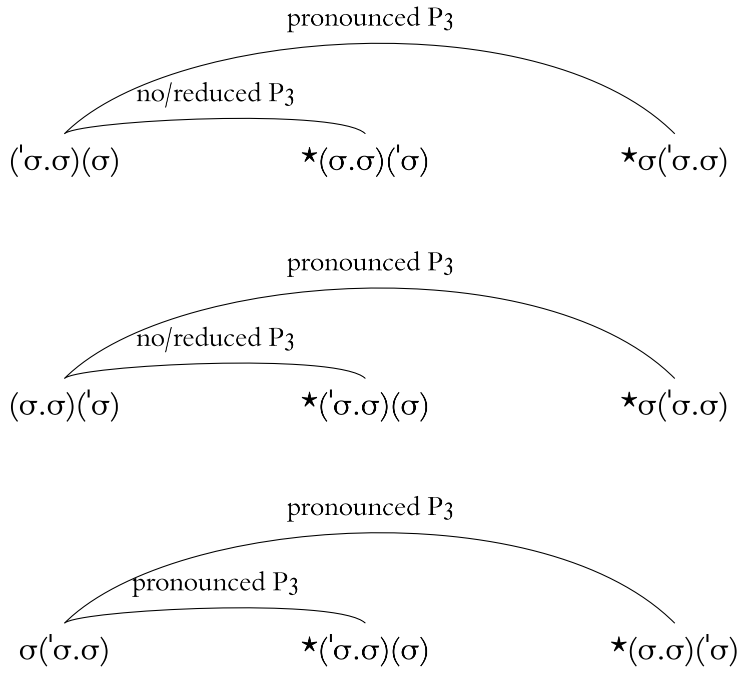
Knaus et al. (2007) examine several experimental designs of ERP studies regarding their sensitivity to manipulations of word stress. In all experiments trisyllabic German words where either presented with correct stress or with stress shifted to one of the other two syllables. ERPs were compared for the condition with correct stress with each violation condition. Table 2.1 gives a short summary of the results.

Table 2.1: Results of Knaus et al. (2007)

Experimental design	Observed effect pattern	Interpretation of effects
Stress evaluation task with auditory presentation	Biphasic N400 – P3 pattern	Inhibition in lexical retrieval reflected by N400, P3 reflects a task dependent evaluation. It is less pronounced and shifted in latency because it is overlaid by the immediately preceding N400.
Stress evaluation task with visual followed by auditory presentation	P3	P3 differing in strength and latency reflects that the task is explicit on stress evaluation/judgment. Latencies of peaks correspond to the perception of the strong syllable.
Voice discrimination task	N400	Inhibition in lexical retrieval, automatic process independent from conscious or unconscious task

Experimental designs that required participants to either recognize the unprimed word itself or to fulfill a task completely unrelated to the critical stimulus evoked an N400 for the violation condition compared to the correct condition. This effect was interpreted as a reflection of increased lexical retrieval costs. In those designs where a conscious evaluation was necessary, i.e., where participants had to focus their perception on the prosodic structure of the stimulus, positive deflections showed up. The latency of these positivities corresponds to the evaluation of the respective stressed syllable. Furthermore, the positivities differ in form and strength. This is only explainable by assuming foot structure (Knaus and Domahs, 2009; Domahs et al., 2008). In short, the results sum up as follows. The comparison of an expected stress pattern with a deviating pattern evokes a positivity effect (P3; more specifically, a so called P3b, cf. Picton, 1992; Coulson et al., 1998, among others). This effect is stronger, if syllables have to be reorganized into new foot structures, see figure 2.1. Thus, the P3-effects found are interpretable if foot structures are assumed.

Figure 2.1: P3 occurrence and foot structures



Knaus and Domahs (2009) use these findings as a basis for an optimality theoretic analysis of German word stress in trisyllabic words.

The need for foot structure is expressed in Optimality Theory by the constraint Parse-σ. Further, ternary feet cannot explain the different strength of the positivities found. The effort needed for the reorganization of prosodic structure would be equal for all three conditions, if we assumed ternary feet. Therefore, FootBinarity has to be a high ranked constraint in German. FootBin dominates Parse-σ, i.e., there are no degenerate feet in German and a single light syllable always remains unparsed. German is regarded as a trochaic system. This shows up in the ERP results as well. Alternative iambic structures for antepenultimate, penultimate and final stress, e.g., (ˈσ)(σσ), (σˈσ)σ, and σ(σˈσ), cannot explain the positivity distributions found because foot structure would have to be rebuilt in each case. Moreover, it would be problematic to find a proper iambic parsing for antepenultimate stress in trisyllabic structures with a light initial syllable. With trochaic parsings there is always the opportunity to form an initial disyllabic trochee in these cases while iambic parsings would suppose a degenerate foot here, that would violate high ranked FOOTBINARITY. Finally, the assumption of a trochaic parsing only for antepenultimate stress and iambs in all other cases, i.e., (ˈσσ)(σ), (σˈσ)σ, and (σ)(σˈσ), would suffer from the same lack of explanatory power as applying iambic structures only. A change in foot structure would be predicted for every stress shift. As a consequence, it is assumed that all feet in German have initial prominence which is encoded in the constraint RHTYPE=T. Together with the equally high ranked FOOTBIN, RHTYPE=T creates a binary alternating trochaic pattern that forms the basic rhythmic pattern in German words.

The tableaux 2.1 and 2.2 show partial rankings of the three constraints introduced. Both structures are taken as examples here as they cover the major part of all possible rankings. It becomes obvious that a ranking of these three constraints already generates the prosodic structures implied by the experimental findings.

Tableau 2.1: Partial ranking for words with three light syllables

	/L.L.L/	RHTYPE=T	FOOTBIN	PARSE-σ
(a)	L.L.L			⋆⋆!⋆
(b) ☞	(ˈL.L).L			⋆
(c) ☞	L.(ˈL.L)			⋆
(d)	(L).(ˈL.L)		⋆!	
(e)	(ˈL.L).(L)		⋆!	
(f)	(ˈL.L.L)		⋆!	
(g)	(L.ˈL).(L)	⋆!	⋆	

However, further constraints are needed to determine a winner for each of the inputs. To generate penultimate stress – which of course is an attested stress pattern in German and even seen as the default or regular pattern in

Tableau 2.2: Partial ranking for words with two light syllables followed by a heavy one

	/L.L.H/	RhType=T	FootBin	Parse-σ
(a)	(ˈL.L).H			⋆!
(b)	L.(ˈL.H)			⋆!
(c)	(L).(ˈL.H)		⋆!	
(d) ☞	(ˈL.L).(H)			
(e) ☞	(L.L).(ˈH)			
(f)	(ˈL.L.H)		⋆!	
(g)	(L.ˈL).(H)	⋆!		

many analyses (Eisenberg, 1991; Kaltenbacher, 1994; Wiese, 2000) – a constraint that determines the position of main stress has to be added to the ranking. This constraint is Rightmost which demands the head foot, i.e., the foot carrying main stress, to coincide with the right word edge. With Rightmost the candidate with penultimate stress L.(ˈL.L) will be selected as winner in tableau 2.1 and the candidate with final stress (L.L).(ˈH) in tableau 2.2. Antepenult stress is seen as a lexical exception by Knaus and Domahs (2009) which may be generated by a lexically indexed NonFinality constraint, i.e., a version of NonFinality that is active only for a prespecified group of words, as is proposed by Pater (2000). This constraint ranked above Rightmost would generate the attested antepenultimate stress patterns in German.

In addition, Knaus and Domahs (2009) – following Alber (1997b, 1998) – assume two further constraints to complete the analysis of stress in German trisyllabic words, ⋆Clash and AllFeet-L.

For trisyllabic inputs the high ranked ⋆Clash blocks the parsing of the initial syllable into a unary foot, as this would result in a structure with two adjacent foot heads in a trochaic language. This way, ⋆Clash is decisive for /H.L.L/ and /H.H.L/ inputs to be parsed as H.(L.L) and H.(H.L) (see tableaux 4 and 2 in Knaus and Domahs, 2009: 1401,1400), whereas /H.L.H/ and /H.H.H/ are parsed as (H.L)(H) and (H.H)(H) but not (H).(L.H) and (H).(H.H) (see tableaux 6 and 7 in Knaus and Domahs, 2009: 1402–1403).

AllFeet-L requires that feet are constructed from the left word edge to the right. This requirement is restricted by Parse-σ that calls for exhaustive parsing. Therefore, candidates like (ˈH).L.L which would satisfy best AllFeet-L but violate Parse-σ several times can never arise as optimal candidate (see tableau 4 in Knaus and Domahs, 2009: 1401). Nevertheless, AllFeet-L can influence the shape of prosodic structure of German words even as lowest ranked constraint. A candidate that completely satisfies Parse-σ by exhaustive footing always has the structure of a disyllabic foot followed by a monosyllabic one, as the reversed pattern would always imply one additional violation to AllFeet-L. Moreover, AllFeet-L restricts the total number of feet in a word. An input /H.H.H/ could never be parsed as (H).(H).(H) because candidates with only two feet would always produce one violation mark less. However, these effects of AllFeet-L are never decisive for the optimal output in trisyllabic words since the relevant candidates violate higher ranked constraints (*Clash, Rightmost, FootBin) as well.

As regards the role of weight encoded by the OT constraint WSP (see 1.12 on page 19) in the ranking of Knaus and Domahs (2009), there is no candidate where adding WSP, no matter where placing it in the hierarchy, would change the optimal output. If WSP plays a decisive role in the investigation of longer words, remains to be determined. Nevertheless, Knaus and Domahs (2009: 1409-1410) could show some initial evidence for weight sensitivity at word end. They elaborate on data from a study reported in Domahs et al. (2008) where words with correct (but lexically exceptional) antepenultimate stress differ in the weight of the final syllable (e.g., *ˈRi.si.ko* "risk" and *ˈLe.xi.kon* "lexicon"). In both word forms, stress shifts to the penultimate syllable involve prosodic restructuring. However, the expected positivity effect is significant only in words with a closed final syllable. According to the OT ranking proposed, words with stress on the penult always have an initial unparsed syllable followed by a trochee, i.e., σ(σσ). Consequently, in words with a closed final syllable, the shift does not only imply prosodic restructuring but also a heavy syllable in a weak position of a foot. In the ranking, the parsing of a heavy final syllable into a single foot is already ensured by the high ranked constraint *Clash, see above.

ERP results from studies on trisyllabic stimuli cannot provide definitive experimental evidence for the constraints *Clash, AllFeet-L, and WSP. Longer structures that offer more directional alternatives and more possibilities of secondary stress realizations might shed some light on this issue. This will be explored in the following chapter where the experimental design introduced so far will be exploited for words with five syllables. In a second section the experimental results will be taken as a basis for a discussion of relevant OT constraints that are involved in accounts for secondary stress placement in German.

To sum up the results for German trisyllabic words, it can be stated that, although there is ample variation in stress positions and a large amount of lexical prespecification (see corpus studies in, e.g., Janßen, 2003; Féry, 1998), German is not a language where stress is just stored with any entry in the lexicon. Word stress placement depends on the internal prosodic structure of a word. Trisyllabic words can either be parsed by a single disyllabic trochee, as in all syllable structures that have a light final syllable, or by two feet if the final syllable is heavy. While the weight of the word final syllable influences foot parsing, the weight of the first syllable does not play any special role. This corroborates analyses which suggest that German is only a partially quantity sensitive language (Alber, 1997b).

2.2 Publications: Knaus et al. (2007) and Knaus and Domahs (2009)

(see next page)

THE PROCESSING OF WORD STRESS: EEG STUDIES ON TASK-RELATED COMPONENTS

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ABSTRACT

The present paper reports results from three ERP studies showing components which reflect the processing of different word stress violations dependent on distinctive task properties (explicit vs. implicit processing).

The main findings were that the presentation of an incorrect stress pattern led to an N400-like component indicating increased costs in lexical retrieval. Such a component is not dependent on the task during the processing of stress violations. Furthermore, an enhanced positivity effect (P300) reflects a stress mismatch detection only if stress judgment was explicitly required in the task.

Keywords: word prosody, stress perception, ERPs, N400, P300

1. INTRODUCTION

The present paper deals with the questions how far the language processor makes use of information from word stress, and in which way the usage of such information is influenced by different tasks.

To test this, we conducted three ERP studies in which the position of main stress in German tri-syllabic words was manipulated. Between experi-ments, the processing tasks varied from explicit judgments on stress violation in different modal-ities to the implicit processing of stress errors. These tasks offer the possibility to examine pro-cesses as different as the lexical integration of stress information, matching of internally gener-ated and externally presented patterns, and the evaluation of stress patterns.

2. EXPERIMENT 1

In order to find out how incorrectly stressed words are processed, we performed an ERP experiment in which participants were presented with correctly and incorrectly stressed words which should be judged explicitly. Previous ERP experiments using a stress discrimination task with bisyllabic words ([1], [4]) revealed inconsistent results with respect to stress effects on word processing.

2.1. Method

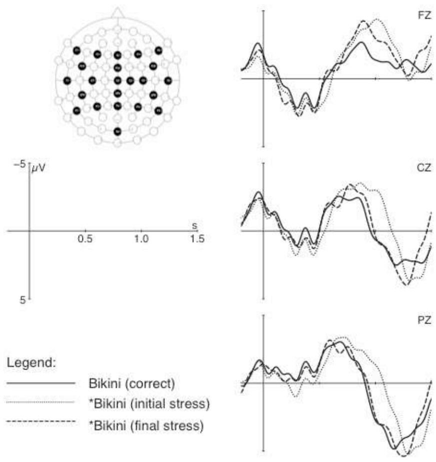
- Naturally spoken trisyllabic German words with penultimate stress containing either correct (e.g. *Bikíni*) or incorrect (initial: **Bíkini* or final: **Bikiní*) stress patterns were recorded. Sampling rate was 44 KHz, 16 bit (mono) using CoolEditPro (version 1.2; Syntrillium Software Corporation) and an electret micro-phone (Sennheiser K6, ME 66).
- The syllabic structure of the stimuli was either XV.XV.XV or XV.XVC.XV and did not contain reduced syllables (mean length of stimuli 1063 ms).
- Stimulus set of critical items consisted of 30 stimuli per condition.
- Each stimulus was spliced into an invariant carrier sentence (*Er soll nun* ***Bikini*** *sagen* ‘He is supposed to say Bikini’).
- Filler items were included to balance the number of correctly and incorrectly stressed words. Each stress pattern occurred in correct and incorrect conditions.
- Participants (18 German monolinguals, 13 fem.) had to judge the correctness of the presented stimuli.
- EEG measurement was by means of 22 AgAgCl electrodes via a *Brainvision* amplifier (C2 electrode served as ground electrode, reference electrode placed at left mastoid), impedances kept below 5 kΩ, EEG and EOG recorded with a digitisation rate of 250 Hz, filtered offline with a bandpass filter from 0.3 to 20 Hz.
- Averages were calculated from the onset of the critical items up to 1500 ms post onset with a baseline of 200 ms before stimulus onset.
- For comparison of mean voltage differences between conditions, three time-windows were selected (from 700 to 1200 ms, from 1100 to 1300 ms, and from 1300 to 1500 ms).

- ANOVAs were calculated for the factor STRESSPOSITION (correct vs. initial or final) over midline electrodes (Fz, Cz, Pz).

2.2. Results

Behavioral Data:
Error rates were below 4 per cent for each condition. Analysis of accuracy scores revealed no differences between correct and incorrect conditions (F(2,34)<1). Reaction time data were not analyzable, since reactions were only required after the offset of the carrier sentence to avoid movement artifacts.
ERP Data:
Negativity effects between 700 to 1200 ms: An overall comparison between conditions revealed a main effect for the factor STRESSPOSITION (F(2,34)=29.01, p<.001). Furthermore, a separate analysis of contrasts between the correct condition and each of the incorrect ones revealed that both types of incorrect stress evoked a negativity effect (*Bikíni* vs. **Bíkini*: F(1,17)=64.72, p<.001; *Bikíni* vs. **Bikiní*: F(1,17)=5.98; p<.037).
Positivity effects between 1100 to 1300 ms / 1300 to 1500 ms: Stress violations with final stress induced a positivity effect between 1100 to 1300 ms (F(1,17)=7.68, p<.014) and with initial stress between 1300 to 1500 ms (F(1,17)=4.491, p<.05). The positivity effect for initially stressed words is shifted in latency due to the preceding strong negativity in comparison to incorrect words with final stress (see Fig. 1).

Figure 1: Grand average curves of correctly (solid line) stressed words, words with incorrect antepenultimate stress (dotted line) and with incorrect final stress (dashed line).



2.3. Discussion

As shown in Fig. 1, the processing of incorrect words led to a biphasic ERP pattern: a fronto-central negativity effect between 700 and 1200 ms and a positivity effect between 1100 to 1300 ms or 1300 to 1500 ms, respectively.

With respect to the negativity, such a component can be interpreted as an instance of an N400 effect implying that a stress shift increases costs in lexical retrieval. Higher costs in lexical retrieval have also been found in behavioral studies (e.g. [3]). The late occurrence of the N400 effect can be ascribed to the presentation modality and the length of the auditory stimuli.

The subsequent positivity effect for incorrect conditions indicates the evaluation process related to the task requirements. Due to the prior negativity effect, the actual latency and strength of the evaluation effect is hidden. In the second experiment, we will investigate how a mismatch detection is processed when higher costs in lexical retrieval are excluded.

3. EXPERIMENT 2

If the negativity effect in the first experiment indicates an increase of activation load during the process of lexical access, we expect that such an effect would be excluded by the visual presentation of each critical stimulus prior to auditory presentation.

We hypothesized that the detection of a stress violation should produce stronger effects if participants compared an internally activated stress pattern with the presented one (additional results of experiment 2 relating to prosodic structure and other patterns of word stress are reported in [5]).

3.1. Method

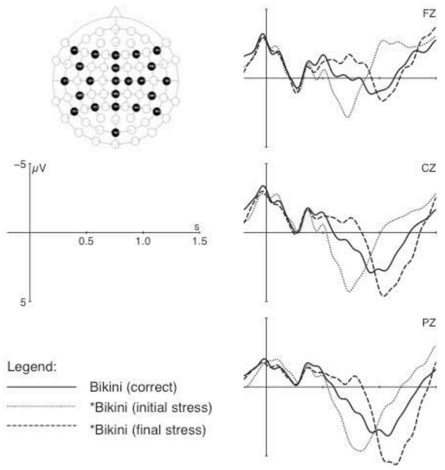
Material, method and EEG measurement were mostly identical to those outlined for experiment 1, with a task modification only for the stimulus presentation: 24 participants (12 females) were first presented with each critical item *visually* (for 500 ms) before they heard the item with either correct or incorrect stress pattern.

For comparison of mean voltage differences between conditions, two time-windows were selected by means of visual inspection (from 500 to 800 ms and from 900 to 1400 ms).

3.2. Results

Behavioral Data:
No decrease in accuracy was detected. Analysis of accuracy scores revealed no differences between correct and incorrect conditions ($F(2,46)=1.716$, $p>.20$).
ERP Data:
Positivity effects between 500 to 800 ms / 900 to 1400 ms: A separate analysis of contrasts between the correct condition and each of the incorrect ones revealed that both types of incorrect stress evoked an enhanced positivity effect (*Bikíni* vs. *Bíkini*: $F(1,23)=33.304$, $p<.001$; *Bikíni* vs. *Bikiní*: $F(1,23)=13.913$; $p<.002$) (see Fig. 2).
Negativity effect for words with final stress occurred between 500 to 900 ms ($F(1,23)=31.98$, $p<.001$); see Fig 2.

Figure 2: Grand average curves of correctly (solid line) stressed words, words with incorrect antepenultimate stress (dotted line) and with incorrect final stress (dashed line).



3.3. Discussion

In contrast to experiment 1, we did not obtain a biphasic ERP pattern, but mainly pronounced positive deflections. Positivity effects for the different stress violations occur in distinctive latencies: incorrect initial stress yielded positivity between 500 to 800 ms, and incorrect final stress between 900 to 1400 ms. Thus, ERPs seemed to be time-locked to the perception of an incorrect strong syllable.

We interpret the ERP findings to indicate that the perception of deviant stress patterns did not produce an N400 effect (the negativity effects observed for the two types of violations are deflections caused by the pronounced positivity), but only effects which seem to be task-related, i.e. related to a stress mismatch detection. Note that the participants' lexical access to the words was provided by the visual presentation of the items. In the literature, such effects have been labeled P300 effects (e.g. [6]). Interestingly, the latency of this type of effect seems to depend on the position of an ill-stressed syllable. This finding is compatible with the Metrical Segmentation Strategy account (e.g. [2]) which assumes that the relevant prosodic information for a word's segmentation is given by the position of main stress.

4. Experiment 3

In a voice discrimination task, the goal was to investigate the processing of stress deviations when the task itself does not require attending to prosodic information. In particular, it was to test the task dependency of the effects found so far, namely the N400 and P300.

4.1. Method

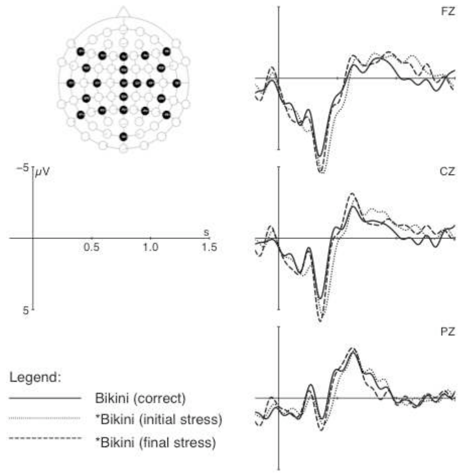
- Recording of naturally spoken trisyllabic words produced by two female speakers (parameters identical to Exp. 1).
- Test material was identical to Experiment 1.
- Each stimulus was presented in isolation and immediately repeated (inter-stimulus interval of 900 ms), by either the same or other speaker.
- Participants (20 German monolinguals, 9 fem.) had to judge whether the second word was produced by the same or a different speaker.
- EEG recording was identical to previous experiments. EEG was filtered offline with a bandpass filter from 0.5 to 20 Hz.
- Averages were calculated from the onset of the first word up to 1500 ms with a baseline of 200 ms before stimulus onset.
- Time window for mean voltage comparisons between correct vs. incorrect stress were chosen from 920 to 1420 ms.

4.2. Results

Behavioral data:
Error rates were appr. 1% for each condition. Analysis of accuracy scores revealed no significant difference between correct and incorrect conditions ($F(2,38)=2.01$, ns).
ERP Data:
Negativity effects between 920 to 1420 ms for incorrect conditions in comparison to the correct

condition: An overall comparison between conditions revealed a significant interaction of the factors STRESSPOSITION and REGION (Fz, Cz, Pz) (F(2, 38)=6.179, p<.002). Post hoc analyses showed a significant difference between correctly stressed words and words with antepenultimate stress in frontal region (F(1, 19)=6.272, p<.023) and a global difference between correctly stressed words and words with final stress (F(2,38)=10.24, p<.006).

Figure 3: Grand average curves of correctly (solid line) stressed words, words with incorrect antepenultimate stress (dotted line) and with incorrect final stress (dashed line).



4.3. Discussion

In the third experiment in which participants had to discriminate voice, and not stress differences, we observed an enhanced fronto-central negativity for both types of incorrectly stressed words. As in experiment 1 we interpret such a negativity as an instance of an N400 effect. In contrast to the previous findings, no positivity effect occurred due to the task difference. Participants focused on voice instead of stress distinctions.

These findings demonstrate that even in implicit stress processing deviant prosodic patterns produce a mismatch during lexical retrieval.

5. GENERAL DISCUSSION

The findings of the present paper contribute to the question how the speech perception system deals with metrical information. In this respect, errors of word stress led to two different electrophysiological responses reflecting diverse cognitive processes.

First, a negativity effect occurred in experiments 1 and 3 where incorrectly stressed words led to an inhibition during the lexical retrieval process. This N400 effect, however, is not related to whether the task requires attention to stress violations.

As a second result, ERP measurements revealed a positivity effect in both Exp. 1 and 2, yet differing in strength and latency. We interpret such a component (P300) to be reflecting the explicit judgment of correct and incorrect stress as required by the evaluation task. In Exp. 1 the P300 is less pronounced and shifted in latency, as the evaluation task could be performed only after lexical retrieval was accomplished. Thus, the P300 interfered with the preceding N400 effect diminishing the amplitude in the positive deflections. In Exp. 2 this interference was avoided by presenting the critical stimuli visually prior to their auditory presentation. Therefore the task allowed a focus on stress judgment. Latency differences of P300 effects between Exp. 1 and Exp. 2 are due to distinct strengths of the N400. The absence of the positivity effect in Exp. 3 confirms that this effect is due to task-relevant match-mismatch processing rather than being due to perception of stress violations per se.

To summarize, the observed effects have two important implications for prosodic processing: i) violations of stress patterns evoke an N400 effect reflecting lexical inhibition which is an automatic process observable in both conscious and unconscious perception, ii) the explicit evaluation of stress patterns surfaces in P300 effects whose latencies are correlated with the perception of a strong syllable.

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Experimental evidence for optimal and minimal metrical structure of German word prosody

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Abstract

In the present paper a constraint-based description of German word prosody is suggested in which the constraint ranking is in crucial parts supported empirically by experimental findings from a pseudoword production task and from studies using electrophysiological measurements. It is shown how stress patterns of existing German words as well as experimental results on diverse prosodic structures can be expressed by minimal violations of prosodic constraints. In this way, our analysis aims to gain more insights into the question, which metrical structures are least marked in German. Furthermore, an aspect of minimality in metrical systems is considered, which regards the structure of metrical feet in German. Can we establish strict binarity of feet or do we find evidence for ternary structures?

Keywords: German; Word prosody; Optimality Theory; Foot type; Quantity sensitivity; Syllable parsing; Event-related potentials

1. Introduction

In the literature on Metrical Theory, a wide range of work is dedicated to the question of how prosodic systems can be described best. In this respect, the metrical account proposed by Hayes (1981, 1995) was most influential, according to which prosodic systems are defined along a set of prosodic parameters. The most important ones are foot type (trochee or iamb), direction (syllable parsing from left to right or vice versa), quantity sensitivity (yes or no), and end rule (right- or leftmost foot is strong; Prince, 1983). From a typological as well as from a single-language perspective such parameters are useful to capture language specific peculiarities and to generalize over a variety of languages in order to define universals on prosodic structure. However, in some languages it is difficult to determine a specific parameter setting. In German for instance, it is not quite clear how crucial some of the parameters are and how they are set. More specifically, many German words follow a quantity-sensitivity parsing (e.g. *Dirigént* 'conductor' or *Agénda* 'agenda'), but there also exists a considerable amount of counter-examples, in which stress is rather assigned to a certain position than to a heavy syllable (e.g. *Fázit* 'conclusion'). In more recent accounts on metrical phonology, the prosodic parameters proposed by Hayes are expressed in terms of optimality-theoretic constraints which allow for a non-categorical parameter setting. In this respect some degree of variation can be explained by the ranking and

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interaction of wellformedness constraints (e.g. Alber, 1997; Féry, 1998; Pater, 2000). Optimality Theory (Prince and Smolensky, 1993/2004) has been proven to be a useful framework to capture prosodic systems with the fundamentals established by McCarthy and Prince (1993) and Kager (1999) among others.

With respect to the analysis of German word prosody, there are still unsolved questions. Are feet strictly binary or do we have to assume ternary structures? Are spare syllables parsed into degenerate feet or left unparsed? Does syllable weight influence the parsing of syllables into feet? The major goal of this paper is to find answers to these questions by discussing experimental findings in the light of theoretical conflicts.

Another aspect of the present paper is concerned with the economy of representing prosodic structures. In phonology, the notion of minimality surfaces mainly in accounts on markedness or underspecification (see also Buchwald, 2008; Scharinger, 2008 for a detailed discussion). Regarding prosodic systems, minimality has also been discussed by means of the minimal shape of prosodic entities. McCarthy and Prince (1998) observed that in a variety of morphophonological processes like prosodically restricted reduplications in Diyari or shortenings of proper names in English output forms must satisfy the minimal word condition. A short name or a reduplicant must consist of at most a foot, which is either bimoraic or disyllabic and thus corresponds to the minimal word. With reference to such requirements our goal is to demonstrate theoretically and empirically that the foot inventory of German is restricted to binary feet only, speaking against the assumption that ternary feet (e.g. dactyls) are possible prosodic entities (as is proposed for instance by Burzio, 1994; Halle and Vergnaud, 1987). Furthermore, we will establish an account of unmarked prosodic structure focussing on the most controversial principles of Metrical Theory in German word prosody: foot type, metrical parsing of stray syllables, and quantity sensitivity.

Our theoretical considerations will be supported by experimental findings from production tasks and from the field of electrophysiological investigations. Analyses of different violations of prosodic structure can show us under which circumstances our brain detects severe metrical structure violations. Violations are induced by a shift in stress positions, leading to a changed prominence relation between syllables and possibly to a reorganization within prosodic hierarchies. Different brain responses for different violations can tell us more about preferences for certain prosodic structures within the language system.

In general the empirical results will evaluate the role of certain prosodic constraints proposed in the OT literature and the importance of these constraints within a constraint hierarchy.

Regarding German word prosody the following properties are commonly assumed: German monomorphemic words allow for three different stress positions: final stress (*Vitamín* 'vitamin'), penultimate stress (*Kasíno* 'casino'), and antepenultimate stress (*Léxikon* 'lexicon'). In words longer than three syllables the Three-Syllable Law (Vennemann, 1991b) restricts the landing site for main stress to the three final syllables showing that in Modern Standard German stress is assigned from the right edge of the word. Regarding the parameters holding for prosodic systems suggested by Hayes (1981, 1995), the German system can be further defined as follows. The rhythm of German words is unequivocally characterized as a trochaic rhythm. It is however under debate whether syllable weight plays a role in the parsing of syllables and in the assignment of stress. Thus, some phonologists argue that penultimate stress is the only regular stress pattern irrespective of the weight of the final and penultimate syllable (e.g. Eisenberg, 1991; Kaltenbacher, 1994; Wiese, 1996/2000) and stress on other positions has to be lexically specified. The underlying prosodic structure, from which the penultimate pattern results, is a word final trochee (e.g. *Ve*(*rán.da*)$_F$ 'porch'). In contrast, Giegerich (1985), Féry (1998), and Ramers (1992) assume that final heavy syllables attract word stress and final light syllables lead to penultimate or antepenultimate stress depending on the structure of the penult. In section 4 we will present a more detailed discussion on quantity sensitivity in German.

2. An OT-analysis of German word stress

In this section, we will present an OT-analysis for German word prosody using OT constraints already proposed in the literature. In certain aspects we will follow previous optimality-theoretic analyses of word stress in German (Alber, 1997; Féry, 1998). But in contrast to the OT-analysis proposed by Alber (1997), our model will concentrate on monomorphematic words of German containing up to three syllables.

Before we present our OT-analysis, we will first introduce some constraints that have been proposed in the OT literature and which have been proven to be highly relevant for the description of prosodic systems. In the second part of this section, we present an OT account on the description of monomorphemic trisyllabic words of German. The aim of our analysis is to capture each type of main stress pattern that is attested in German words. Although most German words are mono- or disyllabic, a better understanding about the German stress system is achieved by investigating trisyllabic words with all possibilities of stressing. Furthermore, to represent only the core metrical structure, our analysis will be oriented along counts of stress distributions in German words and pseudowords with varying syllable structures (Janßen, 2003a). Such analyses of correspondences between syllable structures and certain stress patterns provide us with information on most frequent prosodic structures. Thus, leaving aside exceptional cases, the presented OT-analysis is designed to explain the most frequent stress patterns observed for different types of words varying in syllable structure.

In particular, we will concentrate on Janßen's study on trisyllabic pseudowords, as these reflect regular processes of stress assignment rather than irregular ones (cf. Janßen, 2003a). Janßen found the following distributions of stress patterns: The clearest preferences for a certain stress position were found for trisyllabic words containing the sequences of light (L) and heavy (H) syllables L.L.L, L.H.L and H.H.L. These words were predominantly stressed on the penultimate syllable (L.L.L in 71.5%, L.H.L in 89.6%, and H.H.L in 85.3% of cases). For other structures stress preferences were not distributed so clearly. Words of the sequence L.L.H elicited nearly equal occurrences of antepenultimate stress (42.3%) and ultimate stress (38%). The same holds for H.L.H words (47.8% antepenultimate stress, 34.6% ultimate stress). The most balanced distribution of different stress patterns was found for words of the structure L.H.H (24.8% antepenultimate, 35.3% penultimate and 40% ultimate stress). In the following, the observed preferences for certain stress patterns in words with different syllable sequences will be the starting point for our OT-analysis, whose ranking should capture also the empirical data.

2.1. *Prosodic constraints relevant for the description of German word stress*

In accordance with the major part of the literature on word stress, we claim that stress assignment depends on underlying foot structures. Only footed syllables can be stressed. Therefore, foot structure obligatorily has to be built up. The optimality-theoretic constraint that triggers the formation of feet by grouping syllables together is PARSE-σ.

(1) PARSE-σ
"Syllables are parsed by feet." (Prince and Smolensky, 1993/2004)

Besides PARSE-σ as constraint calling for structure building further constraints demand specific types of foot structures. The OT literature has adopted Hayes' (1981, 1995) view of a strictly binary foot template and has reformulated this template as a violable constraint called FOOTBINARITY.

(2) FOOTBIN
"Feet are binary at some level of analysis (μ, σ)" (Prince and Smolensky, 1993/2004)

This markedness constraint requires that feet must contain either two moras or two syllables. If this constraint is undominated in a language – as we propose in our analysis for German – it also prevents the occurrence of degenerate feet, which consist only of one light (i.e. monomoraic) syllable. The minimal foot should be bimoraic.

The rhythmic requirement described by FOOTBINARITY implies that – from a processing perspective – feet should be constructed either out of one or two syllables. In contrast, ternary feet containing three syllables or three moras ought to occur – if at all – only in rare circumstances. If FOOTBINARITY plays a role in prosodic processing, we should find some experimental reflection of the parser constructing binary structure (see section 3 below).

German is regarded as a language with trochaic rhythm. This foot-internal rhythmic alternation of a strong followed by a weak syllable is expressed by the constraint RHYTHMTYPE=TROCHEE, which is undominated in German (cf. Alber, 1997; Féry, 1998).

(3) RHTYPE=T
"Feet have initial prominence." (Prince and Smolensky, 1993/2004; Kager, 1999; and others)

The overall majority of penultimate stress in German disyllabic words with only light syllables (cf. Féry, 1998) can be interpreted as an indication for the high ranking of RHYTHMTYPE=TROCHEE.

In many languages adjacent stressed syllables are avoided (cf. Liberman and Prince, 1977). This well known dispreference is formulated in the constraint *CLASH.

(4) *CLASH
"No stressed syllables are adjacent." (Kager, 1994, 1999; Alber, 1997)

*Clash is violated if two stressed syllables occur next to each other. This is the case when the heads of two feet are adjacent, i.e. ('σ)('σσ), ('σ)('σ)σ, σ('σ)('σ) or ('σ)('σ)('σ). *Clash is satisfied, e.g. by ('σσ)('σ), σ('σσ) or ('σ)σ('σ).

With respect to the direction of syllable parsing, we assume that stress assignment (including secondary stress) in German proceeds from the left edge of the word to the right (cf. Alber, 1998). Correspondingly, feet are constructed starting at the left word edge. This directionality parameter is expressed in OT terms by the constraint ALLFEET-LEFT. To ensure exhaustive parsing of syllables into feet and left-to-right directionality this constraint must be ranked below PARSE-σ. Due to this low ranking ALLFEET-LEFT does not play an active role in the stress assignment of trisyllabic words. Nevertheless, the consequences of ALLFEET-LEFT violations become visible when secondary stress is assigned, but this is only visible in words longer than three syllables (see Alber, 1997, 1998).

(5) ALLFT-LEFT (ALIGN (FT, L, PRWD, L))
"Every foot stands in initial position in the prosodic word."
(McCarthy and Prince, 1993)

A further crucial property of German main stress is that main stress assignment obeys the three-syllable window restriction (Vennemann, 1991b). Accordingly, one of the three last syllables carries primary stress. In OT, this right edge preference is expressed by the constraint RIGHTMOST.

(6) RIGHTMOST (ALIGN HEAD-FT, R, PRWD, R)
"The right edge of the head foot coincides with the right edge of the prosodic word."
(Prince and Smolensky, 1993)

Considering this basic set of constraints, we can cover the most relevant properties of German word stress, and the ranking of these will be the starting point for our analysis.

2.2. Rankings

In the following tableaux we will show how the constraints (1)–(6) are interacting in a ranking for German word stress. Evaluations of candidates in which groupings of syllables into feet and main stress positions differ will be exemplified by trisyllabic words varying in syllable structure (LLL, LLH, LHL, LHH, HLL, HHL, HLH, and HHH). In the candidates, the parsing of syllables and the stress positions are kept constant across Tableaux 1–8, the tableaux differ only with respect to the word types in the input, in which heavy and light syllables are combined differently. The complete constraint ranking is presented in each tableau, although not all ranking arguments are deducible from every single tableau.

The first word type to be discussed is the group of words consisting of three light syllables like *Bi.kí.ni*, *Ka.sí.no* ('casino'), *Mi.ká.do* ('pick-a-stick'). In Tableau 1, the optimally stressed candidate is determined by the evaluation of 12 possible candidates varying in syllable parsing and stress position.

The high-ranked constraint RHYTHMTYPE=TROCHEE is violated by feet with non-initial prominence (i.e. iambs, see candidate (j)). PARSE-σ ranked above ALLFEET-LEFT requires exhaustive parsing of syllables into feet. Exhaustivity is blocked here by FOOTBINARITY: In words with exclusively light (i.e. monomoraic) syllables, the required trochees can only be parsed in a disyllabic manner: Both monosyllabic (in candidates (c)–(i) and (l)) and even trisyllabic feet (candidate (k)), which satisfy PARSE-σ and ALLFEET-LEFT, can never surface as optimal forms as they violate the undominated constraint FOOTBINARITY.

The ranking of FOOTBINARITY over PARSE-σ ensures that feet have the smallest possible shape. In words with three light syllables a foot can never be larger or smaller than two syllables. As three light syllables can never be parsed

Tableau 1

	/L.L.L/	RhType=T	*Clash	FootBin	Rightmost	Parse-σ	AllFt-L
(a)	('L.L).L				*!	*	
(b) ☞	L.('L.L)					*	*
(c)	('L).(L.L)		*!	*	**		*
(d)	(L).('L.L)		*!	*			*
(e)	('L.L).(L)			*!	*		**
(f)	(L.L).('L)			*!			**
(g)	('L).(L).(L)		*!*	***	**		***
(h)	('L).L.L			*!	**	**	
(i)	('L).L.(L)			*!*	**	*	**
(j)	(L.'L).L	*!			*	*	
(k)	('L.L.L)			*!			
(l)	L.L.('L)			*!		**	**

exhaustively without violating FootBinarity the optimal form must have an unparsed syllable, which is necessarily a violation of Parse-σ. There is no alternative to leaving one of the syllables unparsed, as building up a monomoraic foot would violate FootBinarity (see candidates (c)–(i) and (l)).

Rightmost ranked above Parse-σ and AllFeet-Left has the effect that out of the two remaining candidates (a) and (b), (b) is chosen as the winner. Since the foot carrying main stress should be rightmost in a word, the best position for an unparsed syllable is the left word edge. This ranking ensures that in words consisting of only three light syllables, i.e. without any influence of syllable weight, penultimate stress is the optimal pattern.

The candidates (c), (d), (g) additionally show violations of *Clash as they can have secondary stress adjacent to main stress. In words with three light syllables this does not produce any ranking differences: A stress clash in such words implies that a single light syllable has been footed, therefore a violation of *Clash leads necessarily also to a violation of the equally high ranked constraint FootBin.

A different picture arises in Tableau 2 for words like *Schimpánse* ('chimpanzee'), *Embárgo*, etc. which have two heavy syllables followed by a final light one. Single heavy syllables can form a foot on their own (in the candidates (c), (d), (g), (h), (i)) and satisfy FootBin through their bimoraic structure (the candidates (g), (i) violate FootBin because they additionally have a footed single light syllable). However, these candidates cannot emerge as optimal. If the first

Tableau 2

	/H.H.L/	RhType=T	*Clash	FootBin	Rightmost	Parse-σ	AllFt-L
(a)	('H.H).L				*!	*	
(b) ☞	H.('H.L)					*	*
(c)	('H).(H.L)		*!		**		*
(d)	(H).('H.L)		*!				*
(e)	('H.H).(L)			*!	*		**
(f)	(H.H).('L)			*!			**
(g)	('H).(H).(L)		*!*	*	**		***
(h)	('H).H.L				**	**	
(i)	('H).H.(L)			*!	**	*	**
(j)	(H.'H).L	*!			*	*	
(k)	('H.H.L)			*!			

Tableau 3

	/L.H.L/	RhType=T	*Clash	FootBin	Rightmost	Parse-σ	AllFt-L
(a)	('L.H).L				*!	*	
(b) ☞	L.('H.L)					*	*
(c)	('L).(H.L)		*!	*	**		*
(d)	(L).('H.L)		*!	*			*
(e)	('L.H).(L)			*!	*		**
(f)	(L.H).('L)			*!			**
(g)	('L).(H).(L)		*!*	**	**		***
(h)	('L).H.L			*!	**	**	
(i)	('L).H.(L)			*!*	**	*	**
(j)	(L.'H).L	*!			*	*	
(k)	('L.H.L)			*!			
(l)	(L.'H.L)	*!		*			
(m)	L.('H).L				*!	**	*

syllable of words of the structure H.H.L is parsed into a monosyllabic foot, parsing the following syllable into another foot always results in a *Clash violation (candidates (c), (d), (g)).

As iambic structures (candidate (j)) are ruled out by RhType=T and ternary structures violate FootBin (candidate (k)), the optimal outcome is selected from the candidates (a), (b) and (h). Candidate (b) is evaluated as the optimal outcome as it satisfies Rightmost. Its head foot is perfectly aligned with the right word edge, while the head foot of (a) stands one syllable and that of candidate (h) even two syllables away from the right word edge.

In Tableau 3 candidates of the structure L.H.L are evaluated (e.g. *Aláska*, *Deménti* 'denial', *Dilémma*, *Flamíngo*). Again, Rightmost plays a crucial role in selecting the optimal outcome. Like in Tableau 2 candidate (b) wins over the candidates (a) and (m) because it satisfies Rightmost, while (a) and (m) violate Rightmost as their head foot is one syllable away from the right word edge.

Parsing a word of the weight structure L.H.L into a ternary foot (candidates (k) and (l)) is blocked by the high ranked constraints RhType=T and FootBin. Amphibrachs, dactyls and anapests can only surface in languages where FootBin- and RhType-constraints are low ranked.

Tableau 4

	/H.L.L/	RhType=T	*Clash	FootBin	Rightmost	Parse-σ	AllFt-L
(a)	('H.L).L				*!	*	
(b) ☞	H.('L.L)					*	*
(c)	('H).(L.L)		*!		**		*
(d)	(H).('L.L)		*!				*
(e)	('H.L).(L)			*!	*		**
(f)	(H.L).('L)			*!			**
(g)	('H).(L).(L)		*!*	**	**		***
(h)	('H).L.L				*!*	**	
(i)	('H).L.(L)			*!	**	*	**
(j)	(H.'L).L	*!			*	*	
(k)	('H.L.L)			*!			

Tableau 5

	/L.L.H/	RhType=T	*Clash	FootBin	Rightmost	Parse-σ	AllFt-L
(a)	('L.L).H				*!	*	
(b)	L.('L.H)					*!	*
(c)	('L).(L.H)		*!	*	**		*
(d)	(L).('L.H)		*!	*			*
(e)	('L.L).(H)				*!		**
(f) ☞	(L.L).('H)						**
(g)	('L).(L).(H)		*!*	**	**		***
(h)	('L).L.H			*!	**	**	
(i)	('L).L.(H)			*!	**	*	**
(j)	(L.'L).H	*!			*	*	
(k)	('L.L.H)			*!			
(l)	L.L.('H)					*!*	**

Interestingly, Tableaux 2 and 3 show that the weight of the first syllable is irrelevant for the assignment of word stress. This is in line with the experimental findings of Janßen (2003a). Both H.H.L and L.H.L structures exhibit a clear preference for penultimate stress (85.3% and 89.6%, respectively, see above).

This finding is confirmed by the evaluation of trisyllabic words starting with a heavy syllable followed by two light syllables (H.L.L) in Tableau 4. The optimal candidate (b) has the same foot structure as the winners in Tableaux 1–3. The initial heavy syllable is left unparsed and the two light syllables form a word final trochee. High ranking Rightmost ensures that the head foot is at the end of the word (e.g. candidate (b) vs. (a) or (h)). Exhaustive parsing is blocked by *Clash (candidates (c), (d) and (g)) and FootBinarity (candidates (e–g)).

From the tableaux presented so far we can infer that the candidate with only one right-aligned foot leading to penultimate stress is the optimal one. Now, in the following tableaux with the evaluation of trisyllabic words of the structure L.L.H, L.H.H, H.L.H and H.H.H the situation changes substantially. In contrast to the words analyzed so far, these word structures form two feet without violating high-ranked constraints. If L.L.H is parsed into the foot structure (σσ)(σ), both feet are bimoraic. The same holds for words of the structure L.H.H, H.L.H and H.H.H that can also be parsed into two feet whose weight structure forms an equally perfect landing site for main stress.

In Tableau 5 words of the structure L.L.H are evaluated. In contrast to Tableaux 1–4, the candidate (b) with an initial unparsed syllable cannot be the optimal outcome as Parse-σ is not blocked by any higher ranked constraints here and is

Tableau 6

/H.L.H/		RhType=T	*Clash	FootBin	Rightmost	Parse-σ	AllFt-L
(a)	('H.L).H				*!	*	
(b)	H.('L.H)					*!	*
(c)	('H).(L.H)		*!		**		*
(d)	(H).('L.H)		*!				*
(e)	('H.L).(H)				*!		**
(f) ☞	(H.L).('H)						**
(g)	('H).(L).(H)		*!*	*	**		***
(h)	('H).L.H				*!*	**	
(i)	('H).L.(H)				*!*	*	**
(j)	(H.'L).H	*!			*	*	
(k)	('H.L.H)			*!			

Tableau 7

	/H.H.H/	RhType=T	*Clash	FootBin	Rightmost	Parse-σ	AllFt-L
(a)	('H.H).H				*!	*	
(b)	H.('H.H)					*!	*
(c)	('H).(H.H)		*!		**		*
(d)	(H).('H.H)		*!				*
(e)	('H.H).(H)				*!		**
(f) ☞	(H.H).('H)						**
(g)	('H).(H).(H)		*!*		**		***
(h)	('H).H.H				*!*	**	
(i)	('H).H.(H)				*!*	*	**
(j)	(H.'H).H	*!			*	*	
(k)	('H.H.H)			*!			

Tableau 8

	/L.H.H/	RhType=T	*Clash	FootBin	Rightmost	Parse-σ	AllFt-L
(a)	('L.H).H				*!	*	
(b)	L.('H.H)					*!	*
(c)	('L).(H.H)		*!	*	**		*
(d)	(L).('H.H)		*!	*			*
(e)	('L.H).(H)				*		**
(f) ☞	(L.H).('H)						**
(g)	('L).(H).(H)		*!*	*	**		***
(h)	('L).H.H			*!	**	**	
(i)	('L).H.(H)			*!	**	*	**
(j)	(L.'H).H	*!			*	*	
(k)	('L.H.H)			*!			

ranked above AllFeet-Left. Thus, a non-canonical trochee of the form ('LH) (cf. Hayes, 1995) is avoided here[1] (this is different in L.H.H words, see below).

Candidate (l) satisfies all high ranked constraints, but violates Parse-σ through its two unparsed light syllables. Out of the candidates that exhibit exhaustive parsing, candidate (f) is evaluated as optimal. Candidate (f) wins in comparison to candidate (e) as it has main stress on the ultimate syllable and therefore satisfies Rightmost.

This implies that words like *Residénz* ('residence'), *Vagabúnd* ('tramp') and *Abitúr* ('higher education entrance qualification') represent the regular stress pattern of L.L.H-forms in German, while *Ánanas* ('pineapple') or *Léxikon* have an exceptional stress pattern, which may be lexically prespecified.[2] A constraint like Head-Match (McCarthy, 2000), requiring faithfulness to prosodic heads specified in the input, could accomplish such forms to surface as optimal outputs.

[1] One might argue here that words like *Muséum* are of the type L('LH). Following Giegerich (1985) it is suggested that such forms consist of a Latin ending that cannot bear stress (see also argumentation in section 5.1).

[2] Evidence for a lexical specification of antepenultimate stress may be found in stress violations produced by patients with surface dyslexia (see Janßen, 2003a, 2003b; Janßen and Domahs, in press). Being unable to retrieve lexical information about stress positions, the patients H.T. and R.W. avoided antepenultimate stress in a production task with existing German words. Instead, words with canonical antepenultimate stress were realized with penultimate or final stress.

An alternative explanation along the lines of Pater's (2000) analysis of English stress would be to assume lexically indexed versions of the NonFinality constraint (cf. Prince and Smolensky, 1993/2004). This constraint requires that the head of a prosodic word must not be final in a prosodic word. It bans a word's main stress and head foot from final position (cf. Prince and Smolensky, 1993/2004:68). The general version of this constraint is ranked below Rightmost and thus does not alter the optimal outcome of our ranking so far. A lexically indexed NonFinality constraint is valid only for some part of the lexicon, i.e. a restricted set of words (cf. Pater, 2000).[3] Ranked above Rightmost, it could generate exceptional main stress on the antepenultimate. Candidate (e) would win over its competitors (b) and (f) as these violate $\text{NonFinality}_{\text{LexId}}$ because of the word final position of their head foot.

In this context, it is insightful that Janßen's (2003a) study of pseudowords does not report a clear preference for any of the competing stress patterns. Out of 358 pseudowords with the structure H.L.H, 47.8% were produced with antepenultimate and 34.6% with ultimate stress, out of 234 pseudowords with the structure L.L.H, 42.3% were produced with antepenultimate and 38% with ultimate stress, H.H.H-structures were not taken into account. Furthermore, her analogous analysis of existing words from the CELEX corpus (Baayen et al., 1995; out of 72 H.L.H types: 40.3% with antepenultimate stress (APU), 44.4% with ultimate stress (U); 86 L.L.H types: 68.6% APU, 15.1% U) suggest that many words of these prosodic structures are lexically prespecified for a certain stress pattern.

As exemplified for L.L.H words above, lexically indexed NonFinality could explain the variations between ultimate and antepenultimate stress observed by Janßen (2003a).

Tableau 6 for H.L.H words again shows the crucial role of Parse-σ, which impedes candidate (b) from surfacing as optimal form. Rightmost evaluates candidate (f) with ultimate stress as the optimal form instead of candidate (e) that violates this constraint. Adopting such a ranking, words like *Architékt*, *Exponént* or *Garnitúr* ('suite') are regular patterns, while *Hárlekin* ('harlequin') or *K´änguruh* ('kangaroo') are exceptional ones.

Furthermore, words with three heavy syllables (e.g. *Exemplár* 'specimen') remain to be analyzed (Tableau 7). Though words of this structure are rare in German, they do not cause problems to the ranking established so far. Candidate (b) with an unparsed initial syllable cannot surface as optimal form, as this incomplete parsing is a crucial violation of Parse-σ. Among the candidates with all syllables footed, those with a final disyllabic trochee and the candidate with each syllable parsed in a monosyllabic foot exhibit violations of high-ranked *Clash. Hence we find the same picture as in Tableaux 5 and 6 with two candidates ((e) and (f)) that have an initial disyllabic trochee and a final monosyllabic one, but differ in the position of main stress. Again Rightmost evaluates (H.H)('H) as the optimal output.

Finally, trisyllabic words of the structure L.H.H (e.g. *Redundánz* 'redundancy') are examined in Tableau 8. Comparable to the previous tableaux, candidate (b) is ruled out by its violation of Parse-σ. The two candidates (e) and (f) crucially differ in their evaluation through Rightmost, while satisfying all other high ranked constraints. Both satisfy Parse-σ, as all their syllables are parsed into feet, but violate AllFt-L: They consist of two feet, and only the final monosyllabic foot is perfectly aligned with the left edge of the word.

Rightmost ensures that candidate (f) is evaluated as the optimal form and that words with the weight structure L.H.H receive final stress.

The optimal output with ultimate stress in words of the structure L.H.H implies that a light and a heavy syllable are parsed into an initial trochee (see candidate (f)). Due to its "reverse" weight structure – a heavy syllable is parsed in weak position of a trochee – a (L.H) trochee is a highly marked form.

Notably, Janßen (2003a) reports that the preferences for a certain stress position in L.H.H words are not as clear as in other structures. 22.8% of pseudowords out of 215 were produced with antepenultimate stress, 30.2% with ultimate, and 47% with penultimate stress. Thus, the optimal candidate (f) is not completely in accordance with Janßen's findings. The preference for penultimate stress may be due to an avoidance of the marked trochee (L.H). However, penultimate stress is significantly less frequent than in those words that are analyzed as having penultimate stress in the optimal output (L.L.L, H.H.L, L.H.L and H.L.L) Moreover, considering existing words, it is not surprising that L.H.H-forms are quite rare in German (Janßen reports 27 L.H.H types: 4 with antepenultimate stress, 18 with penultimate stress and 5 with ultimate stress).

Taken together we get the (preliminary) constraint hierarchy illustrated under (8).

(8) RhType=T, *Clash, FootBin, Rightmost $\gg$ Parse-σ $\gg$ AllFt-L

[3] Whether this alternative analysis is possible here depends on how number and size of such sets can be established in a grammar of German. This is still an open issue.

In comparison to earlier OT-analyses of German word stress, this ranking is very close to the one proposed by Alber (1997). For monomorphemic words that are central in the present analysis, however, a constraint like IAMBICTROCHAICLAW proposed by Alber (1997, 1998) to restrict the occurrence of non-canonical trochees like (ˈL.H) and (ˈH.L) is not needed. Here, the ranking itself assures that (ˈL.H) occurs only when exhaustive parsing is possible (see Tableau 8), and (ˈH.L) is restricted to words of the shapes H.L.H, L.H.L, and H.H.L. Similarly, the effects of some constraints suggested by Féry (1998; e.g. NONHEAD(SCHWA)) can be expressed directly via the ranking of a smaller set of constraints.

3. Experimental evidence for the ranking of FOOTBIN and PARSE-σ

As outlined in the previous section, constraints calling for a certain type of structure building are essential for the description of prosodic systems. From an empirical perspective, such structures can be identified by means of stressed syllables within prosodic words. However, this method allows to detect only heads of feet, while one can only speculate on the weak part of a foot. The detection of a strong syllable itself is not enough to postulate foot structures, since a stress position must not result necessarily from an underlying foot structure, but a syllable can be lexically specified for main stress as proposed for instance in a psycholinguistic model on word production (Levelt et al., 1999).

The experiment on prosodic processing presented in the following section will show the importance of the constraints FOOTBIN, PARSE-σ and RHTYPE=T.

3.1. ERP data

In the following, we discuss results from event-related potentials (ERPs) reported in Domahs et al. (2008), which show that only binary foot structures are built up in the German prosodic system. In studies using event-related potentials, electrophysiological brain responses (small changes in mean voltage) are measured time-locked with a certain type of stimulus via electrodes fixed on the scalp. By means of several averaging procedures, different types of event-related potentials can be detected. These so called components are negative or positive deflections, which are associated with certain types of sensory or cognitive processes.

ERPs allow for a very high temporal resolution and are qualitatively distinctive for different types of cognitive processes (e.g. language processes). ERP components are classified according to their polarity, to their latency time-locked with the stimulus onset, and to their topography, i.e. where they are measured on the scalp. In general, not the absolute values of voltage changes induced by a critical condition are interpreted, but voltage differences between two critical conditions (for a detailed description of the methodology see appendix provided by Bornkessel-Schlesewsky and Schlesewsky, 2008; Kutas et al., 2006).

In the ERP study by Domahs et al. (2008), participants were confronted with correctly and incorrectly stressed trisyllabic words, the latter ones leading to a change in prosodic structure. The aim was to investigate whether different types of stress violations/prosodic changes would produce different ERP effects, which might indicate qualitatively distinct processes in the parsing of diverse stress patterns. In this respect, 90 trisyllabic German words were chosen, 30 per stress pattern (e.g. stressed on the antepenultimate syllable: *Léxikon* 'lexicon', stressed on the penultimate syllable: *Kasíno* 'casino', and stressed on the final syllable: *Vitamín* 'vitamin'). The prerequisite for the selection of these words was that they differed in prosodic structure according to metrical analyses (Hayes, 1995): $(\text{Le.xi})_{\text{Fs}}(\text{kon})_{\text{Fw}}$, $\text{Ka}(\text{si.no})_{\text{Fs}}$ and $(\text{Vi.ta})_{\text{Fw}}(\text{min})_{\text{Fs}}$. Each group of words was controlled for the structure of the final and prefinal syllable, the initial syllable was open in 70% of words.[4] Each word was recorded naturally spoken three times with stress on each syllable, i.e. once correctly and twice incorrectly. It was assured that stress on a certain position within a word was realized by identical phonetic parameters irrespective of the correctness or incorrectness of the resulting stress pattern (for statistical analyses on phonetic realization see Domahs et al., 2008). A comparison between correct and incorrect conditions revealed that different types of foot structure violations produced different ERP effects (for more details about the experimental setup and the statistical analyses see Domahs et al., 2008 and Knaus et al., 2007).

[4] Due to structural and lexical restrictions like word frequency we had to include a few items per condition with a closed antepenult. One could argue that such items are parsed differently, building an initial monosyllabic foot. Such a parsing, however, would lead either to unparsed penults in words with antepenultimate and final stress or to a clash situation in words with penultimate stress. Since ERP effects for violations with initial stress in words with penultimate syllable do not speak in favor of the acceptability of initial stress, we assume that the weight of antepenults does not play a role in the parsing of our stimuli.

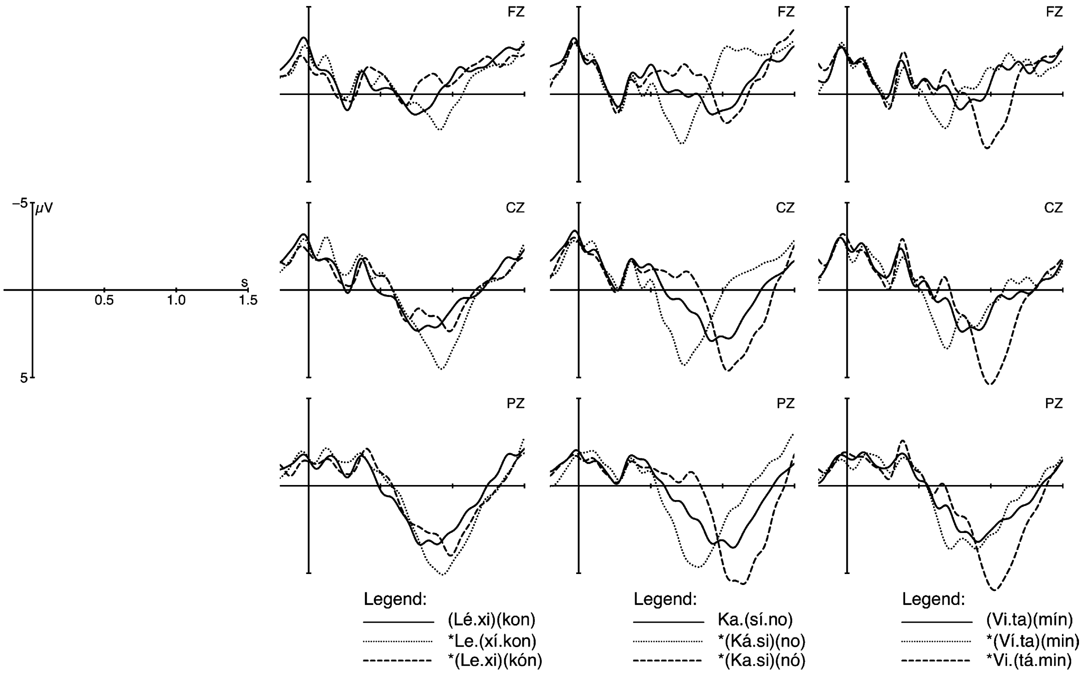

Fig. 1. Grand averages are grouped according to stress conditions. Grand averages are measured from word onset up to 1500 ms thereafter, due to space limits only midline electrodes (Fz, Cz, and Pz) are depicted. In the graphs, the *x*-axis indicates the course of voltage changes over time (in ms) and the *y*-axis the amplitude of voltage changes (in μV) with positive voltages being plotted downwards. On the left hand side the correct condition with initial stress is compared to the two incorrect conditions **Lexíkon* and **Lexikón*. Only the violation with penultimate stress revealed a pronounced positivity effect. The mediate panel shows the conditions for words with penultimate stress, both comparisons between the correct and incorrect conditions yielded enhanced positivity effects. The right hand panel illustrates grand averages for words with final stress, again only violations with penultimate stress produced a violation-of-expectation effect (see Domahs et al., 2008 for statistical analyses).

In this experiment, 24 native speakers of German were presented with each correctly and incorrectly stressed word, however, prior to auditory presentation each word was also presented visually. The participants' task was to decide for each word whether it was stressed correctly or not. The visual presentation of each stimulus was conducted in order to facilitate the decision by excluding lexical search effects (see also Knaus et al., 2007). Participants expected to hear a stress pattern, which would match the stress pattern of the visually presented word. Whether the actually heard stress pattern met this expectation was judged by pressing a yes- or no-response button.

3.2. Evidence for FootBin, RhType=T, and Parse-σ

In data analyses, we focussed on contrasts between a correct condition (e.g. *Léxikon*) and each of two incorrect conditions (e.g. **Lexíkon* or **Lexikón*). By means of comparisons between the critical conditions we obtained the following results.

As can be seen in Fig. 1, comparisons between correct and incorrect conditions led to an enhanced positive deflection in each stress context. However, in words with antepenultimate (*Léxikon*) and ultimate stress (*Vitamín*) the positivity effect occurs only in violations induced by penultimate stress (**Lexíkon* and **Vitámin*), whereas in words with penultimate stress (*Kasíno*) each violation evoked a positivity effect.[5] In Domahs et al. (2008) and Knaus et al. (2007), it was argued that such a positivity reflected a task-related evaluation process, which is sensitive to the significance of a stress violation. It is suggested that only those stress violations requiring a restructuring of syllables

[5] Note that for violations like *Vítamin a positivity effect was obtained, but this effect was reduced in comparison to violations such as *Vitámin (see statistical analyses provided in Domahs et al., 2008).

into feet lead to a pronounced positivity effect. We conclude this from the fact that such positivity effects could not be observed for violations like **Lexikón* or **Vítamin*, in which – assuming that both phonological words consist of two feet – the stress position shifts from one foot to the other without changing the structure, i.e. turning a weak syllable into a strong one and vice versa (for a more detailed discussion of the data see Domahs et al., 2008). Thus, the lack of positivity effects – especially for words with initial stress – can be taken as evidence that these words consist of binary feet only ((Lé.xi)$_F$(kon)$_F$), structures that were suggested in Alber (1997, 1998) and in our account (see section 2.2).

With respect to foot type, the data further show that the positivity effects cannot possibly be explained by assuming ternary foot structures: a switching between dactyls (‘σσσ), amphibrachs (σ’σσ) and anapests (σσ’σ) would require a total restructuring in each violation condition by turning a head syllable into a weak syllable and vice versa. Thus, in words with canonical antepenultimate stress we should find an effect also in violations with final stress (‘σσσ → σσ’σ) and vice versa in words with canonical final stress with incorrect initial stress (σσ’σ → ‘σσσ). This, however, is not attested. The data therefore are capable to distinguish between a weak syllable of a ternary foot and a strong syllable of a trochee, most probably carrying secondary stress. Note that such a difference would hardly be detectable by means of phonetic analysis (see for instance Kleber and Klipphahn (2006) for a phonetic manifestation of secondary stress in German). The fact that we did not obtain positivity effects in such circumstances speaks in favor of strictly binary feet, as has been suggested by the undominated constraint FootBin in section 2.2.

Referring to the undominated constraint RhythmType=Trochee, the data might give an answer to the question whether prosodic words consist solely of trochaic feet or of both trochaic and iambic feet. In the latter case, a trisyllabic word with penultimate stress could alternatively be parsed as (L.’L)L or (L.’H)L and a word with final stress as L(L.’H), only for words with antepenultimate stress we have to assume necessarily a trochaic parsing (’L.L)(H). If these parsings were real, we should have found other results for words with canonical final stress (for canonical penultimate and antepenultimate stress the predictions for trochaic and iambic parsings are the same): a parsing of finally stressed words as L(L.’H) would require a restructuring of feet in violations with antepenultimate stress (*(‘L.L)(H) and a shift in prominence in violations with penultimate stress *L(‘L.H)). Although it is not clear yet what kind of ERP-effect surfaces for shifts in prominence relations, at least violations with antepenultimate stress would lead to an enhanced positivity effect, which is not attested. Thus, it seems that the data can decide between trochaic and iambic structures, at least for foot types of finally stressed words. For more test conditions to evaluate RhythmType=Trochee, further investigations of longer words with an odd number of syllables would be decisive.

Regarding the constraint Parse-σ, the data suggest that words with antepenultimate stress do not consist of an extrametrical, unparsed final syllable (see candidate (a) in Tableaux 5 and 6) as is suggested in Féry’s analysis (1998). If this were the case, we should have found a pronounced positivity effect for words with canonical antepenultimate stress incorrectly stressed on the final syllable. According to these tableaux the output with final stress (candidate (f), (L.L)(‘H)) constitutes even the optimal surface form as it satisfies Rightmost. Violations of such a form did not produce any positivity effect.

In words with canonical final stress that are incorrectly stressed on the initial syllable, a violation of Rightmost as shown in candidate (e) of Tableaux 5 and 6, however, did not surface as a pronounced positivity effect. The lack of an ERP response can be taken as support for a possible lexical specification of this stress pattern by means of HeadMatch or lexically indexed NonFinality (see section 2.2 above).

In sum, the findings of the first experiment reported in Domahs et al. (2008) corroborate the conception of a parser building up binary structure, which is reflected in Prince and Smolensky’s (1993/2004) constraint FootBin. This is not that surprising, since traditional OT-analyses of German word prosody generally assume binary trochees (Alber, 1997, 1998; Féry, 1998). However, our results are the first to show empirically what happens when prominence relations are restructured. Up to now, analyses could only consider prominent positions of words, but our data go beyond that and refer to prominent and non-prominent parts of the prosodic structure of a word. Furthermore, in the case of words with antepenultimate stress, we could show that a form with a parsed final syllable is to be preferred over a form with an extrametrical syllable providing evidence for the importance of Parse-σ at the right edge of a word. However, in words with penultimate stress like *Bikíni*, for which we proposed an optimal parsing like L(‘L.L), we cannot reach a decision based on experimental evidence between an unparsed initial syllable and an initial defective foot, since both potential forms violate constraints important for foot structure formation making the initial syllable an impossible landing site for stress.

4. Does weight matter?

It is a long-standing debate whether German is a quantity-sensitive language. Some phonologists argue that the stress position in German words is calculated on the basis of the syllable weight of the final and prefinal syllable (e.g. Giegerich, 1985; Vennemann, 1990; Féry, 1998; Jessen, 1999). A heavy final syllable attracts stress, otherwise stress is realized on the prefinal syllable. With the definition of heaviness – however – difficulties have arisen. It seems that the traditional notion of weight in terms of a mora-counting system does not hold for German. Thus, words ending in a (bimoraic) long vowel do not necessarily attract word stress (e.g. [ʻkɔnto:] <Konto>, ʻaccount'), whereas words ending in a VC-, VVC-, or VCC-sequence often do (e.g. [pʁoto'kɔl] <Protokoll>, ʻminutes'; [vita'mi:n] <Vitamin>, ʻvitamin'; [diʁiˈgɛnt] <Dirigent>, ʻconductor'). According to Wiese (1996/2000), the stress position is not predictable even for the latter group of words. This is demonstrated by means of varying stress patterns in words ending in identical final syllables (e.g. *Bálkan* ʻthe Balkans' – *Orgán*; *Jápan* – *Kumpán* ʻcompanion'; Wiese, 1996/2000:279).

With respect to the relation of vowel length and syllable weight, a proposal to explain word stress in Dutch might be insightful for an analysis of German as well. The observation that long and short vowels are distributed complementarily – i.e. long (tensed) vowels occur in open syllables and short (lax) vowels in closed syllables – led to the proposal that vowel length does not contribute to syllable weight at all in Dutch (Kager, 1989; Lahiri and Koreman, 1988). Instead, it is assumed that only closed syllables are heavy. Following Kager (1989) and Trommelen and Zonneveldt (1999) only a closed (= heavy) final syllable is parsed as a monosyllabic foot, open final syllables are parsed as weak syllables of trochees. We will suggest here that in German the same definition of syllable weight should be adopted, since vowel length seems to be an uncertain predictor for the parsing of syllables into feet according to their weight. In German, open syllables contain tensed vowels (except for /a/ and /ɛ/), which are longer than lax vowels in closed syllables. Since vowel length is not an independent factor, but is crucially determined by the syllabic make-up, one can argue that vowel length does not contribute to syllable weight. Similarly, Vennemann (1990, 1991a) argues for a distinction between open and closed syllables by means of syllable cut properties. One caveat should be mentioned here, namely that a minimal German word might consist of an open syllable with a long vowel like *nie* ʻnever' or *wie* ʻhow'. From such forms we can conclude that open syllables at least have the potential to be heavy, but – as argued above – are not as good as predictor for heaviness as closed syllables are.

In a pseudoword-reading task, Janßen (2003a) observed that most words ending in a syllable with one or two coda consonants were stressed either on the final or antepenultimate syllable (77%), whereas words ending in an open final syllable were predominantly stressed on the penult (82%). This finding confirms that at least the weight of the final syllable determines the prosodic structure of a word.

Taken together, there are some considerations speaking in favor of a quantity-sensitive system. However, as Wiese (1996/2000) points out, the German stress system is by no means quantity-sensitive in the traditional sense (Hayes, 1995). In the following section, we will discuss experimental findings on the influence of syllable weight and illustrate the role of quantity in relation to other relevant prosodic constraint.

4.1. ERP data

In order to elucidate the role of quantity sensitivity in German we present findings from another ERP study reported in Domahs et al. (2008), in which the word material allows to differentiate between effects induced by either violations of stress position and syllable weight or by stress violations alone. For this purpose, we selected words with antepenultimate stress that differed with respect to the structure of the final syllable: Half of the words contained a closed final syllable (CVC-structure; e.g. *Léxi**kon***) and half an open final syllable (CV-structure; e.g. *Rísi**ko***). The idea was that stress violations of such words caused by penultimate stress (e.g. **Lexíkon*, **Risíko* ʻrisk') might produce different effects in ERPs because correct words with penultimate stress contain predominantly an open final syllable and rather rarely a closed one (see discussion above).[6] If this asymmetry is meaningful in German, more pronounced violation effects for incorrect words like **Lexíkon* should be observed than for words like **Risíko*.

[6] In a corpus analysis of 1017 trisyllabic words selected from Celex lexical database of German (Baayen et al., 1995), Janßen (2003a, 2003b) observed that words with penultimate stress ending in a syllable with full vowel are open in 64.2% and closed in only 33.8%. Note further that words with closed final syllable mainly consist of a Latin or Greek ending which cannot bear stress (e.g. *Museum* ʻmuseum', *Bazillus* ʻbacillus', or *Franziskus* ʻmale name').

4.2. Evidence for the processing of syllable weight

To test this hypothesis, an ERP experiment was conducted (Domahs et al., 2008) in which 15 words with antepenultimate stress contained a closed final syllable and 15 words an open final syllable. Each word was presented twice in both correct and incorrect (penultimate) condition; filler items with incorrect antepenultimate stress and correct penultimate stress were added to exclude confounding strategies (for a detailed description of the experimental method and the statistics see Domahs et al., 2008). The participants' task was identical to the one outlined in section 3.1.

Fig. 2 depicts that there are indeed differences between the two presented stress violations: The violation-to-expectation effect is stronger for words with a closed final syllable than for words with an open final syllable. This finding suggests first of all that the language processing system is sensitive to the frequency of occurrences of particular structures, since penultimate stress occurs more frequently in words with an open than in words with a closed final syllable. With reference to the results we obtained for the criterion ''foot type'' in section 3.2, the asymmetry of ERP effects seems to reflect that a structure like **Risíko* is more wellformed than a structure like **Lexíkon*. Note that in the latter case a heavy final syllable is parsed as a weak syllable of a trochee (Le(xí.kon)$_F$), whereas in the first case two open syllables form an optimal trochee (Ri(sí.ko)$_F$). Therefore, our findings support the assumption as reported in section 2.2 that closed syllables are heavy and build feet on their own. However, this can be observed mainly for final heavy syllables.

The findings of the ERP study show that syllable weight influences the processing of prosodic word forms (and even of those not lexically stored). Despite the fact that both forms (**Lexíkon* and **Risíko*) are violations that can be judged as incorrect with comparative accuracy (97% and 93%, ns), we can conclude that German speakers' perceptional system is sensitive to syllable weight. Note that we do not have any empirical results suggesting that the vowel length of syllables contributes essentially to the weight of a syllable. Therefore, our results support the assumption outlined in

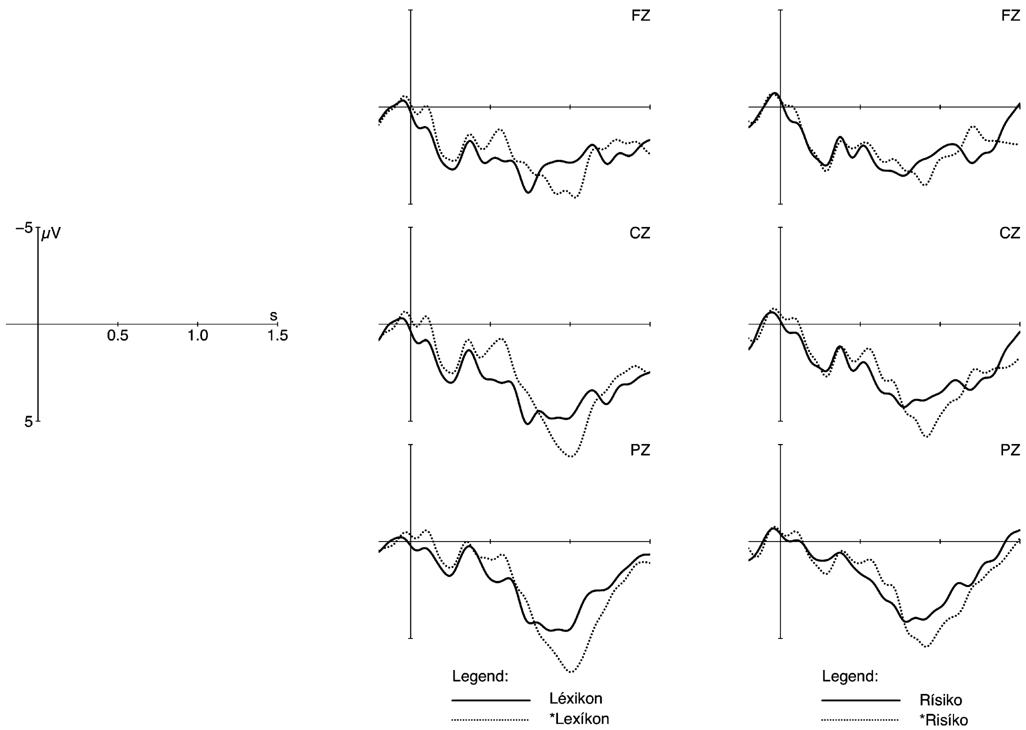

Fig. 2. Grand averages are grouped according to stress conditions. Grand averages are measured from word onset up to 1500 ms thereafter, due to space limits only midline electrodes (Fz, Cz, and Pz) are depicted. On the left hand side, the correct condition with a heavy final syllable is compared with the incorrect condition *Lexíkon*. As a result, such a violation with penultimate stress produces a pronounced posterior positivity effect. On the right hand side, contrasts between brain responses for correct words with open final syllables and incorrectly stressed words (*Risíko*) are illustrated. Interestingly, for this type of words the violation effect is moderate and statistically not significant (see Domahs et al., 2008 for statistical analyses).

section 3.1 (Janßen, 2003a; Kager, 1989; Trommelen and Zonneveld, 1999) according to which only the presence or absence of coda consonants distinguishes between heavy and light syllables.

However, this sensitivity in the perception of weight differences is not deducible from our OT-analysis. If we compare the candidates (b) from Tableaux 1 and 5 – L.('L.L)-structures like **Risíko* and L.('L.H)-structures like **Lexíkon* – the differences in syllable weight are not reflected by any violations in the ranking. In both tableaux candidate (b) violates PARSE-σ and ALLFEET-LEFT. The present ranking takes only the positional properties of stress into account, but not syllable weight properties per se.

From an OT-perspective the described ERP effects of the alternating stress positions in *Léxikon*, **Lexíkon* and *Rísiko*, **Risíko* would be described best by the constraint WEIGHT-TO-STRESS-PRINCIPLE (WSP, Prince and Smolensky, 1993/2004). WSP requires heavy syllables to be stressed.

The correct form *Léxikon* has the prosodic structure ('L.L)(H) with an assumed exceptional antepenultimate main stress (stress is possibly lexically prespecified, since RIGHTMOST would opt for final stress here, see discussion of Tableau 5). When main stress is shifted to the penultimate syllable (**Lexíkon*) the foot structure changes. According to our analysis (see Tableaux 5–7, candidate (b)) word forms with penultimate stress always exhibit a final disyllabic trochee and an unparsed initial syllable, hence the prosodic structure of this form should be L('L.H). Thus, induced by a restructuring of feet, WSP is violated as the final heavy syllable occurs in the weak position of the final foot. This violation of wellformedness of weight structure is visible in the observed ERP effects.

In contrast, main stress alternations of words like *Risiko* show a different picture. Here, we assume that the correct form *Rísiko* again has a lexically prespecified main stress. According to our OT-analysis, stress would normally occur on the penultimate syllable if we assume the weight structure L.L.L.[7] L.L.L-forms would normally exhibit penultimate stress (i.e. a final disyllabic trochee and an unparsed initial syllable). As proposed in Tableau 1, antepenultimate stress is exceptional, since RIGHTMOST must be dominated by a constraint like HEADMATCH that ensures a faithful realization of stress already present in the input or by an indexed version of NONFINALITY (see above, discussion of Tableau 5). This would result in the parsing ('L.L)L or ('L)(L.L). However, shifting main stress to the penultimate syllable (*Risíko*) requires restructuring of feet. But although the potentially optimal form L('L.L) has a completely different foot structure compared to the correct condition ('L.L)L or ('L)(L.L), **Risíko* forms do not produce positive deflections. The lack of a positivity effect could be interpreted to be the result of the fact that in contrast to **Lexíkon* no WSP violation occurs. Therefore, the ERP method is sensitive to the markedness of structures, accepting incorrect forms if they constitute unmarked prosodic structures.

If we incorporated WSP into the ranking proposed so far, it would be ranked below *CLASH as German is only a partially quantity-sensitive language (cf. Alber, 1997). This is expressed by the irrelevance of the weight of the first syllable in trisyllabic words for stress assignment (compare e.g. Tableau 2 with Tableau 3).

However, the occurrence of WSP would never change the optimal outcomes of Tableaux 1–8. Accordingly, this constraint does not seem to be relevant for the analysis of stress assignment in trisyllabic words. It should be noted further that with **Risíko* and **Lexíkon* two non-optimal forms are compared here. OT normally was not designed to be able to account for differences between losers in a ranking.

Nevertheless, the peculiarity remains that we have an experimental prove that German speakers are sensitive to syllable weight during processing, but this sensitivity is not needed to derive wellformed stress patterns of trisyllabic words. Possibly, WSP is needed in an analysis of longer words which is beyond the scope of this paper and will be left for future research.

5. Summary

We have presented an OT-analysis for German word stress that can explain the distribution of stress patterns attested for German trisyllabic monomorphemic words (in particular those reported in Janßen, 2003a). Main stress on the penultimate syllable is the most frequent pattern in German, which is basically assured by the ranking FOOTBIN, RIGHTMOST ≫ PARSE-σ. This entails that ternary feet are generally excluded and that in trisyllabic words in most cases only one final disyllabic trochee is built up. Thus, construction of feet goes on in a minimal fashion. Maximally disyllabic feet can occur word finally and word initially, while monosyllabic feet are restricted to certain conditions: A

[7] Note that a form like *Rísiko* could also be analyzed as H.L.L structure due to a stressed and therefore long initial vowel without changing the optimal output. But see discussion on syllable weight in section 4.

heavy syllable can constitute a bimoraic trochee on its own only in word final position and when stress clash is avoided (e.g. (L.L)(H)). Only if these wellformedness restrictions are fulfilled, more than one foot is built up. Note that initial heavy syllables never form a foot alone, their weight does not contribute to the assignment of word stress.

Foot structures are generally limited to trochees of the form (ˈL.L), (ˈH.L) and (ˈH). Non-canonical trochees of the form (ˈL.H) can only surface in L.H.H-words where the low ranked PARSE-σ is not blocked by higher ranked constraints and exhaustive parsing is possible. (L.H)-feet also never occur word finally (see below).

All in all, the prosodic structure of words is determined by multiple restrictions requiring that the shape and the size of feet be as minimal and as least marked as possible.

In comparison to earlier analyses (Alber, 1997; Féry, 1998) the set of constraints used here is kept as small as possible. The phenomena that are described by constraints like for instance IAMBICTROCHAICLAW (Alber, 1997) or NONHEAD(ə) (Féry, 1998) are expressed through ranking interactions of other, more basic constraints. Nevertheless, in large parts Alber's analysis is congruent to the one presented here. Our OT-analysis is further confirmed by the results of the presented ERP-studies. The ranking of FOOTBIN over PARSE-σ can be empirically grounded through the observed occurrence or non-occurrence of the enhanced positive deflection in the ERP-data (see section 3). Furthermore, our experimental findings strongly suggest that even in clearly non-lexicalized forms like **Lexíkon* and **Risíko* quantity plays a role in prosodic processing (see section 4). German clearly is a partially quantity-sensitive language, as violations of the quantity-wellformedness restriction (which may be expressed by WSP, but see discussion above) show up as significant deviations in ERP curves.

To summarize the main findings of our OT-analysis, we suggest that:

- Stress on the penultimate is the most common pattern in German. The majority of the tableaux shows that candidates with penultimate stress are preferred at the cost of underparsing the first syllable. Only in cases where a trisyllabic word form can be parsed into two wellformed trochees, the penultimate pattern is abandoned. This is the case in words ending in an LH sequence, in which penultimate stress would result from a highly marked trochee. In such cases the parsing into the foot sequence (XL)(H) is unmarked, which is a challenge to prosodic accounts that postulate penultimate stress to be the only unmarked stress pattern (e.g. Kaltenbacher, 1994; Wiese, 1996/2000).
- The formation of foot structures always proceeds in a minimal way (FT-BIN $\gg$ PARSE-σ). As binarity is ranked above exhaustive parsing, a syllable is left unparsed whenever possible (i.e. if no other high ranked constraints interfere).
- The weight of the first syllable does not play any role in the assignment of word stress (Tableaux 2 and 3). In some circumstances the first syllable is incorporated into a foot, but crucially this does not depend on the weight of the first syllable and happens only when the final syllable forms a foot on its own. This becomes obvious in the comparison between forms like (L.L)(ˈH) and (H.L)(ˈH) (Tableaux 5 and 6).
- Trochees of the form (ˈL.H) are marked in German. They occur only if exhaustive parsing cannot be accomplished otherwise.

While the experimental results provide evidence for most of the constraints used in our analysis, there is no experimental support for the constraints expressing directionality and *CLASH yet. Whether effects of stress clash are mirrored by deviations of ERP data can be checked in a future experiment with a critical condition in which the presented stimuli contain stress clashes. In contrast, it seems to be more complicated to provide violations of directionality constraints for main stress by using a comparable experimental design, but the constraint RIGHTMOST is affirmed by the uncontroversial three-syllable law.

Further, it is an open question how primary and secondary stress interact and whether the word rule is differently set for the two types of prosodic prominence. If we follow Alber (1997, 1998), primary stress is aligned with the right edge of words and secondary stress with the left edge. However, this generalization allows for some exceptions that might be related to stress preservations in derived words and to syllable weight effects. In order to get deeper insight into this problem, further examinations of polymorphemic words are necessary.

6. Conclusion

In the present paper, the relevance of constraints on prosodic structure in German was investigated by virtue of experimental findings from pseudoword production and from studies using event-related potentials. Overall, the data confirmed that feet are maximally binary in German, excluding ternary structures clearly. Constraints militating against violations of binarity and trochaic foot type are undominated in the constraint hierarchy at the cost of exhaustive syllable parsing. Thus, on the one side, a prosodic word of German does not consist of a maximal number of feet, but rather foot construction takes place only as far as allowed by binarity and foot type. On the other side, the number of feet must be maximal as the number of unparsed syllables is restricted to one. Finally, a crucial result is that syllable weight has an impact on foot structure, since heavy syllables may constitute feet on their own.

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3 Secondary word stress in German — feet and brainwaves

Where does secondary stress occur in German words? In the linguistic literature, there are divergent answers to this question. While some authors assume that secondary stress depends on foot structure (e.g., Nespor and Vogel, 1986; Alber, 1998) others suppose that secondary stress is primarily determined by the overall rhythmical structure of the sentence in which the word occurs and thus varies due to rhythmical preferences and the prosodic context (e.g., Vennemann, 1995; Noel Aziz Hanna, 2003).

So far, there is no clear empirical evidence on this topic. Phonetic studies could not reveal a decisive acoustic correlate of secondary stress in German (Mengel, 1997; Kleber and Klipphahn, 2006). As secondary stress might be realized only optionally in German and phonetic parameters are hard to control against influences from factors unrelated to secondary stress, this is not terribly surprising.

Neurolinguistic studies on trisyllabic German words (see previous chapter) have shown that the assignment of main stress depends on feet. A study on longer word structures, which exhibit (more) possible positions for secondary stress realizations, could give some insight on the distribution of secondary stress in German. To this end, an experimental study on German words that are five syllables long was planned and conducted.

The experimental study and its results are described in section 3.1 of this chapter. Implications for linguistic theory, in particular, an optimality theoretic modeling of the experimental findings will be discussed in section 3.2.

3.1 A neurolinguistic study on pentasyllabic words

The experimental design of this study was closely oriented to that of previous ERP studies on word stress in German (see chapter 2; Knaus et al., 2007; Domahs et al., 2008; Knaus and Domahs, 2009). In the following, the group of participants, presented stimuli (including a phonetic analysis), and the experimental procedure are described in detail. Behavioral and ERP data are presented and discussed in 3.1.2, before a final conclusion summarizes the results.

3.1.1 Materials and methods

Participants (20 right-handed native speakers of German, 8 women, mean age 23.3 years) had to judge if the words were stressed correctly or not. All participants had normal or corrected to normal vision and no hearing deficits. Participants received payment for their participation. They were seated in front of a screen in a dimly illuminated and quiet room.

Stimuli were naturally spoken pentasyllabic German words produced by a linguistically trained female speaker. Sound files were recorded at a sampling rate of 44 kHz, 16 bit (mono) using SoundStudio (Felt Tip Inc.) and an electret microphone (Beyerdynamic MC 930). The words were produced either with correct main stress or with main stress shifted to one of the other four syllables. To avoid interferences with phrasal intonation, words were produced in the carrier sentence *Er soll nun … sagen* "He is supposed to say …". All words were cut out of the sentence they were produced in and spliced into a single invariant token of the carrier sentence.

Each experimental trial began with the presentation of a fixation star for 500 ms, followed by the visual presentation of the target word for 600 ms and a blank screen for 300 ms. Directly after this, the auditory stimulus was played via loudspeakers. The mean length of the complete sentences was 2977 ms. Next, a question mark appeared on the screen with a timeout of 2000 ms and participants could press buttons on a response device. The assignment of answers ("yes, correctly stressed" and "no, incorrectly stressed") to the buttons was counterbalanced between participants. After their response participants were allowed to blink and rest their eyes until the next trial started. Intertrial interval was 2000 ms.

Each participant listened to 660 stimuli in randomized order, divided into 10 blocks. The critical stimuli were words with correct main stress either on the antepenult, the penult or the final syllable. Each of these three conditions consisted of 15 words, with 225 words in total ((1×15 correctly stressed words $+ 4 \times 15$ incorrectly stressed words) $\times 3$ conditions). Filler items were included to balance the exposure to correct and incorrect stimuli. These consisted entirely of words with correct stress, namely, 15 words with antepenultimate, 15 words with penultimate, and 15 words with final stress. In addition, 30 words with stress on the first and 30 words with stress on the second syllable were presented to achieve correctly stressed stimuli in all positions. All stimuli were presented twice during the experiment.

All words[7] were derived forms as there are no (genuine) monomorphemes of this length in German. A complete list is given in the appendix (see page 145). As far as possible (3 words did not have a database entry, namely *Annullierbarkeit* "annullability", *Kandidatenschaft* "candidacy", and *Respektierbarkeit* "respectability"), the critical stimuli were controlled for frequency according the database "Wortschatz Universität Leipzig" (http://wortschatz.uni-leipzig.de).[8] Frequency classes of the critical stimuli ranged from 11 to 24.

In a post-hoc phonetic analysis of the stimuli, the phonetic parameters duration, pitch (F_0), and intensity were measured for each syllable (using Praat; Boersma and Weenink, 2012). Table 3.1 shows the mean values of stressed syllables for the correct and incorrect stimulus conditions.

[7] with exception of *Abrakadabra* "abracadabra" and *Aristoteles* "Aristotle" which were used as filler items only

[8] The database records frequency information as logarithmic frequency classes, i.e., a word of frequency class 10 is approximately 2^{10} times more frequent than the most frequent word in the corpus, which is *der* (art. masc.).

Frequency class (word) = $\left\lfloor \log_2 \left(\frac{\text{instances of } der}{\text{instances of word}} \right) \right\rfloor$

Table 3.1: Mean values of the phonetic parameters pitch (F_0), intensity and duration for stressed syllables. Correct conditions are shaded.

		Target stress context			
		filler	antepenult	penult	final syllable
Stress realized	Pitch, Hz (sd)	212.84 (11.09)	210.42 (8.28)	211.61 (10.31)	209.93 (6.68)
on	Intensity, dB (sd)	55.58 (4.68)	51.87 (4.79)	54.35 (4.22)	51.57 (5.00)
first syllable	Duration, ms (sd)	224 (48.4)	234 (64.0)	206 (48.4)	249 (83.6)
Stress realized	Pitch, Hz (sd)	210.08 (8.63)	204.32 (6.29)	206.75 (8.85)	209.87 (9.36)
on	Intensity, dB (sd)	52.72 (4.32)	51.33 (5.66)	51.06 (5.50)	52.96 (4.47)
second syllable	Duration, ms (sd)	320 (78.5)	294 (32.7)	277 (37.5)	248 (44.0)
Stress realized	Pitch, Hz (sd)	217.20 (5.59)	194.74 (8.48)	196.90 (8.29)	194.68 (8.24)
on	Intensity, dB (sd)	53.64 (4.44)	51.76 (4.39)	50.945 (5.24)	49.75 (5.50)
antepenult	Duration, ms (sd)	287 (39.0)	289 (38.1)	256 (36.3)	247 (41.7)
Stress realized	Pitch, Hz (sd)	215.89 (7.43)	203.05 (7.48)	206.42 (10.81)	208.59 (9.52)
on	Intensity, dB (sd)	57.15 (2.36)	48.01 (2.99)	50.42 (3.09)	51.42 (4.48)
penult	Duration, ms (sd)	333 (34.4)	288 (31.9)	342 (43.7)	273 (39.5)
Stress realized	Pitch, Hz (sd)	225.03 (5.28)	208.80 (9.50)	207.10 (7.86)	203.72 (4.20)
on	Intensity, dB (sd)	50.80 (5.11)	41.83 (4.45)	49.65 (6.91)	46.21 (4.77)
final syllable	Duration, ms (sd)	501 (69.7)	523 (34.7)	417 (46.1)	441 (60.1)

A comparison of these parameters revealed a number of difficulties. Due to the large number of stimuli, recordings of filler items had to be postponed to a separate session. Moreover, although filler items were produced with slightly higher parameter values (especially in the conditions with stress realizations on the last three syllables, see "filler" column in table 3.1), they were not corrected or rerecorded as these items were not used as critical conditions in ERP analysis. For this reason, filler items were only used for a statistical comparison[9] of correct and incorrect stresses on the first and the second syllable, as there were no other correct stress realizations at these positions. For this comparison the number of filler items for stresses on the first and the second syllable was reduced by randomly choosing 15 out of 30 words to achieve equal group sizes. In order to get a manageable overview of contrasts, a linear mixed effects model was computed that compared the phonetic parameters of stressed syllables for correct and incorrect stress realizations within each identical stress pattern (correctness was defined as a fixed effect and random slopes for correctness by item were included as random effect). Mixed effects modeling was performed following the guidelines of Barr et al. (2013). Table 3.2 reports the t-values of the fixed effects coefficients resulting from the model. t-values above 2 and below -2 are considered significant (Baayen et al., 2008).[10] No significant differences showed up for pitch and intensity realizations between correct and incorrect stresses on the same syllable. For the parameter duration, however, correct and incorrect stresses on the second syllable, the antepenult and the penult differed significantly ($b = -0.07$, $t(1) = -3.04$ for stress on the second syllable, $b = -0.04$, $t(1) = -3.01$ for stress on the antepenult, and $b = -0.06$, $t(1) = -4.45$ for stress on the penult).

[9] For all statistical analyses in this chapter the statistical computing language R (R Core Team, 2013) was used with the packages ez (Lawrence, 2012) for repeated measures ANOVAs, doBy (Højsgaard et al., 2013) for descriptive statistics, and lme4 (Bates et al., 2013) for mixed effects models.

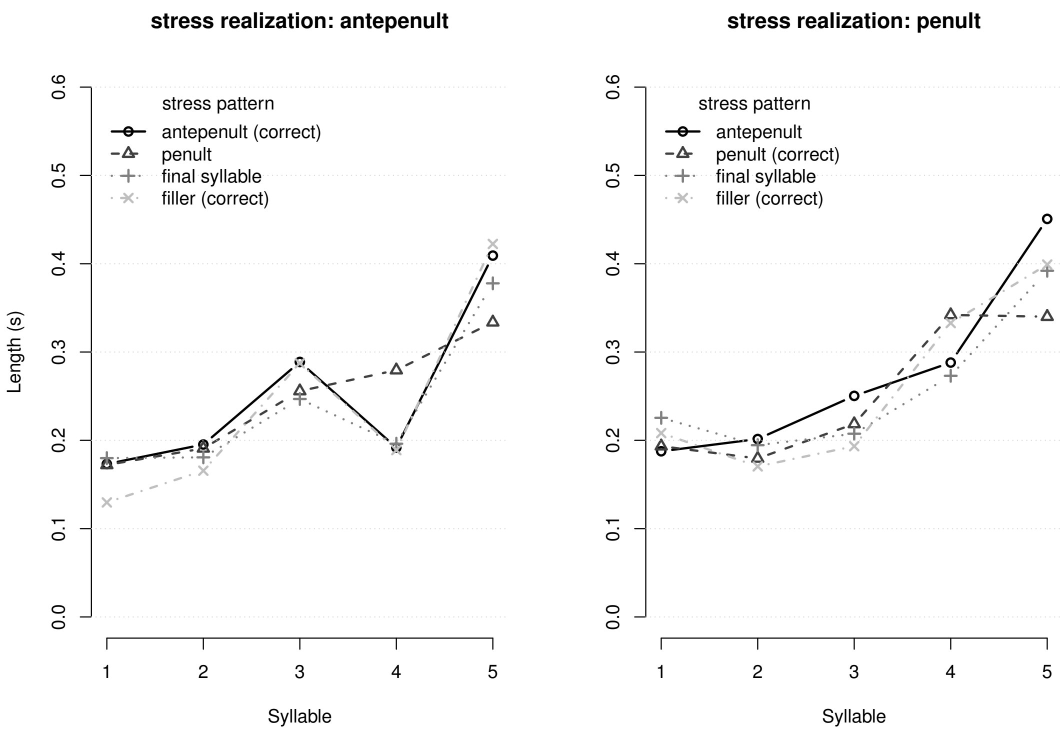
[10] Positive signs indicate that incorrect conditions were produced longer, louder or higher pitched, negative signs that incorrect conditions were produced shorter, more quietly or lower pitched than the correct condition.

Table 3.2: Comparison of phonetic parameters for correct and incorrect stress realizations on the same syllable. *t*-values of fixed effects extracted from linear mixed effects models that compared correct with incorrect realizations.

	Pitch	Intensity	Duration
Stress realized on first syllable	0.97	−1.90	0.89
Stress realized on second syllable	1.01	1.18	−3.04
Stress realized on antepenult	0.40	−0.89	−3.01
Stress realized on penult	−0.18	−0.58	−4.45
Stress realized on final syllable	1.83	−0.23	1.43

Durational differences of stress realized on the second syllable can be ascribed to the separate recording of filler items. The differences in length of the stressed syllable for realizations on the antepenult and penult can be explained by the unavoidable variance in syllabic structure of pentasyllabic German words. Within the conditions in question, the speaker had to produce stress on syllables with high front vowels (e.g., *Sen.si.bi.li.ˈtät* – **Sen.si.ˈbi.li.tät*, "sensitivity"), on /ə/-syllables (which were realized as [eː], e.g., *Ü.ber.ˈle.gen.heit* – **Ü.ber.le.ˈgen.heit*, "superiority"), directly before syllables that contained long vowels (e.g., *Le.gi.ti.ˈmie.rung* – **Le.gi.ˈti.mie.rung*, "legitimization"), etc. These were complicated tasks for the speaker and make a higher degree of variation in the realization of stress inevitable. Artificial manipulations of the phonetic parameters were dismissed to keep the study comparable to the previous ones (see chapter 2) where items were produced naturally. Furthermore, an artificial, software-based production of ill-positioned stresses would have been an at least equally complex task as well, due to the high number of stimuli and manipulations. Moreover, although the incorrect stresses were not realized with exactly the same duration in the discussed cases, the stressed syllable was clearly detectable in all correct and incorrect conditions as it bore comparatively higher values in duration, pitch and intensity compared to the other syllables within the same word. This is shown in figure 3.1 for stress realizations on the antepenult and the penult (for a complete overview of descriptive plots for mean length, pitch and intensity of syllables in all conditions see appendix, page 149). The stressed syllables (3 = antepenult, in the left hand plot, 4 = penult, in the right hand plot) are longer than the preceding unstressed syllable. Stressed antepenults are also longer than the immediately following syllable, except for words with canonical penultimate stress. However, the unstressed penultimate syllable is shortened here compared to its stressed realization shown in the right hand plot. Durational values for the final syllable are longest in all conditions as tagging of syllable boundaries included aspiration, lengthened fricatives, and other phenomena occurring at word offset. Overall, stress was clearly recognizable which was most important for the experimental task.

Figure 3.1: Mean syllable lengths of words stressed on the antepenult and the penult.



EEGs were measured with 24 Ag/AgCl electrodes via a BrainAmp amplifier (Brain Products) with the C2 electrode serving as ground electrode. The reference electrode was placed at the left mastoid. EEGs were re-referenced offline to linked mastoids. Four electrodes (above and below the left eye and at the outer canthus of both eyes) were used to record EOGs (electrooculograms) to control for eye-movement artifacts. Experimental trials that contained artifacts with an amplitude above 40 µV were excluded from evaluation (15.4% of all trials, 12.7 – 19.3% per condition). All electrode impedances were kept below 5 kΩ. EEGs and EOGs were recorded with a digitization rate of 250 Hz, and filtered offline with a bandpass filter from 0.3 Hz to 20 Hz. ERPs were created by averaging over participants, conditions, and electrodes within a time window from word onset up to 2100 ms thereafter. Within these ERPs, positive deflections for the conditions with stress violations were analyzed relative to the condition with correct stress. For the statistical analysis of these positivities, time windows (see tables 3.4, 3.5, and 3.6 in next section) were selected by visual inspection of grand average plots, and regions were defined as frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4). Repeated measures ANOVAs were calculated over the factors stress position (correct stress on antepenult, penult, or final vs. incorrect on initial, second and antepenultimate, penultimate, or final syllable depending on the respective correct position) and region (frontal, central, parietal).

3.1.2 Results and discussion

3.1.2.1 Behavioral data

Error rates were collected from the participants' judgements of the presented stress patterns. Reaction times are not meaningful with this experimental design (cf. Knaus et al., 2007; Domahs et al., 2008; Knaus and Domahs, 2009), as there was a pause between the offset of the whole sentence and the point where participants were allowed to press a yes-no response button.

Mean correctness rates for each stress condition are given in table 3.3. For filler items, table cells for the stress shift conditions are left empty, as only correctly stressed filler items were presented. Pairwise comparisons of the ac-

Table 3.3: Correctness per condition (mean with standard error of the mean in parentheses). Rows indicate experimental conditions, viz., the correct position for stress. Columns indicate the actually stressed syllable. Correct stress realizations are shaded.

	Stress realized on … syllable				
	first	second	antepenult.	penult.	final
antepenult	88% (1.40)	97% (0.70)	99% (0.43)	94% (0.98)	93% (1.08)
penult	83% (1.59)	97% (0.78)	96% (0.84)	97% (0.69)	92% (1.15)
final syllable	73% (1.89)	95% (0.92)	95% (0.95)	96% (0.84)	98% (0.59)
filler (1st syll.)	96% (0.59)	–	–	–	–
filler (2nd syll.)	–	98% (0.41)	–	–	–
filler (antepenult)	–	–	96% (0.84)	–	–
filler (penult)	–	–	–	99% (0.35)	–
filler (final syll.)	–	–	–	–	96% (0.82)

curacy scores revealed significant differences for words with correct final stress between stress realized on the first syllable and all other stress positions (stress on the first vs. stress on the second syllable, $F(1, 19) = 25.13, p = .001$; stress on the first vs. stress on the antepenultimate syllable, $F(1, 19) = 29.39, p = .000$; stress on the first vs. stress on the penultimate syllable, $F(1, 19) = 28.80, p = .000$, stress on the first vs. stress on the final syllable, $F(1, 19) = 17.90, p = .005$). For the condition with correct stress on the penult, significant differences occurred only between stress realized on the first vs. stress realized on the second syllable ($F(1, 19) = 12.05, p = .026$) and between stress realized on the first syllable and on the antepenult ($F(1, 19) = 11.12, p = .035$). No other comparison reached significance at the $p = .05$ level. It should be noted, however, that the reported p-values are Bonferroni-corrected. Due to the large number of comparisons, this conservative method might hide some of the actual differences. If we dismiss Bonferroni corrections, comparisons between stress realized on the first syllable and on any other syllable reach significance in every experimental condition. All other comparisons remain below significance level.

The results show that participants have more difficulty in detecting incorrect stress when it is realized on the first syllable compared to stress violations on other syllables. This is especially true for words with correct penult and final stress patterns, as these results remain significant even after a Bonferroni correction with $n = 10$ hypotheses.

Overall, the behavioral data indicate a special status of the initial syllable. In terms of a foot based interpretation as proposed for German trisyllabic words, this could imply that the initial syllable is a prosodically strong position and that all critical pentasyllabic words, whether carrying main stress on the antepenult, the penult or the final syllable, start with a foot head. Stress shifts to foot heads are harder to perceive (see chapter 2; Domahs et al., 2008; Knaus and Domahs, 2009). In strings of five syllables further strong positions may exist. However, these are not reflected in the behavioral data. The high variability in the participants' responses, which is reflected by the high standard error of the mean values for many of the experimental conditions, shows the difficulty of the task at hand. ERP data may strengthen these findings and reveal more fine grained differences between syllables.

3.1.2.2 ERP data

Figure 3.2 provides an overview of grand average ERPs for the three stress pattern types (antepenultimate, penultimate and final stress) compared with each violation condition. To allow for a visual survey of all contrasting experimental conditions, only Cz electrodes are presented. Plots of all comparisons with the nine electrodes that are used for the statistical analyses (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) are given in the appendix (pages 152 – 163). Grand averages are plotted from the onset of the critical words up to 2100 ms thereafter with a baseline of 200 ms before stimulus onset.

For each of the three stress pattern types, the correct stress realization was compared with each of the incorrect stress realizations. These comparisons revealed positive deflections for the incorrect realizations in relation to the correct realization.[11] The time windows in which these positivities appeared correlate with the position of the incorrectly stressed syllable, which can be read off easily from figure 3.2. In each row, the positive deflections of incorrect conditions (dashed lines) seem to move from left to right. The more frontal a stressed syllable is located in a word, the earlier the positivities occur and vice versa. Due to the variation in the syllabic structure of the words, time windows slightly differ between violation conditions that involved stress shifts to the same syllable. All positivities found are highly significant.

In words with canonical antepenultimate stress (see table 3.4 and first row in figure 3.2), main effects for the factor stress position (i.e., correct vs. incorrect) were revealed for shifts to the initial syllable (550 – 960ms, $F(1,19) = 19.01, p = .000$, with significant interactions in all regions) and to the second syllable (630 – 1140 ms, $F(1,19) = 27.81, p = .000$). Further, a significant interaction in centroparietal region for shifts to the penult was detected (1080 – 1590 ms, $F(1,19) = 22.78, p = .000$ and $F(1,19) = 36.42, p = .000$). In the same condition, stress shifts to the final syllable did not evoke a significant effect (1080 – 1170 ms, $F(1,19) = 1.73, p = .204$), which is clearly reflected in the grand average plot by the curves lying on top of each other (see the rightmost plot in the first row of figure 3.2).

[11] As regards negative deflections preceding the positivities, e.g., from 780 – 990 ms in words with canonical antepenult stress stressed on the penult (*Kon.trol.ˈlier.bar.keit* vs. **Kon.trol.lier.ˈbar.keit*, "controllability"), the distribution of effects is less clear than that of the positivities. One might think of an interpretation in the line of Domahs et al. (2008: 19-20) who assume a contingent negative violation (CNV) for stress violations in trisyllabic words in cases where an initial syllable, which originally carried main stress, was de-stressed and the wrongly stressed syllable follows. In brief, the CNV reflects that a listener cannot yet reject the wrongly stressed word but has to wait for the actual stress to have sufficient information for judgement. While this might be a possible interpretation for cases like **Kon.trol.lier.ˈbar.keit*, as the originally stressed syllable (although not initial) is followed by the wrongly stressed syllable, it does not explain negativities preceding the positivity effects in words like **En.ˈthu.si.as.mus* ("enthusiasm"). It is however possible that these negativities might be a CNV in reaction to the de-stressing/reduction of a syllable in secondary stress position here. Overall, the high degree of variation in the phonetic parameters (see above) might blur the visibility of negativity effects here. I will therefore not interpret these deflections any further.

Figure 3.2: Overview of grand average plots (Cz electrode only) for correct stress realizations (solid lines) vs. incorrect stress realizations (dashed lines). Experimental conditions, viz. correct stress positions, are arranged horizontally. Comparisons with stress shifts to the same syllable are arranged vertically.

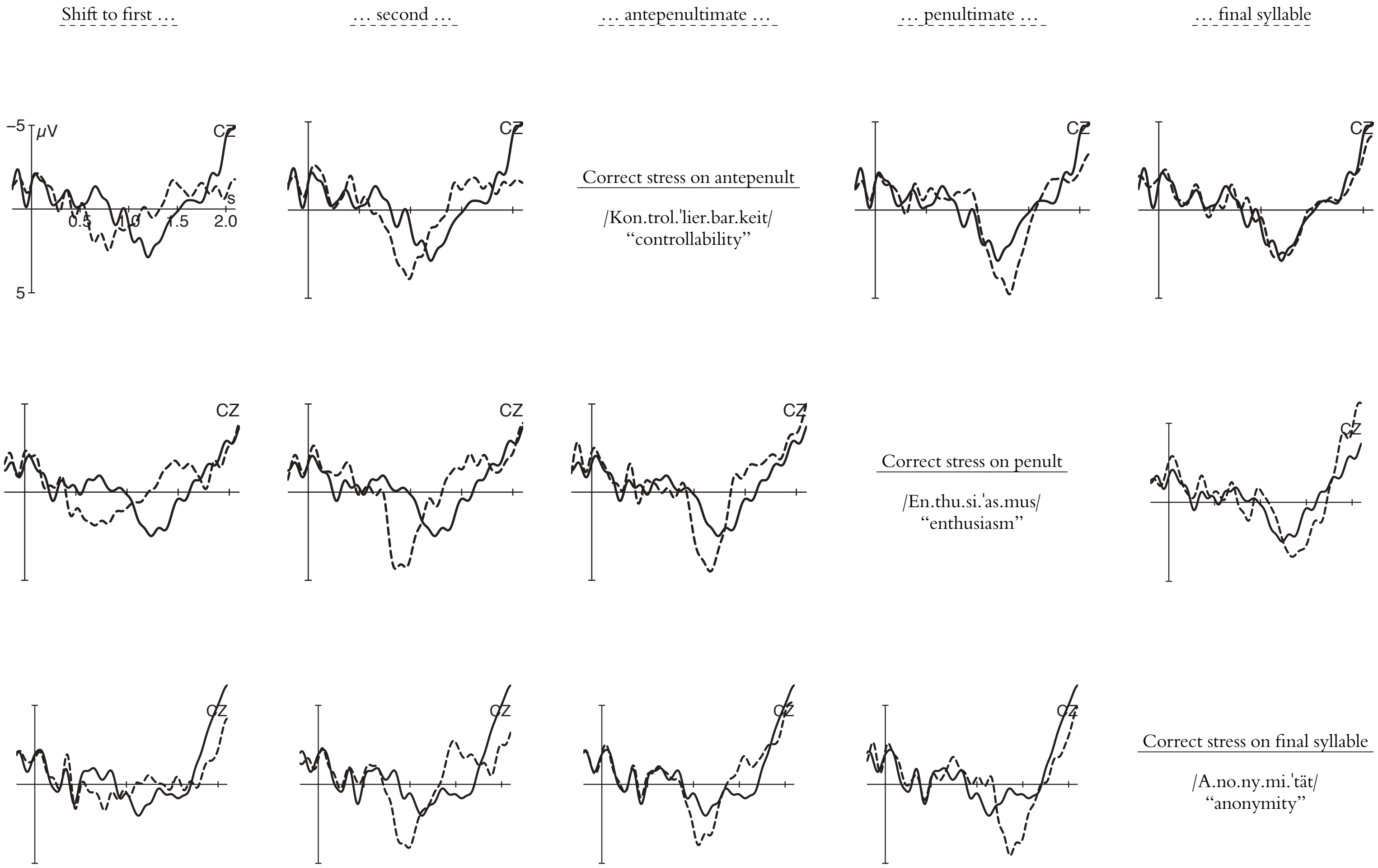


Table 3.4: Words with correct antepenultimate stress – Results of statistical analyses of mean voltage changes for the factor stress position (StressPos) calculated over regions (frontal: F3, Fz, F4; central: C3, Cz, C4; parietal: P3, Pz, P4).

Comparison	Time window	Effect	*DFn*	*DFd*	*F*	*p*	η_p^2
Correct stress on antepenult vs. shift to first syllable	550 – 960 ms	StressPos	1	19	19.01	.000	0.500
		Region	2	38	9.91	.003	0.343
		StressPos × Region	2	38	4.63	.036	0.196
		StressPos in frontal Region	1	19	7.55	.038	0.284
		StressPos in central Region	1	19	23.09	.000	0.549
		StressPos in parietal Region	1	19	20.76	.001	0.522
Correct stress on antepenult vs. shift to second syllable	630 – 1140 ms	StressPos	1	19	27.81	.000	0.594
		Region	2	38	14.40	.001	0.431
		StressPos × Region	2	38	1.57	.227	0.076
Correct stress on antepenult vs. shift to penult	1080 – 1590 ms	StressPos	1	19	18.68	.000	0.496
		Region	2	38	57.39	.000	0.751
		StressPos × Region	2	38	8.10	.007	0.299
		StressPos in frontal Region	1	19	2.84	.325	0.130
		StressPos in central Region	1	19	22.78	.000	0.545
		StressPos in parietal Region	1	19	36.42	.000	0.657
Correct stress on antepenult vs. shift to final syllable	1080 – 1170 ms	StressPos	1	19	1.73	.204	0.083
		Region	2	38	13.38	.001	0.413
		StressPos × Region	2	38	0.52	.521	0.027

All p-values are Huynh–Feldt-corrected and effect sizes are given as partial eta squared values (η_p^2). Significant interactions are resolved and p-values of resolved interactions are Bonferroni-corrected by adjusting the p-values and keeping the p =.05 significance level.

Table 3.5: Words with correct penultimate stress – Results of statistical analyses of mean voltage changes for the factor stress position (StressPos) calculated over regions (frontal: F3, Fz, F4; central: C3, Cz, C4; parietal: P3, Pz, P4).

Comparison	Time window	Effect	*DFn*	*DFd*	*F*	*p*	η_p^2
Correct stress on	400 – 900 ms	StressPos	1	19	65.35	.000	0.775
penult vs.		Region	2	38	1.41	.254	0.069
shift to first syllable		StressPos × Region	2	38	2.77	.100	0.127
Correct stress on	750 – 1100 ms	StressPos	1	19	38.86	.000	0.672
penult vs.		Region	2	38	30.55	.000	0.617
shift to second syllable		StressPos × Region	2	38	7.83	.007	0.292
		StressPos in frontal Region	1	19	25.96	.000	0.577
		StressPos in central Region	1	19	38.38	.000	0.669
		StressPos in parietal Region	1	19	36.22	.000	0.656
Correct stress on	970 – 1300 ms	StressPos	1	19	19.59	.000	0.508
penult vs.		Region	2	38	21.84	.000	0.535
shift to antepenult		StressPos × Region	2	38	2.34	.139	0.110
Correct stress on	1250 – 1740 ms	StressPos	1	19	15.38	.001	0.447
penult vs.		Region	2	38	42.90	.000	0.693
shift to final syllable		StressPos × Region	2	38	20.57	.000	0.520
		StressPos in frontal Region	1	19	0.23	1	0.012
		StressPos in central Region	1	19	25.37	.000	0.572
		StressPos in parietal Region	1	19	49.21	.000	0.721

In words with canonical penultimate stress (table 3.5 and second row in figure 3.2), the factor stress position was significant for all comparisons. Stress shifts to the first syllable (400 – 900 ms, $F(1, 19) = 65.35, p = .000$), the second syllable (750 – 1100 ms, $F(1, 19) = 38.86, p = .000$, with significant interactions in all regions), and the antepenult (970 – 1300 ms, $F(1, 19) = 19.59, p = .000$) revealed main effects. Shifts to the final syllable were highly significant in central and parietal region (1250 – 1740 ms, $F(1, 19) = 25.37, p = .000$ and $F(1, 19) = 49.21, p = .000$).

For comparisons with canonical final stress (table 3.6 and last row in figure 3.2), shifts to the first syllable (530 – 820 ms, $F(1, 19) = 17.59, p = .000$) and to the second syllable (730 – 1100 ms, $F(1, 19) = 47.16, p = .000$) differed significantly from the correct stress realization. Words with stress shifts to

Table 3.6: Words with correct final stress – Results of statistical analyses of mean voltage changes for the factor stress position (StressPos) calculated over regions (frontal: F3, Fz, F4; central: C3, Cz, C4; parietal: P3, Pz, P4).

Comparison	Time window	Effect	*DFn*	*DFd*	*F*	*p*	η_p^2
Correct stress on final syllable vs. shift to first syllable	530 – 820 ms	StressPos	1	19	17.59	.000	0.481
		Region	2	38	2.38	.132	0.111
		StressPos × Region	2	38	1.63	.217	0.079
Correct stress on final syllable vs. shift to second syllable	730 – 1100 ms	StressPos	1	19	47.16	.000	0.713
		Region	2	38	49.60	.000	0.723
		StressPos × Region	2	38	1.81	.188	0.087
Correct stress on final syllable vs. shift to antepenult	920 – 1270 ms	StressPos	1	19	15.43	.001	0.448
		Region	2	38	71.97	.000	0.791
		StressPos × Region	2	38	3.59	.068	0.159
		StressPos in frontal Region	1	19	17.11	.002	0.474
		StressPos in central Region	1	19	19.28	.001	0.504
		StressPos in parietal Region	1	19	5.46	.092	0.223
Correct stress on final syllable vs. shift to penult	1210 – 1660 ms	StressPos	1	19	30.60	.000	0.617
		Region	2	38	40.94	.000	0.683
		StressPos × Region	2	38	4.67	.034	0.197
		StressPos in frontal Region	1	19	14.58	.003	0.434
		StressPos in central Region	1	19	29.48	.000	0.608
		StressPos in parietal Region	1	19	42.43	.000	0.691

the antepenult (i.e., incorrect stresses) were significantly different from correctly stressed words in frontal and central regions (920 – 1270 ms, $F(1, 19) = 17.11, p = .002$ and $F(1, 19) = 19.28, p = .001$), but even in parietal region a tendency ($p = .092$ with, and $p = .031$ without Bonferroni-correction) was detected. Shifts to the final syllable revealed a main effect (1210 – 1660 ms, $F(1, 19) = 30.60, p = .000$) with significant interactions in all regions.

Overall, the comparison of correct and incorrect stress realizations in pentasyllabic German words yielded pronounced positive components similar to those found in previous studies (see chapter 2 and Domahs et al., 2008). Again, the observed P3 effects differ in latency. The time of their occurrence depends on the position of the wrongly stressed syllable. However, the differences in the strength of the P3 are less pronounced than those found in the experimental studies on trisyllabic words (cf. figure 2.1 on page 35).

Only stress shifts to the final syllable in pentasyllabic words with canonical antepenultimate stress show a clearly distinct pattern. Comparable to shifts from antepenultimate to final syllable in trisyllabic words, they do not evoke any positivity effect. This result can be interpreted as a first piece of evidence that foot structures play a role in the processing of stress violations in pentasyllabic words as well. For pentasyllabic words with antepenultimate stress a foot structure with exhaustive parsing (σσ)(σσ)(σ) can be assumed. The correct main stress position implies a foot head on the antepenult. Behavioral data indicate a prosodically strong initial syllable (see section 3.1.2.1 above) as well. The non-occurrence of a positivity effect for stress shifts to the final syllable could indicate a further prosodically strong position at word end. The question arises however, why only this position stands out and why similar patterns of reduced or non-occurring positivities do not show up elsewhere.

A closer look at the morphological structure of critical stimuli with correct antepenultimate stress (cf. list on page 145 in the appendix) reveals that all stimuli of this group end in the derivational suffixes *+heit*, *+keit*, *+schaft*, and *+tum*. They consist of a heavy syllable that can build a foot on its own and start with a consonant. Wiese (2000: 67) assumes that these suffixes license a phonological word. In the other two groups, many critical items end in suffixes that are not assumed to have the status of a phonological word (e.g., *+or*, *+ung*, *+at*, *+ie*, *+ist*). Thus, the shift to the final syllable in words with canonical antepenultimate stress is in each case a movement to a specially licensed strong position.

Across all other comparisons depicted in figure 3.2, the positivities are highly significant. Nevertheless, the purely visual impression suggests that the strengths of the positivities differs. Shifts to the first syllable seem to be less pronounced than all other positivity effects (see plots in the first column of figure 3.2). In words with canonical final stress, the positivity effect for shifts to the antepenultimate syllable seems slightly less pronounced as well, compared to the “neighboring” contrasts with shifts to the second and the penultimate syllable (see plot in the middle of the last row in figure 3.2). Moreover, this shift only tended in direction to significance level in the parietal region (p = .092, see table 3.6 and complete plot on page 162 in appendix).

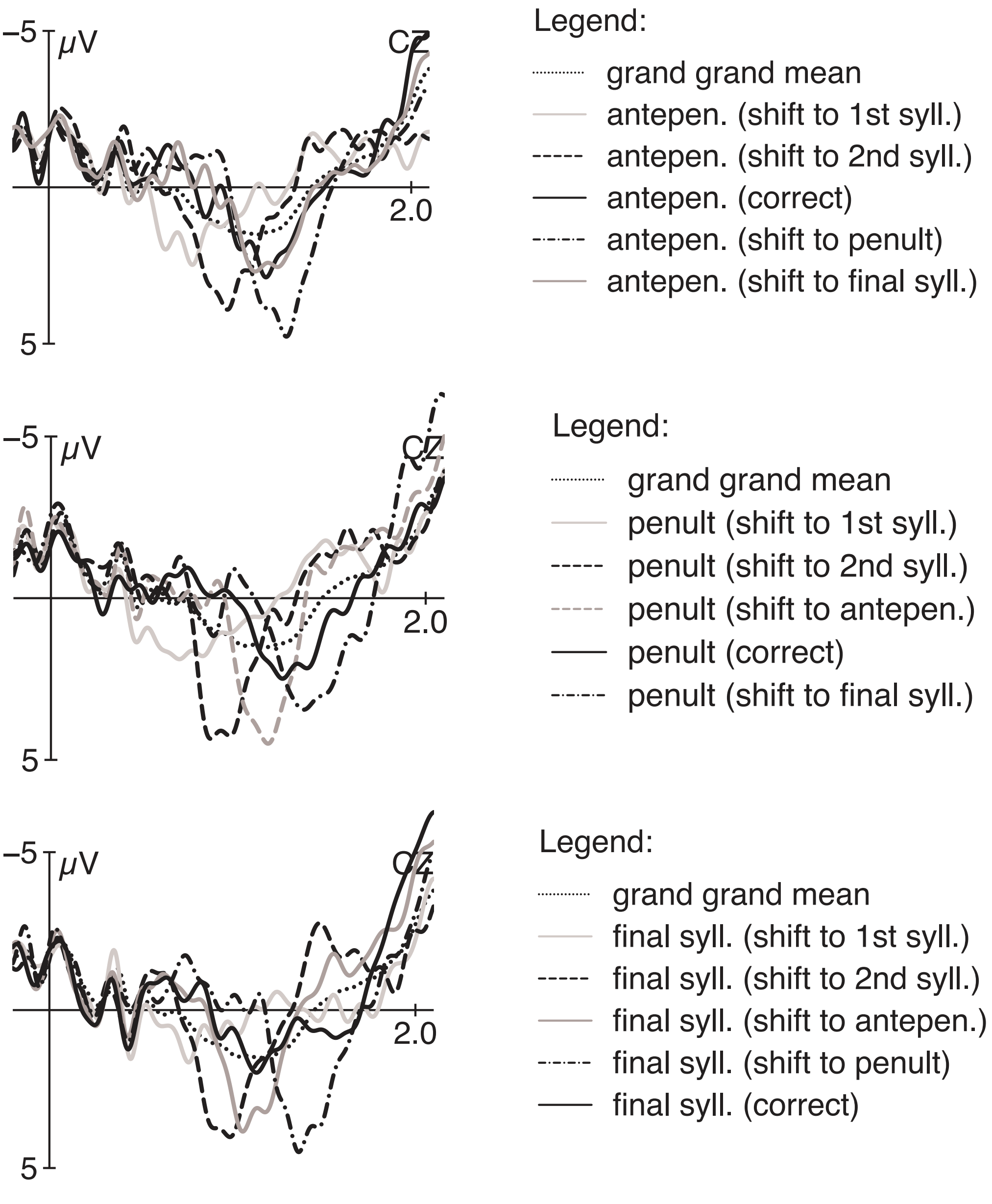
Abiding by the findings from trisyllabic words that prosodically strong, viz., foot head positions evoke less pronounced positivities, the visually observed patterns suggest the following foot parsings: Words with canonical antepenultimate or final stress foot start with two disyllabic trochees followed by the final syllable parsed into a unary foot (σσ)(σσ)(σ). Words with canonical penultimate stress exhibit only two head positions, namely the first syllable and the correct stress position. Thus, they start and end with a disyllabic trochee (σσ)σ(σσ). The medial weak syllable is potentially left unparsed.

A statistical comparison of the strength of the positivities is a very complicated operation here, as all effects have the same polarity and are highly significant. A possible, albeit non-standard way of analysis is to compare the amplitude of the positive deflections.

It is not practical to compare the correct with each of the incorrect conditions directly (by computing difference curves) and retrieve the μV-values at the point of maximal deflection within the time window of the positivity. This would ignore the fact that the correct condition (the solid lines in figure 3.2) is different in each of the time windows.

To achieve an independent and more constant basis for amplitude measurements a so called grand grand average (or grand grand mean) was computed, i.e., an average over all grand averages of all experimental conditions including the filler items. These grand grand averages were in turn compared with the grand averages of each correct and incorrect condition. This procedure highlights distinctive characteristics of each grand average. Figure 3.3 shows the grand grand average (dotted line) grouped with all grand averages for each of the three experimental conditions. Again, the visual impression seems to imply (although less clear for shifts from the final syllable to the antepenult) that shifts to assumed foot heads (solid lines) are less pronounced than shifts to non-head positions (dashed and dash-dotted lines).

Figure 3.3: Comparisons between grand averages of experimental conditions and grand grand average. Solid lines are curves for conditions with stress shifts to assumed strong positions, dashed and dash-dotted lines are curves for shifts to weak positions. The grand grand average is the dotted line.



The time windows in which the reported positivity effects occurred were adjusted to the time in which they deviated from the grand grand average. Furthermore, time windows for positive deviations of the correct conditions were determined (see table 3.7 for an overview).

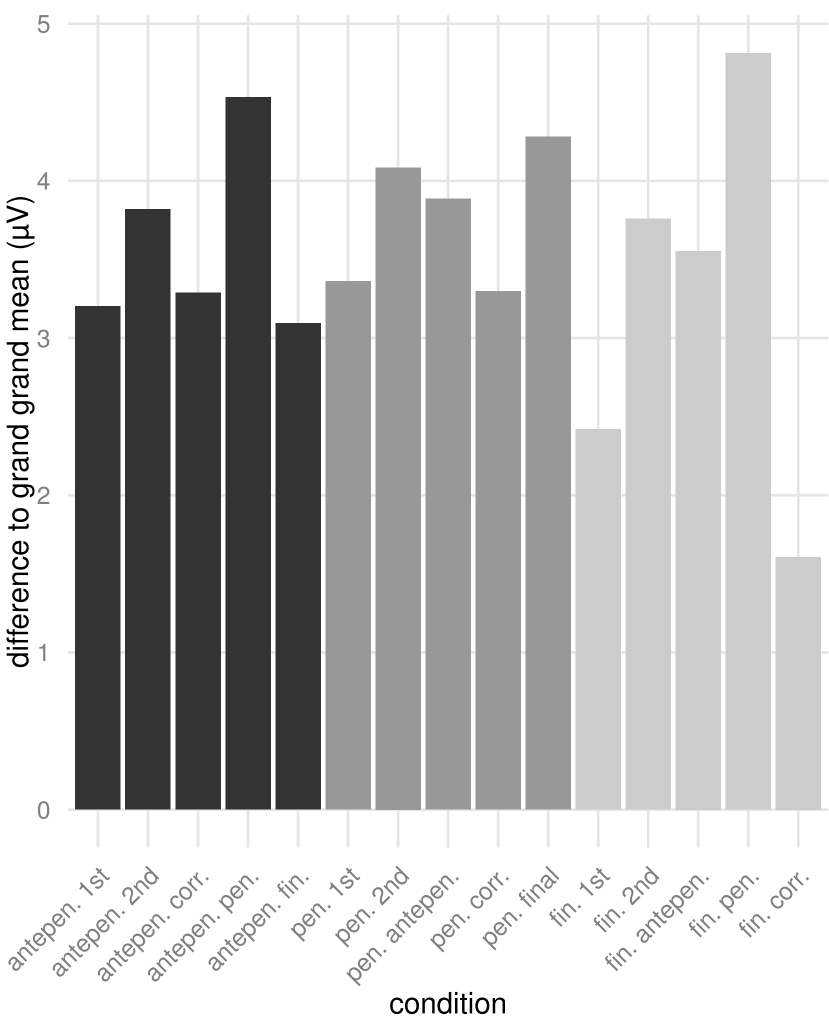
Table 3.7: Time windows of positive deflections from grand grand average. Shaded cells are the correct conditions.

	antepenult	penult	final syllable
first syllable	560 – 880 ms	380 – 860 ms	540 – 800 ms
second syllable	680 – 1150 ms	770 – 1090 ms	750 – 1120 ms
antepenult	1040 – 1550 ms	990 – 1300 ms	940 – 1260 ms
penult	1070 – 1580 ms	1130 – 1630 ms	1230 – 1760 ms
final syllable	1080 – 1420 ms	1220 – 1720 ms	1080 – 1190 ms

Next, differences of grand subject averages, i.e., the subject-wise average of the single-subject averages over all conditions, and all single subject averages were computed, i.e., difference data for each subject was calculated. Out of this data, the maximal amplitude for each positive deflection was retrieved in the relevant time window. By this procedure, a set of data was obtained that contained amplitude measurements of all conditions relative to the grand grand average. These data were independent from one another, as the shape of the correct condition played no direct role in retrieval and temporally independent, as amplitude maxima are just points in time. A descriptive overview of the data is shown in figure 3.4. The descriptive data show that amplitudes for foot head positions – first, antepenultimate, and final syllable in words with correct antepenultimate and final stress or the first and penultimate syllable in words with correct penultimate stress – are always the least pronounced in each group of experimental conditions.

For inferential statistics, a simplified comparison between head and non-head conditions was drawn (see table 3.8). Repeated measures ANOVAs revealed highly significant effects between stress realized on a foot head and a prosodically weak position in all three experimental conditions ($F(1, 19) = 22.37, p = .000$ for words with correct antepenultimate stress,

Figure 3.4: Mean differences of maximal positive amplitudes to grand grand average. Bars are grouped by color according (correct) stress patterns.



$F(1, 19) = 13.45, p = .002$ with significant interactions in all three regions for words with correct penultimate stress, and $F(1, 19) = 73.51, p = .000$ for words with correct final stress).

Table 3.8: Comparsion of positivity amplitudes of head vs. non-head positions (differences to grand grand average). The factor StressPos denotes the head/non-head distinction.

Correct stress pattern	Effect	*DFn*	*DFd*	*F*	*p*	η_p^2
antepenultimate	StressPos	1	19	22.37	.000	0.541
	Region	2	38	3.72	.054	0.164
	StressPos × Region	2	38	0.23	.672	0.012
penultimate	StressPos	1	19	13.45	.002	0.414
	Region	2	38	3.45	.069	0.154
	StressPos × Region	2	38	3.78	.052	0.166
	StressPos in frontal Region	1	19	7.56	.038	0.285
	StressPos in central Region	1	19	12.29	.007	0.393
	StressPos in parietal Region	1	19	14.75	.003	0.437
final	StressPos	1	19	73.51	.000	0.795
	Region	2	38	15.81	.000	0.454
	StressPos × Region	2	38	2.17	.148	0.102

To sum up, the ERP results revealed positivity effects for stress violations in relation to the correct stress condition. Time windows of these positivities are correlated with the position of a stressed syllable, i.e., the earlier a stressed syllable appears in a word, the earlier the occurrence of the positivity. Furthermore, a comparison of amplitudes revealed that the positivity effects differ in strength. Stresses realized on foot heads have less pronounced amplitudes than those realized in non-head positions.

3.1.3 Conclusion

The study on pentasyllabic German words extended previous findings for trisyllabic words (see chapter 2). Positivity effects (P3s) for incorrect stress placement were found, that are time-locked to the occurrence of a stressed syllable. Moreover, the positivities reflect how easily prosodic mismatches are detected. A comparison of amplitudes of positive deflections revealed that the effects differ in strength. If stress is shifted to a foot head, positivities are less pronounced than with shifts to a non-head position. Behavioral data showed that especially the first syllable is a preferred landing site for stress.

Shifts of main stress indicate where the realization of stress is preferred and wellformed. The phonetic realization of secondary stress might be optional and depend on various external factors like speech rate, prosodic context, etc. If secondary stress is realized, however, it is placed in a wellformed position, i.e., on a foot head. Presumably, this is the first syllable in most cases.

Hence, secondary stress positions are primarily determined by word internal prosodic structure. If the overall prosodic context requires a change of word internal prosodic structure, this process is supposed to increase processing costs (cf. experimental study of Bohn et al., 2013). Therefore, secondary stress is less variable than assumed by, e.g., Noel Aziz Hanna (2003) which is further discussed in chapter 4 and the publications reported therein (Knaus et al., 2011; Domahs et al., to appear).

The results corroborate the finding that stress positions are rhythmically distributed within the domain of prosodic words (Knaus et al., 2007; Domahs et al., 2008; Knaus and Domahs, 2009). German words have a distinctive foot structure. Stress manipulations are harder to process when they imply shifts to prosodically strong positions, viz., foot heads. Thus, foot structures play a decisive role in German pentasyllabic words. Experimental findings indicate that the first, the antepenultimate and the final syllable are strong positions in words stressed on the antepenult. In words with penultimate stress, the first syllable and the penult are strong positions. These rhythmical patterns are licensed by the foot structures (σσ)(σσ)(σ) for pentasyllabic words stressed on the antepenult or the final syllable and (σσ)σ(σσ) for words stressed on the penult.

In the next section, these findings will serve as a basis for a discussion of relevant optimality theoretic constraints on secondary stress in German.

3.2 OT constraints on secondary stress in German

In Knaus and Domahs (2009, see chapter 2), findings from ERP studies on German trisyllabic words were used for an optimality theoretic analysis. This analysis abstracted away from the open debate about the definition of syllable weight in German (see discussion in Knaus and Domahs, 2009: 1408) by providing a ranking that fitted all possible combinations of light (L) and heavy (H) syllables ($2^3 = 8$).

Such an approach would not be fruitful for pentasyllabic words due to the sheer number of possible inputs ($2^5 = 32$) and the even larger number of possible foot parsings (70) within the set of candidates.[12] Only a small fraction of these inputs was experimentally tested.

In terms of experimental design, stimuli differed in syllabic (e.g., ambisyllabic consonants, schwa syllables) and morphological structure (e.g., different stem classes, some prefixations, as well as suffixes that also may have had different prosodic status, see page 77 above) and were not controlled according to syllable weight. The latter is in part also not clearly defined theoretically (see previous paragraph) and it is uncertain if all logically possible combinations of light and heavy syllable really exist.

Critical conditions consisted only of words correctly stressed on the last three syllables. A complete and resilient OT analysis of pentasyllabic words based on experimental evidence would also need to account for stress on the first and the second syllable, which were included only as correctly stressed filler items.

All of these restrictions were inevitable, as neurolinguistic experiments also require stimuli to be controlled for a large number of other possible influen-

[12] The number of possible parsings of unary, binary and unparsed syllables is calculated as follows for a string of five syllables: If there is just one disyllabic foot, there are 3 syllables left that can be either parsed into a unary foot or stay unparsed. Thus, we have $4 \times 2^3 = 32$ possible permutations here. For two disyllabic feet, there are 3 possible patterns with one syllable left that can be parsed or unparsed, i.e., there are $3 \times 2 = 6$ permutations. If there are only unary feet or unparsed syllables, $2^5 = 32$ permutations are possible. This sums up to $32 + 6 + 32 = 70$ permutations. Of course, some of these could be excluded *a priori* for an analysis (e.g., a completely unparsed candidate).

tial factors, e.g., lexical frequency and emotionally neutral semantic content. Achieving a set of stimuli that was large enough for statistical analysis already implied making compromises. Consequently, the present study was mainly exploratory and should show whether the experimental design was sensitive to secondary stress positions as well – which it did successfully.

Thus, a definitive analysis of stress in German pentasyllabic words on the basis of the experimental data cannot be achieved, due to the high variation in syllable weight and morphological structure. Nevertheless, the study shows interesting results that allow for a discussion of the optimality theoretic constraints that are involved in the assignment of primary and secondary stress in German pentasyllabic words.

First, there is experimental evidence from behavioral as well as ERP data for the initial syllable being a preferred landing site for secondary stress. A direct approach in terms of optimality theory would encode this finding in the alignment constraint ALIGN-PRWD-L (McCarthy and Prince, 1993: 95, see 1.16 on page 22), which demands that the left edge of any prosodic word coincides with a foot, i.e., that any word starts with a foot. In a trochaic language like German, this always implies that the first syllable is head of a foot. Existing comprehensive optimality theoretic analyses on German word stress have all assumed this constraint in their rankings (though with different naming, e.g., Alber, 1997a: 72, Alber, 1997b: 9, Alber, 1998: 12, Féry, 1998: 117). Thus, the experimental results can be interpreted as further support for its applicability.

Beyond the special status of the initial syllable, the analysis of amplitude differences of the observed positivity effects – although it proved to be a difficult account and the use of non standard procedures was necessary – revealed that not all word medial syllables are equal (cf. figures 3.3 and 3.4). Differences in amplitude reflect the ease or the difficulty evaluating the stress violation pattern. They are larger for stress realized on the weak syllable of an assumed foot and smaller for stress realized on an assumed foot head. This can be considered as an indication for the existence of further word internal feet which provide further potential positions for secondary stress realization.

From an optimality theoretic perspective, this stresses the role of Parse-σ (see 1.10) which requires exhaustive parsing. An exhaustive parsing beginning at the left word edge has been shown to be effected by a ranking interaction of Parse-σ and lower ranked AllFeet-L (see 1.17) which requires all left edges of feet to be aligned with the left word edge (Alber, 1997b: 18).

In the discussion of experimental results in the previous sections, the foot structures (σσ)(σσ)(σ) for antepenultimate and final stress and (σσ)σ(σσ) for penultimate stress were proposed. The question now arises how these structures can be produced by an optimality theoretic grammar. Tableau 3.1 shows the ranking interactions of some constraints possibly involved. The ranking of constraints is compatible with the one proposed in Knaus and Domahs (2009) from which the low ranking of Parse-σ and AllFeet-L is adopted. The newly added constraint Align-PrWd-L must be ranked below Rightmost to make correct predictions in trisyllabic words. Rightmost requires every right edge of a prosodic word to be aligned with the right edge of the head foot (see 1.19).[13] In words with three light syllables, the reversed ranking would select the candidate (ˈL.L).L with an unparsed final syllable and main stress on the antepenult, instead of L.(ˈL.L) with an initial unparsed syllable and main stress on the penult (see section 2.2 above, tableau 1 in Knaus and Domahs, 2009: 1400). The directional counterpart of Align-PrWd-L is Align-PrWd-R which blocks candidates with final unparsed syllables. It is added to the tableau to reveal the general influence of the Align-PrWd constraints in the ranking.

It becomes obvious that the exhaustively parsed candidates (a), (e) and (f) cause no violations other than those of AllFeet-L. Since we abstract away from syllable weight in this tableau, candidates with an unparsed syllable (b – d) are inferior to those with exhaustive parsing through their violation of Parse-σ. Moreover, the candidates (c) and (d) show that neither Align-

[13] This is an important difference between the analysis of Alber (1998: 23-24) and mine. She assumes Rightmost demands that every right edge of a prosodic word is aligned with the right edge of the syllable carrying main stress. Alber interprets "head of a prosodic word" recursively as main stressed syllable. My interpretation remains at foot level and interprets "head of a prosodic word" as strongest foot (see also Knaus and Domahs, 2009: 1399).

Tableau 3.1: Exhaustive foot parsing in German pentasyllabic words and important ranking interactions between constraints possibly involved

/σσσσσ/		Rightmost	Align-PrWd-L	Align-PrWd-R	Parse-σ	AllFeet-L
(a)	(ˌσσ)(ˌσσ)(ˈσ)					⋆⋆ ⋆⋆⋆⋆
(b)	(ˌσσ)σ(ˈσσ)				⋆	⋆⋆⋆
(c)	(ˌσσ)(ˈσσ)σ	⋆		⋆	⋆	⋆⋆
(d)	σ(ˌσσ)(ˈσσ)		⋆		⋆	⋆ ⋆⋆⋆
(e)	(ˌσσ)(ˌσ)(ˈσσ)					⋆⋆ ⋆⋆⋆
(f)	(ˌσ)(ˌσσ)(ˈσσ)					⋆ ⋆⋆⋆

PrWd constraint is needed to determine an optimal outcome, as they are only violated if the initial or the final syllable remains unparsed and this also implies a violation of the independently justified Parse-σ. A violation of low ranked Parse-σ is already crucial in this ranking. With exhaustive parsing, Align-PrWd-R is also not decisive as it always infers the same violations in as Rightmost which is needed independently for main stress assignment. Thus, if we assume that word internal prosodic structure in longer German words is generated by an exhaustive parsing of syllables into feet, the observed ERPs and amplitude differences will already be explainable by an OT ranking that does not need additional alignment constraints beyond Rightmost and AllFeet-L.

Returning to the candidates (a), (e) and (f), the constraints in tableau 3.1 are not able to select an optimal output between these competitors. Further constraints are needed to achieve this. The constraint hierarchy proposed in Knaus and Domahs (2009) includes the high ranked FootBinarity (1.9) and ⋆Clash (1.25) which are able to determine the output candidate here. Candidates (e) and (f) contain unary feet in non-final position. Both constraints restrict the occurrence of this foot type. Unary feet that consist of a light syllable, i.e., degenerate feet, are always ruled out by FootBinarity. If unary feet contain a heavy syllable, they can form a bimoraic foot. Nevertheless, this causes a violation of the constraint *Clash, as we always have adjacent foot heads in candidates where the unary foot is non-final.[14] Crucially, in candidate (a) the final unary foot does not cause a *Clash violation as it is preceded by an unstressed syllable (in the weak part of a foot). Thus, two disyllabic trochees followed by a unary foot that carries main stress is the optimal output. Secondary stress can be realized on the first or the antepenultimate syllable. This structure is the one predicted by the experimental findings for stimuli with correct main stress on the final syllable.

With the ranking proposed so far, other foot parsings will only occur if the final syllable is light and cannot be parsed into a unary foot. Yet, all the stimuli used in the study have heavy final syllables. Footings of words with main stress on the antepenult or the penult must therefore be treated as exceptional cases here.

For antepenultimate main stress, this is straightforward as the same stress position was already treated as exceptional in the analysis of trisyllabic words (Knaus and Domahs, 2009). Again, exceptionality of main stress position could be directly expressed by Head-Match, proposed by McCarthy (2000: 183), a correspondence constraint that requires that prosodic heads specified in the input be realized in the output. An attractive and more restrictive alternative is the assumption of a NonFinality constraint (see definition 1.7 b.), requiring that a strong (head) foot is not final in a prosodic word. This constraint must be lexically indexed for the group of words with main stress on the antepenult. Lexical indexation of constraints was proposed by Pater (2000) in an analysis of English secondary stress and developed further into

[14] ⋆Clash is interpreted here in the way proposed in Knaus and Domahs (2009: 1399), i.e., it evaluates whether heads of feet are adjacent and abstracts away from the question whether stress is actually realized at these positions or not. An alternative solution could be to strictly evaluate only *de facto* realized stresses. In this case, a further constraint like WSP (that requires heavy syllables to be stressed, see definition 1.12) is needed. It would rank below Rightmost and would be violated if neither primary nor secondary stress was realized on these feet. However, such variants in realization are hard to assess in "classic" optimality theory.

a general model in Pater (2007) and Pater (2010). In the case at hand, lexically indexed NonFinality can only be violated by non-wellformed structures in words of this lexical group, all other words vacuously fulfill the constraint. Looking at the morphological structure, a lexical subsetting is plausible as the word final suffixes in the experimental stimuli never carry main stress. The non-indexed version of the constraint is placed below Rightmost and does not change the normal outcome with final stress. Placing the indexed version of the constraint above Rightmost yields an optimal output with antepenultimate main stress and secondary stress on the first syllable and another head position at the final syllable, see tableau 3.2.

Tableau 3.2: Partial ranking showing that NonFinality$_{LexID}$ yields antepenultimate stress.

/σσσσσ/	NonFinality$_{LexID}$	Rightmost	NonFinality	Parse-σ	AllFeet-L
(a) ☞ (ˌσσ)(ˈσσ)(ˌσ)		*			** ****
(b) (ˌσσ)(ˌσσ)(ˈσ)	*!		*		** ****
(c) (ˌσσ)σ(ˈσσ)	*!		*	*	***
(d) (ˌσσ)(ˈσσ)σ		*		*!	**
(e) σ(ˌσσ)(ˈσσ)	*!		*	*	* ***

The foot pattern for pentasyllabic stimuli with main stress on the penult cannot be explained without reference to morphological structure as well. Word final suffixes all have the shape of a disyllabic trochee, either individually or in combination if two affixes are involved (*/-Cis.mus/, /-Cas.mus/, /-Ca.tor/, /-Cie.rung/, /-Cis.tik/, /-Ciert.heit/*, where a *C* denotes any kind of consonant, including glottal stop, or a glide; cf. appendix, page 145). This foot type is structurally wellformed and might form a lexically prespecified template. A possible explanation for the penultimate pattern would be that this foot template is already specified in the input. Once more, this could be couched in optimality theory by introducing a correspondence constraint that demands a prespecified pattern to be realized in the output (in this case a disyllabic trochee). Such constraints are suggested by Pater (1995, named StressIdent), Alber (1998, PK-Max-(B/O) = the stress peak in the base has a correspondent in the output), and Kager (1999b, Head-Max-(B/O)). As an alternative that is consistent with the procedure so far, I propose a version of the NonFinality constraint indexed for the group of penultimate words. This constraint demands that a prosodic head is not realized on the final syllable of a word (see definition 1.7 a.). This recursive interpretation of NonFinality (i.e., the head of a prosodic word is the head of the head foot rather than the head foot only) is crucial for the generation of the exceptional penultimate pattern, which consists of an initial and a final disyllabic trochee and a medial unparsed syllable (see tableau 3.3). The constraint (named Nonfinality-$ˈ\sigma_{LexID}$) is violated by the candidate (b) with final stress.[15] Rightmost rules out the candidates (a) and (d) which do not realize main stress on a foot that is word final. Lowest ranked AllFeet-L designates candidate (c) as optimal output because this candidate has its initial foot aligned with the left word edge. Thus, the only possible position for secondary stress is the initial syllable then. The penultimate pattern is the only one that deviates from exhaustive parsing. This minimal deviation is an effect of lexical indexation.

In summary, the foot structures indicated by the experimental results can be derived by a ranking that assumes exhaustive parsing whenever possible. The amplitude differences found are interpreted as indirect reflections of prosodically weak or strong positions in a word, i.e., heads of feet or weak positions within feet.

The foot structure (ˌσσ)(ˌσσ)(ˈσ) for words with correct final stress follows directly from the constraint ranking already proposed in Knaus and Domahs (2009). The constraint *Clash (eventually in combination with WSP, see fn. 14) plays an important rule in selecting the experimentally observed patterns among the possible exhaustive parsings. The foot structures (ˌσσ)(ˈσσ)(ˌσ) for

[15] An approach that also uses different NonFinality constraints referring either to foot or to syllable level is presented by Alber (1997a: 150-177).

Tableau 3.3: Partial ranking showing that NONFINALITY-'σ_{LexID} yields penultimate stress.

/σσσσσ/		NONFINALITY-'σ_{LexID}	RIGHTMOST	NONFINALITY	PARSE-σ	ALLFEET-L
(a)	(ˌσσ)(ˈσσ)(ˌσ)		*!			** ****
(b)	(ˌσσ)(ˌσσ)(ˈσ)	*!		*		** ****
(c)☞	(ˌσσ)σ(ˈσσ)			*	*	***
(d)	(ˌσσ)(ˈσσ)σ		*!		*	**
(e)	σ(ˌσσ)(ˈσσ)			*	*	* ***!

correct antepenultimate and (ˌσσ)σ(ˈσσ) for correct penultimate stress are subject to lexical prespecification expressed by lexically indexed NONFINALITY constraints. Crucially, the lexical prespecification makes use of prosodic structures that may be indexed for groups of morphemes. How these groups are established is left open for further studies that control for morphological structure and examine comparable subsets. A complete analysis will also possibly have to focus on the details of morphophonological relations in longer words.

Contrary to the initial assumption, ALIGN-PRWD-L is not needed to derive the preference for secondary stress on the initial syllable. PARSE and ALLFEET-L already account for exhaustive parsing which, as a side effect, assures that the initial syllable is always the head of a foot and thus is a landing site for secondary stress. This finding is derived independently from the presence or absence of an acoustic correlate.

The experimental findings question approaches which assume word internal syllables to be largely unparsed due to constraints on foot wellformedness like IAMBICTROCHAICLAW (e.g., Alber, 1997b). The current experimental outcome is, however, not capable of disproving medial underparsing completely, as it tested only a subset of all possible structures and largely abstracted away from open questions about syllable weight.

The study on pentasyllabic words offers further evidence for the role of metrical structure in the processing of word stress information. Foot structure indicates the distribution of secondary stresses in German words. Factors relevant for main stress and secondary stress assignment interact with each other. Optimality theory is a suitable framework for an analysis of these interdependencies.

4 Relations of word stress and higher prosodic levels

In the previous chapter experimental evidence for secondary stress positions in German words was shown. It was revealed that secondary stress depends on foot structure. However, the studies presented so far have abstracted away from influences of higher prosodic levels on word stress. This issue was addressed in two studies (Knaus et al., 2011; Domahs et al., to appear) which are briefly summarized and discussed in the following section.

4.1 Influences of prosodic context on word stress and foot parsing

To investigate the influence of immediate prosodic context on word stress, Knaus et al. (2011) conducted a study that focused on rhythmical violations in compounds. The stress evaluation paradigm established in earlier studies (see chapters 2 and 3) was now applied to newly made up compounds[16] consisting of a trisyllabic first and a pentasyllabic second constituent.

In both constituents of the compounds, correct stresses appeared either on the penultimate or the final syllable. While the first constituent was always stressed correctly, the second constituent was either presented with correct main stress or with stress shifted to the first or the second syllable. The stim-

[16] The compounds were possible German words, that were carefully chosen to be immediately understandable. Although these words are probably not found in any dictionary, they may be (or even may have been) produced by German natural speakers.

ulus design generated an additional contrast between stimuli that contained a stress clash at the constituent boundary (final stress in the first, initial stress in the second constituent) or not (penultimate stress in the first, initial stress in the second constituent). This made it possible to test if stress shifts to a prosodically weak position (i.e., to the second syllable) were preferred over shifts to a foot head position (i.e., to the initial syllable), if the latter induced a clash.

The results confirm the findings of the study on single pentasyllabic words (see chapter 3). Again, P3b effects for the stress violation conditions in comparison to the correct stress conditions were revealed. Positivities were less pronounced (for words with penultimate stress, e.g., *En.thu.si.ˈas.mus* "enthusiasm") or absent (for words with final stress, e.g., *Sen.si.bi.li.ˈtät* "sensitivity") if stress was shifted to the initial syllable. Shifts to the second syllable of the pentasyllabic constituent evoked pronounced positivity effects in all conditions. Crucially, the effects appeared throughout all clash or no-clash contexts and the morphological shape of each effect was very similar in both contexts.

Hence, the study once more revealed that stress shifts to the initial syllable are harder to evaluate than shifts to the second syllable. This argues for the view (taken in chapter 3) that there is a disyllabic trochee at word onset. The initial syllable thus has a special status, it is the preferred position for the realization of secondary stress. This structural preference is stable and not influenced by stress clashes occurring in an immediate prosodic context. Clash avoidance does not play a role at the level of secondary stress.

The lack of rhythmical repair strategies within compounds indicates that word internal prosodic structure is built up independently from higher level prosodic structure. This supports the interpretation of compounds as prosodic phrases rather than prosodic words (Wiese, 2000).

In comparison to the findings on single pentasyllabic words, differences between shifts to head and non-head positions of a foot showed up more clearly, which was true for the strength of the positivity effects as well as for the behavioral data. A possible reason for this might be that – although the design was balanced – participants had to process a larger number of different but overall relatively subtile stress violations. A less complex task seems to reveal more differentiated effects.

As regards the shifts to the initial syllable, words with correct final stress projected no positivity at all, whereas words with correct penultimate stress evoked a significant but less pronounced positivity effect compared to shifts to the second syllable. This difference could possibly be due to the longer distance of main stress to the word boundary in words with correct final stress. The expectation of a further (secondary) stress may be higher than in words with correct penultimate stress, especially if we assume a strong tendency to exhaustive parsing as it is suggested in chapter 3.

Looking at influences of sentence level prosody, Domahs et al. (to appear) conducted a study that investigated on trisyllabic words in focus or non-focus position within a sentence. The experimental paradigm, methods and procedures were adopted from the previous studies (see chapter 2; Domahs et al., 2008), i.e., words correctly stressed on the antepenult, penult, or final syllable where presented with correct stress or stress shifted to one of the other two syllables. In contrast to the earlier studies, the words were embedded in two different sentences. In one of the sentences the critical stimulus appeared in focus position, in the other one it followed the nuclear stress of the sentence.

Overall, comparable ERP effects for words in focus and non-focus position were found. Although less pronounced in non-focus position, the expected positivities evoked by evaluations of different stress violations were revealed for both contexts in the majority of cases.

However, some of the effects did not show up when the word was presented in non-focus position. Stress shifts to the antepenult in words with correct penultimate stress and the opposite contrast, made up by stress shifts to the penult in words with correct antepenultimate stress, did not yield an effect. Thus, stress conditions where either the correct or the incorrect positions appeared at word onset were not evaluated as expected. The finding is explainable if phonetic parameters of word stress are considered. For word stress on initial syllables, pitch is a decisive parameter. If the perception of pitch information is disturbed, evaluation of correct and incorrect stresses is prone to errors. This was the case in the non-focus condition, where initial syllables follow a pitch rise in sentence intonation.

The findings of the study of Domahs et al. (to appear) showed that word and sentence prosody are structurally separate levels. Word prosody is an independent bottom-up process starting with the construction of feet. Nevertheless, higher level prosody can have an influence on word stress perception and processing, in particular when both make use of the same phonetic parameters.

4.2 Publications: Knaus et al. (2011) and Domahs et al. (to appear)

(see next page)

SECONDARY STRESS IS DISTRIBUTED RHYTHMICALLY WITHIN WORDS: AN EEG STUDY ON GERMAN

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ABSTRACT

The present paper report results of an ERP-study on German noun-noun compounds in which the influence of stress clash on stress positions within compounds is tested. In particular, it is examined whether secondary stress within a second constituent is affected by the stress pattern of a first constituent as well as by the main stress position of the second constituent. Stimuli used were polysyllabic compounds which allowed manipulating the stress positions such that alternative hypotheses about foot structure and its constraints could be tested.

The main result is that the preferred position for secondary stress in German is the initial syllable. Furthermore, the distribution of secondary stresses is computed within words, not within larger contexts: Stress clashes caused by these contexts do not influence the distribution of stresses.

Keywords: German, word stress, secondary stress, compounds, ERP

1. INTRODUCTION

The present paper deals with the questions how word stress and stress on higher levels of the prosodic hierarchy are related, and what the preferred positions of secondary stress in German are.

Within the relevant literature, there are conflicting assumptions on the relation of word stress and higher level stress. Some accounts (e.g. [8, 9]) claim that secondary stress is variable and depends on the rhythmical structure of the sentence in which they occur. Which syllable receives stress then is determined by the interplay of primary and secondary stresses of words in a sentence context. Accordingly, interactions of word stress patterns and rhythmical preferences should have a strong influence on stress placement. A second approach (e.g. [4, 7]) argues that stresses are determined by the internal structure of a word, i.e. its feet and syllables. This internal structure is built up independent of higher-level prosodic structures.
Empirical data on the distribution of secondary stresses is sparse and contradictory [3]. What are possible positions of secondary stress, and which are the preferred ones? Alternatively, one could doubt the existence of secondary stress at all in German loanwords [6]?

Generally, the paper addresses the following questions: is secondary stress derived from within the structure of the word, from the context of this word (here, a compound), or from both?

2. AN EEG STUDY ON GERMAN COMPOUND STRESS

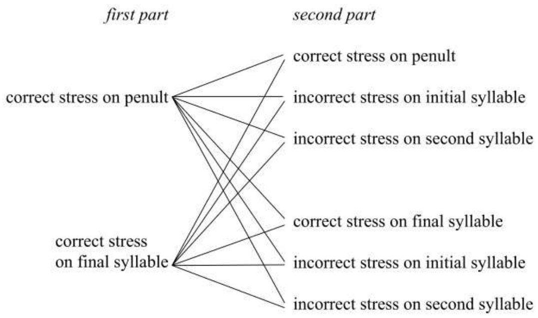
To shed light on these questions we conducted a neurolinguistic experiment on stress in complex German words. Previous EEG-studies on the processing of word stress in German [2, 5] have shown the sensitivity of this experimental method to manipulations of word stress: stress violations leading to illformed or dispreferred structures (e.g. **Vi(ˈta.min)* instead of *(Vi.ta)(ˈmin)*: (LL)(ˈH) becomes L(ˈLH)) produce significantly stronger electrophysiological effects (P3b) than violations maintaining the foot structure *(*(ˈVi.ta)(min):* (LL)(ˈH) becomes (ˈLL)(H)). Thus, the studies show the grouping of syllables into feet, and the potential stress positions in German words irrespective of main or secondary stress positions. Manipulations of main stress can therefore be used as a diagnostic tool to identify secondary stress positions. It is noteworthy that to date no explicit phonetic correlate of secondary stress has been found.

In the current experiment, participants (22 German monolinguals, 12 women) were presented with correctly and incorrectly stressed compounds embedded in a carrier sentence (*Er soll nun (Eu ˈropa)$_\omega$(enthusiˈasmus)$_\omega$ sagen* 'He is supposed to say …'). The task was to judge whether the critical word was stressed correctly or not (by pressing a button). The material was selected such that it allowed for the evaluation of metrical structure and their conditioning factors.

2.1. Method

- Stimuli were naturally spoken German noun-noun compounds, comprising a trisyllabic first part and a pentasyllabic second part, recorded at 44 kHz sampling rate, 16 bit (mono) using *Amadeus Pro* (HairerSoft) and a Beyerdynamic MC 930 electret microphone.
- The design of the stimuli is illustrated in Figure 1. The trisyllabic first constituent of the critical items was stressed either on the penult or the final syllable. These first parts were always stressed correctly. In the pentasyllabic second constituent, correct main stress appeared on the penult or the final syllable. These constituents were derived words, all comprising main and (supposed) secondary stresses. Following the rationale explicated in [2], possible secondary stress positions should be identifiable via main stress shifts. Therefore, manipulations are applied only to the second constituent in which main stress was shifted from the correct position to the initial or the second syllable. Compound main stress lies on the first part and our manipulations do not affect compound stress but word stress of the second constituent. The use of morphologically complex noun stimuli could not be avoided because of a lack of suitably long monomorphemic nouns.

Figure 1: Overview of the stimulus design and the 12 experimental conditions (2x2x3).



- This experimental design (Fig. 1) allowed us to investigate whether the stress shifts within the second part of the compound indicate possible secondary stress positions (i.e. heads of feet) and whether the position of main stress in the first part of the compound (stress context) has an influence on the processing of these stress shifts (i.e. clash avoidance effects, cf. [10]). For an example of each of the cases, see Figure 2.
- The set of stimuli consisted of 15 stimuli per condition, presented twice. Each pentasyllabic constituent appeared in each of the experimental conditions (i.e. once with stress in the correct position, and twice with stress in incorrect positions).
- In order to balance the number of correctly and incorrectly stressed words the stimulus set included also 30 filler items with stress on the first and second syllable each.
- EEGs were measured via 22 AgAgCl electrodes (C2 as ground, reference placed at left mastoid) and a *Brainvision* amplifier. Impedances were kept below 5 kΩ; EEG/EOG were recorded with a sampling rate of 250 Hz, filtered offline with a 0.3-20 Hz bandpass filter.
- Averages were calculated from the onset of the second part of the compounds up to 1900 ms post onset.
- For comparison of mean voltage differences between correct and incorrect conditions, two time windows were selected by means of visual inspection (from 330 to 580 ms for shift to the first syllable and from 500 to 900 ms for shift to the second syllable).
- ANOVAs were calculated for STRESSPOSITION (correct vs. initial or second syllable) over three BRAINREGIONS (frontal: F3, Fz, F4; central: C3, Cz, C4; parietal: P3, Pz, P4).

2.2. Results

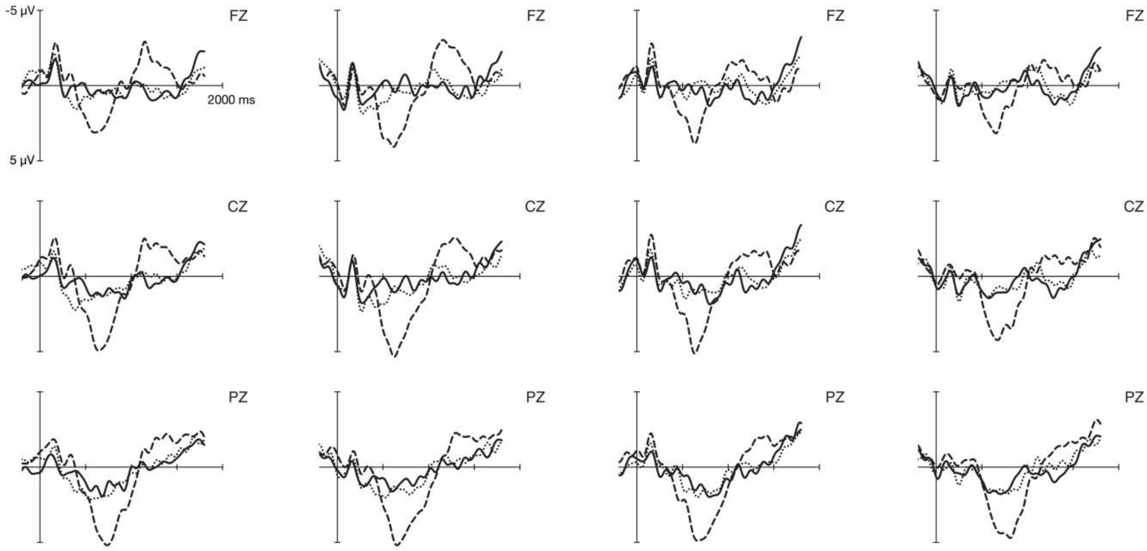
2.2.1. Behavioral data

Reaction times are not analyzed here, as participants had to react with a delay after the offset of the carrier sentence to avoid movement artifacts. Error rates were below 9% for most conditions, whereas the error rates for stress shifts to the first syllable ranged from 41% to 50%. Crucially, there were no differences between the stress contexts provided by the differently stressed first parts of the compounds.

2.2.2. ERP data

A comparison of the averaged EEG data of the correct conditions with the two conditions containing stress violations in the second part of the compounds revealed positivity effects (see Figure 2). In the following, it is outlined how stress context and main stress position of the second constituent modulate the positivity effects.

Figure 2: Grand average plots (midline electrodes) of correctly stressed pentasyllabic words (solid lines) and the same words with incorrect stress on the first syllable (dotted lines) and incorrect stress on the second syllable (dashed lines).



Euˈropa-Enthusiˈasmus
* Euˈropa-ˈEnthusiasmus
* Euˈropa-Enˈthusiasmus
"enthusiasm for Europe"

Parlaˈments-Enthusiˈasmus
* Parlaˈments-ˈEnthusiasmus
* Parlaˈments-Enˈthusiasmus
"enthusiasm for the parliament"

Aˈroma-Sensibiliˈtät
* Aˈroma-ˈSensibilität
* Aˈroma-Senˈsibilität
"sensitivity to flavours"

Aggresˈsions-Sensibiliˈtät
* Aggresˈsions-ˈSensibilität
* Aggresˈsions-Senˈsibilität
"sensitivity to aggression"

Shifts within the second constituent with penultimate stress: Shifts from the penultimate syllable to the initial syllable evoked, irrespective of stress contexts (e.g. **Euˈropa-ˈEnthusiasmus* and **Parlaments-ˈEnthusiasmus*), a positivity effect between 330 to 580 ms post stimulus onset (F(1,21)=16.98, p<.001 and F(1,21)=7.52, p<.012). Stress shifts to the second syllable *(Enˈthusiamus)* revealed an even larger positivity effects in both stress contexts (**Euˈropa-Enˈthusiasmus* and **Parlaˈments-Enˈthusiasmus*) between 500 and 900 ms post onset (F(1,21)=27.76, p<.000 and F(1,21)= 41.31, p<.000).

Shifts within the second constituent with final stress: Violations evoke asymmetrical effects. Stress shifts to the initial syllable evoke no positivity effect in neither stress context (e.g.**Aˈroma-ˈSensibilität* and **Aggresˈsions-ˈSensibilität*) measured again within 330 to 580 ms (F(1,21)= 3.07, p=.094 and F(1,21)>1). In contrast, stress shifts to the second syllable produce enhanced positivity effects in both contexts (**Aˈroma-Senˈsibilität* and **Aggresˈsions-Senˈsibilität*), again between 500 and 900 ms (F(1,21)=35.46, p<.000 and F(1,21)=36.15, p<.000).

2.3. Discussion

The present study aimed at finding evidence for potential secondary stress positions in derived German loanwords and, in addition, the factors which influence secondary stress positions. It is suggested that words bear initial secondary stress in multisyllabic words whose main stress allow for further prominent syllables (e.g. [1]). Alternatively, it has been suggested that secondary stresses of words are influenced by rhythmical alternations at the sentence level (e.g. [8]).

The present study replicates findings from earlier experiments on stress perception using a stress evaluation paradigm, as the electrophysiological effects obtained are again positivity effects, interpreted as instances of a P3b reflecting a task-specific process in [2, 4]. Again the occurrence and non-occurrence of the P3b tells us how stress positions are rhythmically distributed by means of feet within the domain of prosodic words. The first crucial result is that for neither analysis the stress context played a role. We did not find a greater acceptance of stress shifts to the second syllable in words with finally stressed first constituent than in stress contexts with penultimate stress.

The evaluation of stress shifts and the obtained ERP-results strongly suggest that the initial syllable is the preferred secondary stress position in German. In this respect, it is noteworthy that shifts to the initial syllable produce no positivity at all in pentasyllabic words with final canonical stress. This shows a high acceptance of initial stress irrespective of the stress context. Clash contexts have no influence on the processing of the initial syllable. Thus, clash avoidance in words like **Aggresˈsions-ˈSensibilität* does not play a major role in the prosodic processing of the critical items. The suggestion is not that clash avoidance does not play a role in prosodic processing at all, but that the level of secondary stress is not affected by the level of compound stress. Feet are constructed within words independently of the phrasal context. This finding is corroborated by the analysis of the behavioural data. Shifts to the second syllable had significantly lower error rates, i.e., they were easier to detect, while shifts to the first syllable produced up to 50% error rates, i.e., participants were uncertain about the correctness of this stress position.

As regards stress shifts to initial syllables we find asymmetrical results for pentasyllabic words with final and penultimate stress. Whereas in the former case no P3b was obtained, the latter case produced a significant effect though not as pronounced as in shifts to second syllables. Our interpretation of the differentiated results is that a possible realization of secondary stress in finally stressed pentasyllabic words is expected more than in words with penultimate stress. This might be due to the distance between main stress and the left word boundary *((ˌSen.si)(bi.li)(ˈtät)* vs. *(ˌEn.thu)-si(ˈas.mus)),* or due to the better parsing conditions in finally stressed words opposed to words with penultimate stress.

Finally, our data provide evidence for the parsing routine underlying assignment of secondary stress. In linguistic theory, it is under debate whether main and secondary stresses result from the same parsing procedure or whether main stress is aligned to the right word edge and secondary stress to the left edge. For the alternative foot analyses see the following examples.

- ??En.(thu.si).(as.mus)
- (En.thu).si.(as.mus)

The less pronounced violation effect for words with stress shift to the first syllable as well as the high acceptance of initial stress in the judgements speak in favour of the second option with an initially parsed syllable; secondary stresses are aligned with the left edge of words [1]. Whether the parsing is quantity-sensitive or not is unsolved so far and has to be addressed in future studies. Rhythmical preferences within larger domains, for example within a compound, do not override this foot placement.

3. CONCLUSIONS

The preferred position for secondary stress in (pentasyllabic) German words is demonstrated to be the word-initial syllable. Stress clashes resulting from immediate context do not influence this overall preference. Within the constituents of a compound prosodic structures are built up independently of each other. This supports the idea that compounds are a special case of prosodic phrases rather than prosodic words [11].

In both clash and non-clash contexts, a stress shift to the initial syllable is tolerated, while shifts to the second syllable always are detected as incorrect. The lack of clash avoidance effects across word boundaries argues for the view that word prosody and prosody above the word are separate levels of prosodic structure and processing.

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Word prosody in focus and non-focus position:

An ERP-study on the interplay of prosodic domains

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Abstract

In the present paper, the online processing of stress manipulations in German words embedded in either focus or non-focus position within a sentence was investigated utilising event-related potentials. In particular, the aim was to find out how word and sentence prosody are related and whether the word level constitutes an autonomous structural domain.

As a major result, it was shown that evaluations of different stress violations produced comparable electrophysiological effects for words embedded in focus and non-focus position. However, some effects observable in focus position failed to be present in a non-focus position in which the critical words were preceded by a pitch rise. Especially elements immediately following high tone elements as parts of pitch accents seem to be prone to being misinterpreted according to their prosodic status as either stressed or unstressed. The reason for the impact of pitch accents on initial syllables seems to be that values of phonetic parameters as cues for word stress vary across word positions: initial stress are mainly realised by pitch, medial stress by pitch and length, and final stress mainly by length. Thus, initial syllables are prone to being misinterpreted as stressed or unstressed in cases where they follow a pitch rise in intonation as the stress information here relies mainly on pitch information. However, other aspects of words prosody seemed to be processed independently from higher prosodic levels, namely length distinctions in stressed and unstressed syllables.

Keywords: sentence prosody, word stress, ERPs, processing of rhythm, P300

1. Introduction

Rhythm is described in terms of differences in prominence between phonological units on various levels of the prosodic hierarchy, e.g. word or phrasal stress. While word stress is determined by the internal structure of a word, i.e., by the grouping of syllables into feet (e.g. Liberman & Prince 1977; Hayes 1995), sentence prosody results from the structuring of elements higher up in the prosodic hierarchy. In contrast to the position of word stress, the position of sentence stress is influenced by syntactic, semantic, and pragmatic factors, and is therefore displays more flexible variation.

Yet it is still an open question, how word stress and rhythm above the word are related. Opinions about the status of word stress differ on the question whether it is dependent of sentence rhythm (e.g. Vennemann 1995; Noel Aziz Hanna 2003) or not (e.g. Nespor & Vogel 1986; Knaus & Domahs 2009). In the former account, word stress assignment (at least for secondary stress) is supposed to be variable and to result from the distribution of stresses within a phrase or sentence. In this respect, default metrical patterns and the avoidance of stress clashes might be responsible for the variation in prosodic structures of words. In the latter account, phonological words are assumed to display a prosodic structure of their own, i.e, they consist of feet, which are derived by constraints applied to word phonology. Hence, prosodic word structures are built up prior to structures of higher level prosody and are therefore autonomous entities.

In the following introductory sections, we give a short overview over theoretical approaches to the prosodic structure of words and sentences and review previous neurolinguistic findings on word and sentence prosody.

1.1 Prosodic hierarchy

Since the seminal paper on linguistic rhythm by Liberman and Prince (1977), it is assumed in generative grammar that rhythmic properties derive from prominence relations between syllables, feet, prosodic words or prosodic phrases which are seen to be organised into hierarchical layers of prosodic constituents. In this respect, the most influential model on the prosodic hierarchy has been proposed by Nespor and Vogel (1986), in which seven prosodic levels are postulated (see figure 1 below). In Nespor & Vogel's terms, the phonological word is defined to include the prosodic entities of syllable and foot and is part of the higher levels clitic group, phonological phrase, intonational phrase and phonological utterance. According to the Strict Layer Hypothesis (Selkirk 1984), each foot must be parsed into the next higher category phonological word (ω) and each syllable of a foot must belong to the same phonological word.

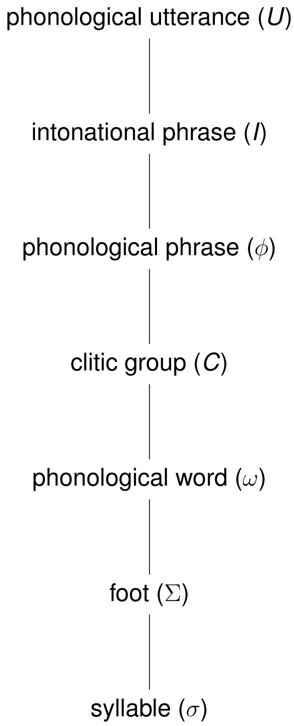

Figure 1: *The prosodic hierarchy (with constituents according to Nespor & Vogel 1986)*

On the word level, it is rather uncontroversial that trochaic feet are constructed from the right word edge to the left (e.g. Giegerich 1985; Féry 1998; Janßen 2003; Jessen 1999; Wiese 2000). However, it is less clear whether syllable weight plays a role for foot parsing. There is some evidence that heavy (i.e., closed) final syllables build monosyllabic feet (Janßen 2003; Alber 2005; Domahs et al. 2008; Janßen & Domahs 2008; Knaus & Domahs 2009), and that the rightmost foot within a word receives main stress (Alber 2005; Féry 1998; Giegerich 1985; Knaus & Domahs 2009; Wiese 2000). With respect to secondary stress in German words, it has been proposed that syllables of words are fully parsed into feet and that the positions of main and secondary stress depend on this foot structure (Alber 2005; Knaus & Domahs 2009). However, alternative approaches assume that secondary stress rather depends on the rhythmical distribution of strong syllables within a two-step system involving main stress assignment followed by rhythmically-based assignment of secondary stresses (see the Primary-Accent-First Theory; van der Hulst 1996, 1997, 2009) or on rhythmical properties of higher-level prosody (see Noel Aziz Hanna 2003). According to Noel Aziz Hanna (2003), secondary stress positions in German complex words depend mainly on the rhythmical context of the sentence in which they occur, i.e., words following a strong syllable tend to be stressed on the second syllable (e.g. *ˈmein Ophˌthalmoˈloge*, ‘my ophthalmologist’) whereas words following one or two weak syllable(s) on the first syllable (e.g. *ein ˈjunger/ˈjüngerer ˌOphthalmoˈloge,* ‘a young/younger ophthalmologist’).

Sentence prosody largely consists of intonational patterns that indicate sense units, which have been described as melody contours over sentences or parts of them. One further characteristic of intonational phrases is a high or low boundary tone indicating the end of an intonation contour. A neutral intonational pattern of declaratives has nuclear stress realised in focus position, i.e., the new information within a sense unit, and often show a declination towards the end of the intonational phrase. The nuclear syllable is the most accented syllable that can be phonetically implemented by different accent types. In (1), some pitch accent types occurring in German declaratives are depicted (according the convention of the German Tones and Break Indices (GToBI, Grice et al. 1996; Reyelt et al. 1996).

(1) a) H*+ L-%
Mein **ZAHN** tut WEH. (Grice & Baumann 2002:19)
(My TOOTH hurts.)

b) L*+H L-%
Das **WEISS** ich SCHON! (Grice & Baumann 2002:19)
(I KNOW that already.)

So far, word level and sentence level prosody have mainly been investigated separately from each other. The main objective of the present study is to examine how word level prosody is affected by higher level prosody. To this end, ERPs (event-related potentials) evoked by manipulations of word stress will be investigated in focus and non-focus position.

1.2 EEG studies on prosodic processing

In the ERP[1] literature, some work has been devoted to the prosodic structure of words (e.g. Friedrich, Kotz, Friederici, & Alter, 2004; Magne et al., 2007; Domahs et al., 2008; Marie, Magne, & Besson 2011; Domahs et al., to appear) and to the processing of prosodic phrases and intonation (e.g. Steinhauer, Alter, & Friederici, 1999; Schmidt-Kassow & Kotz, 2009a/2009b; Rothermich, Schmidt-Kassow, Schwartze, & Kotz, 2010). However, the interplay of word and sentence prosody has to our knowledge not been investigated yet. In the following, we will discuss some ERP-components correlated with prosodic processing at different levels.

In an experiment investigating metrical violations presented in jabberwocky sentences (e.g. *ˈSchlopfzu ˈhätte ˈFligme ˈpeile ˈdögent naˈPEN ˈsollen*, the metrical violation given in bold letters), Rothermich, Schmidt-Kassow, Schwartze, and Kotz (2010) observed a frontal negativity between 200 and 350 ms which was interpreted as an instance of a general error detection mechanism. In other domains of cognitive processing, such a component has also been labelled RAN (right anterior negativity) and was found for instance for rhythmical violations during the processing of music (e.g. Koelsch, Gunter, Friederici, & Schröger, 2000).

In studies investigating the lexical status of word stress information, an N400-like component was found for the processing of ill-stressed words (Knaus, Wiese, & Janssen, 2007). Furthermore, priming experiments using pitch contours as primes revealed a reduced P350 for targets that were primed by a matching pitch contour (Friedrich, Kotz, Friederici. & Alter, 2004).

Another component associated with stimulus related attention is the P300b. This positivity was modulated by the violation of predicted stress patterns (Knaus, Wiese, & Domahs, 2007;

[1] In studies using ERPs, electrophysiological brain responses (small changes in mean voltage) are measured time-locked with a predefined type of stimulus via electrodes fixed on the scalp. By means of several averaging procedures, different types of event-related potentials (ERPs) can be detected. These so called ERP-components are negative or positive deflections of the electrophysiological signal associated with certain types of sensory or cognitive processes. ERPs allow for a very high temporal resolution and are qualitatively distinct for different types of cognitive processes (e.g. language processes). They are classified according to their polarity, to their latency time-locked with the stimulus onset, and to their topography, i.e., where they are measured on the scalp. In general, not the absolute values of voltage changes induced by a critical condition are interpreted, but voltage differences between two critical conditions (for a detailed description of the methodology see Kutas et al., 2006). Frequently reported ERP components include the N400, a negative deflection at around 400 ms post stimulus onset reflecting deviations from expectations, or the P600, a late positive component evident, e.g., in syntactic processes.

Domahs et al., 2008), by the presentation of duration deviations of syllables (Magne et al., 2007; Marie et al., 2010), and by the temporal predictability of tones (Schmidt-Kassow, Schubotz, and Kotz, 2009). In the ERP study by Domahs et al. (2008), participants were confronted with correctly and incorrectly stressed trisyllabic words, the latter ones leading to a change in prosodic structure. The aim was to investigate whether different types of stress violations/prosodic changes would produce different ERP effects, which might indicate qualitatively distinct processes in the parsing of diverse stress patterns. A comparison between correct and incorrect conditions revealed that different types of foot structure violations produced different ERP effects (for more details about the experimental setup and the analyses see Domahs et al. (2008) and Knaus et al. (2007)). Similarly, Magne et al. (2007) and Marie et al. (2010) manipulated the length of initial syllables in trisyllabic French words and found comparable positivity effects that were interpreted to reflect the processing of unexpected phonetic parameters.

In studies investigating the processing of phrasal or sentence prosody, Steinhauer, Alter, & Friederici (1999), Friederici et al. (2004), as well as Pannekamp, Toepel, Alter, Hahne, & Friederici (2005) observed a late positivity effect at intonational phrase boundaries (Closure Positive Shift, henceforth called CPS) indicating a “specific on-line brain response to prosodic processing” (Steinhauer, Alter, & Friederici 1999:191). In a series of ERP experiments with either natural sentences, jabberwocky sentences, delexicalised sentences, or hummed intonation contours, the authors observed a positive deflection of EEG signals time-locked with the processing of a prosodic boundary, irrespective of the syntactic structure of the phrase. Intonational phrase boundaries which were not indicated by a pause further suggested that the CPS rather reflects the processing of prosodic contour patterns (rising or falling of the pitch contour within a phrase) than an acoustic marking of the boundary.

All these components were obtained in studies on linguistic processing of prosodic information, but the findings are confounded by general cognitive processes influenced by phrasing, temporal predictability and error detection mechanisms. However, though these components are not likely to reflect linguistic processing directly, they are measures to investigate which metrical properties play a role in language processing.

The aim of the present paper is to identify ERP effects that can be traced back to the interaction between nuclear and word stress. For this purpose, the experimental design used by Domahs et al. (2008) was modified. We performed an experiment in which words in focus and non-focus position were manipulated with respect to main stress positions. The modulation of the P300 component was predicted to tell us how the perception of word stress can be influenced by prosodic entities higher up in the prosodic hierarchy.

2. ERP-study on the relation between word prosody and sentence rhythm

Measuring electrophysiological responses to correctly and incorrectly stressed words, Domahs et al. (2008) identified a late positive component (also reported in Böcker, Bastiaansen, Vroomen, Brunia, & De Gelder (1999) in a stress matching task) which the authors functionally classified as an instance of a P300 component (Picton 1992; Verleger 1988), and which indicates the degree of mismatch between an expected stress position and its deviation. The major result of this work was to show that the processing of main stress in German words is strongly related to the processing of the prosodic structure of the phonological word. More specifically, it could be shown that stress shifts produced enhanced P300 effects only in those cases where the shift led to a change in foot structure. So far, these results have been taken as evidence for the internal structure of words, i.e., for the hierarchical ordering of syllables into feet and of feet into prosodic words. However, the critical words appeared in prominent (= focus) position of the carrier sentence. Therefore the experimental manipulation was not only restricted to the domain of word prosody, but rather affected word and sentence prosody alike. The question will be addressed whether the earlier results are indeed capable to identify the foot level of phonological words, or whether they merely offer a window into the rhythmical structure of intonational phrases.

2.1 Method

2.1.1 Material

In the present study, we adopted the methodological procedure reported in Domahs et al. (2008), see section 1.2 above: the experimental manipulation as well as the stimulus material were identical. Stimuli were trisyllabic, monomorphemic nouns of German with stress either on the antepenultimate, penultimate or final syllable, accented both on the correct syllable (e.g. *Kaˈsino*, 'casino') and on the two syllables leading to stress violations (e.g. *ˈ*Kasino* and **Kasiˈno*; for more details on the word properties see Domahs et al., 2008). All items were controlled for syllable structure, segmental properties and word frequency.

The experiment differed from the earlier study in that each word was embedded in two different sentences: i) a sentence in which the position of manipulated word stress coincided with the position of the nuclear stress of a sentence, i.e., the most prominent syllable of this sentence, and ii) a sentence in which both stresses were realised on different and non-adjacent positions within the sentence. The examples in (2a) and (2b) illustrate examples of the critical conditions.

(2a)		H*		nuclear stress of the sentence
		x		word stress
	Er soll nun	Bi.kí.ni	sagen.	'He is supposed to say Bikini'

(2b)		L*H			nuclear stress of the sentence
			x		word stress
	Er hat	nur noch	Bikíni	gesagt.	'He said nothing but Bikini'

Ninety words embedded in each sentence type were recorded with each stress pattern (90 × 2 × 3), and also 180 additional filler words to keep the number of correctly and incorrectly stressed words balanced. In total, 720 stimuli (critical and filler) were recorded.

For data analysis, only the electrophysiological responses to the trisyllabic critical words were considered. Note that the slightly different lexical contents of the two sentences had no impact on the semantics of the critical words, because both sentences consisted of a pronoun (*er* 'he'), a modal/an auxiliary verb (*soll* 'should', *hat* 'have$_{3.sg.}$'), one or two particles (*nun* 'now', *nur noch* 'just only'), and as the only content word the infinitive or past participle of the verb *sagen* ('to say'). Moreover, the critical words appear in a citation-like context in both sentences, indicated by a sentence internal prosodic pause without pitch fall (see Figure 2a and 2b).

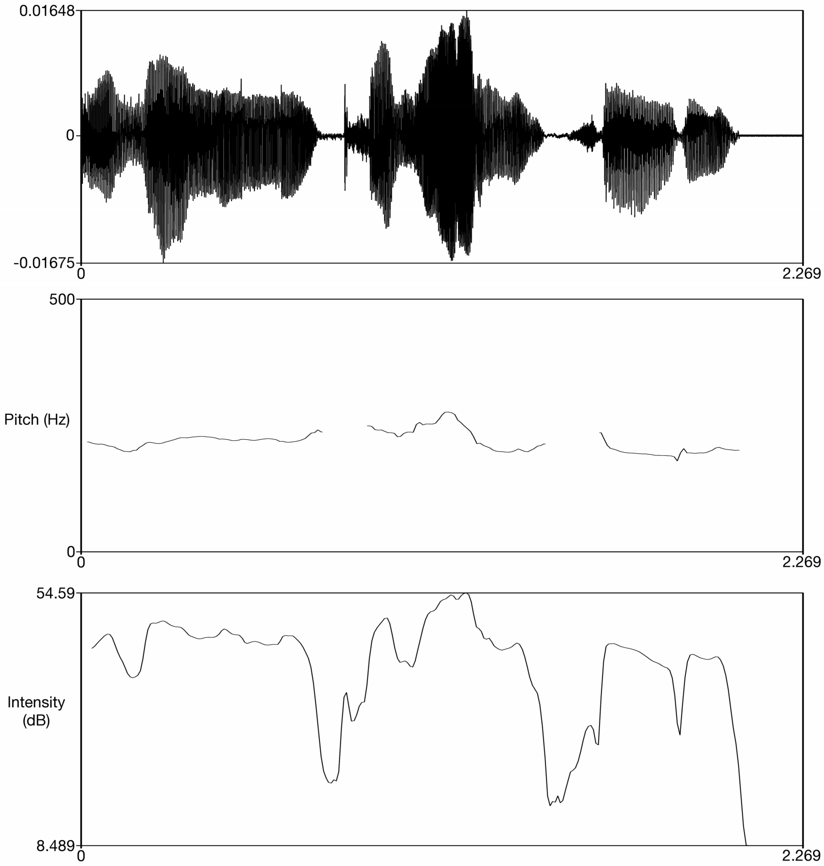

Figure 2a: *Oscillogram, pitch and intensity contours of a sentence with a critical item in focus position. (Er soll nun Kasino sagen.)*

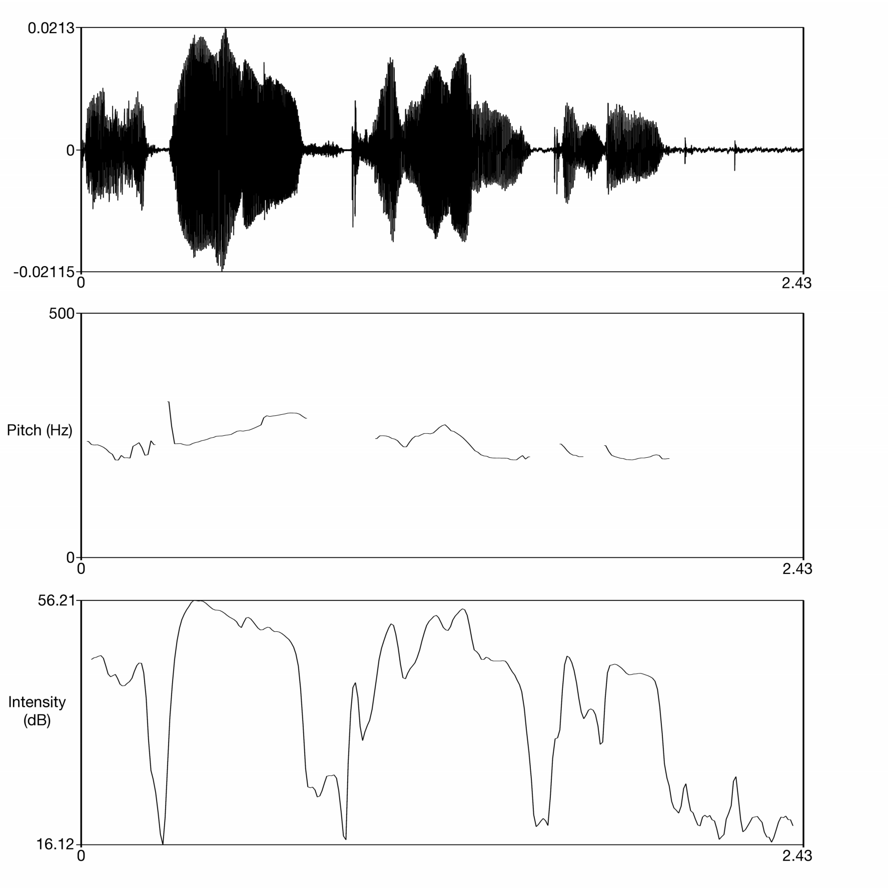

Figure 2b: *Oscillogram, pitch and intensity contours of a sentence with a critical item in non-focus position. (Er hat nur noch Kasino gesagt.)*

Sentences were recorded by a female, linguistically trained speaker of German. Stimuli were recorded digitally at 44 kHz in 16 bit (mono), using *Amadeus Pro* sound editor software (Hairersoft, version 1.5.2) and an electret microphone (Beyerdynamic MC 930). Each critical word was recorded embedded in both carrier sentences. After recording, each stimulus was spliced into the identical realisation of each of the two carrier sentences with a defined pause before (70 ms) and after (100 ms) the critical item. This was done in order to be able to determine the onsets of the critical items and to avoid different contextual inferences to the critical items. Additionally, it was ensured that the combinations of carrier sentence and critical item sounded naturally and did not violate the pitch contour of the carrier sentences. Figure 2a and 2b exemplify a spectrogram and phonetic parameters for both sentence types.

A post hoc analysis of the phonetic parameters realised in the two types of sentences revealed that the phonetic parameters of syllables varied with respect to stress position only, but not in correlation with the correctness of stress position (see statistics in Table 1). The analysis of the phonetic parameters fundamental frequency, duration, and intensity was performed by using *Praat* (version 5.1.45, Boersma & Weenink 2010).

As can be seen from the phonetic values presented in Table 1, incorrect stress patterns were not spoken with exaggerated or atypical phonetic values, but each ill-stressed word was produced with similar phonetic values comparable to the correct realisation of the same stress pattern (e.g. *ˈ*Bikini* comparable to ˈ*Alibi*).

Table 1 – Mean values of phonetic parameters for each stress pattern:
Overview over mean values (SD) of the parameters duration, fundamental frequency, and intensity for the stressed syllables of each word condition. The parameters of unstressed syllables are not listed due to place limitations but have been considered in the statistical analyses. (Correct conditions are shaded)

sentence 1: critical items in focus position

		phonetic parameter		target stress context: antepenult	penult	final	statistics	
realised stress pattern	antepenultimate	length	(ms)	201.5	227.6	213.2	F (2,58) = 8.487,	p = .001
		pitch	(Hz)	250.44	244.62	243.65	F (2,58) = 12.626,	p = .000
		intensity	(dB)	42.75	44.33	42.72	F (2,58) = 1.525,	p = .226
	penultimate	length	(ms)	235.5	242.6	236.6	F (2,58) = 35.188,	p = .000
		pitch	(Hz)	244.07	242.45	244.53	F (2,58) < 1	
		intensity	(dB)	43.56	42.94	43.30	F (2,58) = 1.196,	p = .310
	final	length	(ms)	337.0	289.1	390.3	F (2,58) = 8.044,	p = .001
		pitch	(Hz)	225.94	227.22	227.30	F (2,58) < 1	
		intensity	(dB)	40.84	42.91	39.52	F (2,58) = 3.259,	p = .051

sentence 2: critical items in non-focus position

		phonetic parameter		target stress context: antepenult	penult	final	statistics	
realised stress pattern	antepenultimate	length	(ms)	188.3	203.0	193.5	F (2,58) = 14.314,	p = .000
		pitch	(Hz)	274.05	261.39	259.42	F (2,58) = 5.245,	p = .009
		intensity	(dB)	43.21	45.12	44.07	F (2,58) = 1.503,	p = .231
	penultimate	length	(ms)	216.0	218.8	219.9	F (2,58) = 18.191,	p = .000
		pitch	(Hz)	252.29	249.96	247.69	F (2,58) < 1	
		intensity	(dB)	44.64	44.58	44.66	F (2,58) = 2.495,	p = .099
	final	length	(ms)	334.5	298.0	386.2	F (2,58) = 8.791,	p = .000
		pitch	(Hz)	244.72	240.54	239.79	F (2,58) = 3.696,	p = .031
		intensity	(dB)	42.94	44.97	41.72	F (2,58) = 2.722,	p = .077

2.1.2 Participants

Eighteen out of 24 right-handed native speakers of German (10 women) with normal or corrected-to-normal vision and without hearing deficits were included in the data analysis. Six participants had to be excluded due to high drop out rates caused by movement artefacts reducing the number of analysable events per condition to less than 20. The mean age of the analysable group was 25 years (ranging from 19 to 30 years). Each participant was paid for participation.

2.1.3 Procedure

Participants were comfortably seated in front of a computer screen in a dimly illuminated room. The experimental stimuli were presented auditorily via loudspeakers and the participants' task was to decide as accurately as possible whether the critical word within each sentence was stressed correctly or not. To exclude effects of lexical retrieval, the critical items were given visually on a computer screen prior to auditory presentation.

Each trial started with a fixation cross that appeared for 500 ms. Then, a critical item was presented visually for 500 ms followed by a blank screen of 250 ms before the auditory presentation of the stimulus embedded in one of the two carrier sentences started (see Figure 3). The mean duration was 2349 ms for sentence 1 and 2497 ms for sentence 2. After the offset of each sentence, a question mark appeared and remained on the screen for 2000 ms. Participants were instructed to press a yes- or no-button with their thumbs as soon as the question mark appeared. All responses were given with a delay after offset of the critical items to avoid movement artefacts. The assignment of thumbs to the yes- and no-buttons was counterbalanced across participants. The appearance of the question mark further indicated that participants were allowed to blink and rest their eyes. After an inter-trial-interval of 2000 ms the next trial started.

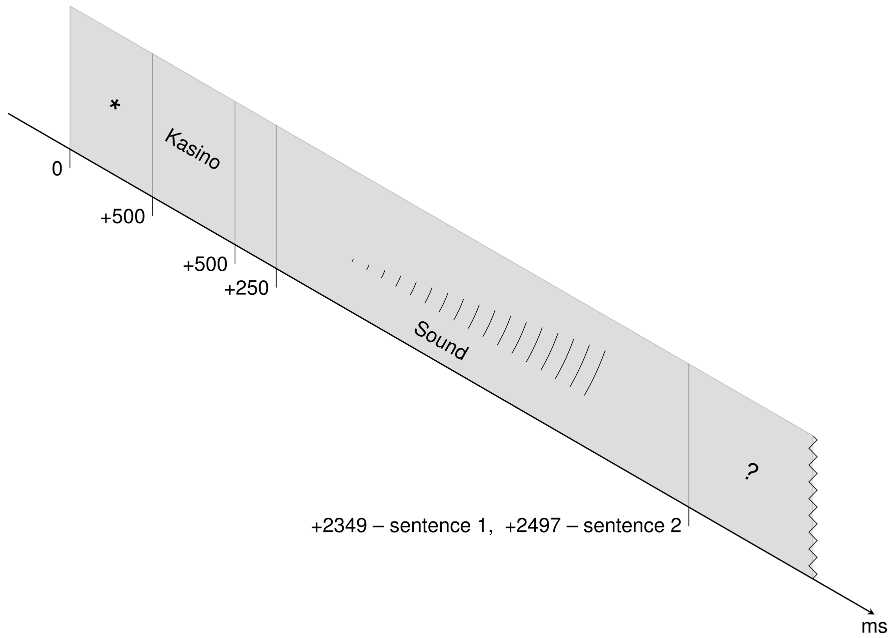

Figure 3: *Procedure*

The 720 stimuli were presented in 10 experimental blocks preceded by a short practice phase. Experimental and filler items were presented in a pseudo-randomised order, each word appearing only once within each block. In order to avoid sequence effects, the order of the blocks was varied for each participant. The entire duration of an experimental session was approximately 90 minutes.

2.1.4 ERP measurements

The EEG (electroencephalogram) was recorded by means of 22 Ag/AgCl electrodes via a Brainvision amplifier with the C2 electrode serving as ground electrode. The reference electrode during recording was placed at the left mastoid. EEGs were re-referenced off-line to both mastoids. To control for eye-movement artefacts, vertical eye movements were recorded by electrodes above and below the participant's left eye, and horizontal eye movements by two electrodes fixed to the outer canthus of both eyes (electrooculogram, EOG). Electrode impedances were kept below 5 kΩ. EEGs and EOGs were recorded continuously with a digitisation rate of 250 Hz, and filtered offline with a bandpass filter from 0.3 to 20 Hz.

ERPs were computed for each participant, condition and electrode. Trials with eye movement artefacts and incorrect responses were removed from the data (approximately 6.1 % of trials). Averages were calculated starting at the onset of the critical word up to 1500 ms thereafter. We compared each incorrect condition with the respective correct condition.

In a repeated measurements design, the factor StressPosition (antepenultimate, penultimate, ultimate) was considered for each SentenceType (focus, non-focus) and WordType (words with canonical antepenultimate, penultimate, final stress) separately. The time-windows were chosen on the basis of visual inspection. Since the latency of effects strongly depends on the word stress position (see Domahs et al. 2008), different time windows were identified for different stress violations (see Table 3 for an overview over time-windows and statistical results). The ANOVA was calculated for electrodes of particular regions (Region) defined as frontal (electrodes F3, FZ, F4), central (electrodes C3, CZ, C4), and parietal (electrodes P3, PZ, P4).

2.2 Results

2.2.1 Behavioural Data

Reaction times are not meaningful and are therefore not reported here, as they were measured from the offset of sentence presentation and not from the beginning of the critical words.

Error rates, however, were analysed in order to control for the accuracy of stress perception. An overview of the error rates is depicted in Tables 2a and 2b.

Table 2a: *Mean accuracy scores (in %) and standard deviations (in parentheses) for critical conditions – words in focus position*

		target stress context		
		antepenult	penult	final syllable
realised stress pattern	antepenultimate stress	93.5% sd 5.0	95.8% sd 8.4	87.3% sd 11.7
	penultimate stress	94.3% sd 4.8	98.3% sd 2.4	98.5% sd 2.6
	final stress	87.2% sd 12.1	99.6% sd 1.1	97.3% sd 2.5

Table 2b: *Mean accuracy scores (in %) and standard deviations (in parentheses) for critical conditions – words in non-focus position*

		target stress context		
		antepenult	penult	final syllable
realised stress pattern	antepenultimate stress	97.3% sd 2.6	92.6% sd 10.0	83.6% sd 16.0
	penultimate stress	91.2% sd 8.5	99.1% sd 1.6	90.9% sd 7.7
	final stress	84.7% sd 18.9	99.6% sd 1.1	98.5% sd 2.4

A generalised ANOVA over the factors SENTENCETYPE (stress manipulation in focus and non-focus context), WORDTYPE (words with canonical antepenultimate, penultimate, and final stress), as well as STRESSPOSITION (antepenult, penult, final) revealed a main effect for each factor and each possible interaction (see Table 2c).

Table 2c: *Generalised Anova on accuracy scores calculated on the factors SENTENCETYPE, WORDTYPE, and STRESSPOSITION.*

Factors	**Contrasts spanned by subjects**	**Contrasts spanned by items**
SENTENCETYPE	$F(1, 17) = 5.69$, $^{*}p = .029$	$F(1, 29) = 4.79$, $^{*}p = .037$
WORDTYPE	$F(2, 34) = 25.36$, $^{***}p = .000$	$F(2, 58) = 11.09$, $^{***}p = .000$
STRESSPOSITION	$F(2, 34) = 8.45$, $^{**}p = .002$	$F(2, 58) = 4.98$, $^{*}p = .010$
SENTENCETYPE vs. WORDTYPE	$F(2, 34) = 4.54$, $^{*}p = .023$	$F(2, 58) = 1.64$, $p = .206$
SENTENCETYPE vs. STRESSPOSITION	$F(2, 34) = 4.73$, $^{*}p = .019$	$F(2, 58) = 2.15$, $p = .125$
WORDTYPE vs. STRESSPOSITION	$F(4, 68) = 8.01$, $^{**}p = .004$	$F(4, 116) = 13.47$, $^{***}p = .000$
SENTENCETYPE vs. WORDTYPE vs. STRESSPOSITION	$F(4, 68) = 7.36$, $^{***}p = .000$	$F(4, 116) = 5.45$, $^{***}p = .001$

Table 2d: *Pairwise comparisons of error-rates (t-tests) for each condition within the two SENTENCE-TYPES. p-values are Bonferroni corrected (corrected p < .0056).*

Conditions	**Contrasts spanned by subjects**	**Contrasts spanned by items**
APU corr.	T (17) = -3.69; **p = .003**	T (29) = -2.22; p = .033
PU incorr. in APU	T (17) = 2.0; p = .061	T (29) = 1.55; p = .133
U incorr. in APU	T (17) = 1.05; p = .307	T (29) = 1.15; p = .260
APU incorr. in PU	T (17) = 2.96; **p = .008**	T (29) = 1.78; p = .084
PU corr.	T (17) = -1.72; p = .103	T (29) = -.89; p = .382
U incorr. in PU	T (17) = .00; p = 1.00	T (29) = .00, p = 1.00
APU incorr. in U	T (17) = 1.91; p = .072	T (29) = 1.63; p = .114
PU incorr. in U	T (17) = 4.15; **p = .002**	T (29) = 2.55; p = .015
U corr.	T (17) = .1.43; p = .171	T (29) = -1.20; p = .238

Table 2e: *Pairwise comparisons of error-rates (t-tests) between each correct and corresponding incorrect stress pattern (e.g. ˈLexikon vs. *LeˈxiKon). p-values are Bonferroni corrected (corrected p < .008)*

Factors	**Contrasts spanned by subjects**		**Contrasts spanned by items**	
	Words in focus position	**Words in non-focus position**	**Words in focus position**	**Words in non-focus position**
APU corr. vs. PU incorr.	$T(17) = -.43$; $p = .670$	$T(17) = 2.77$, $^{*}p = .014$	$T(29) = -.37$, $p = .714$	$T(29) = 3.2$, $^{**}\boldsymbol{p = .003}$
APU corr. vs. U incorr.	$T(17) = 1.79$, $p = .092$	$T(17) = 2.65$, $p = .017$	$T(29) = 1.8$, $p = .082$	$T(29) = 5.1$, $^{***}\boldsymbol{p = .001}$
PU corr. vs. APU incorr.	$T(17) = -1.17$, $p = .258$	$T(17) = -2.68$, $p = .016$	$T(29) = -2.26$, $p = .031$	$T(29) = -2.88$, $^{**}\boldsymbol{p = .007}$
PU corr. vs. U incorr.	$T(17) = -2.10$, $p = .051$	$T(17) = -1.12$, $p = .279$	$T(29) = -1.87$, $p = .072$	$T(29) = -1.03$, $p = .313$
U corr. vs. APU incorr.	$T(17) = -3.59$, $^{**}\boldsymbol{p = .002}$	$T(17) = -4.08$, $^{***}\boldsymbol{p = .001}$	$T(29) = -4.04$, $^{***}\boldsymbol{p = .001}$	$T(29) = -5.0$, $^{***}\boldsymbol{p = .001}$
U corr. vs. PU incorr.	$T(17) = 1.19$, $p = .251$	$T(17) = -3.97$, $^{***}\boldsymbol{p = .001}$	$T(29) = 1.18$, $p = .247$	$T(29) = -2.62$, $p = .014$

A post hoc analysis using pairwise comparisons of correct and incorrect conditions in both SENTENCETYPES (see Table 2d) showed in particular that the evaluation of correct antepenultimate stress, of stress violations with antepenultimate stress in words with canonical penultimate stress, and of stress violations with penultimate stress in words with canonical final stress are more error-prone when presented in non-focus than in focus position (in the subjects' analyses). In contrast, words with final stress (either correct or incorrect) yielded comparable correctness scores in both contexts. Furthermore, the pairwise comparisons of each correct and corresponding incorrect condition per SENTENCETYPE (see Table 2e) show that incorrect antepenultimate stress in words with final stress led in subjects' analyses to a meaningful increase in error rates in both sentence contexts, while in non-focus context this was only the case for incorrect penultimate stress in words with final stress. The items' analyses revealed an increase of error-rates for penultimate and final stress in antepenultimate words, and for antepenultimate stress in penultimate words, all in non-focus position. The behavioural data suggest that to some extent the evaluation of stress manipulations depends on the embedding of a word within the intonation contour. The asymmetrical results for violations with antepenultimate and penultimate stress in comparison to violations with final stress will be examined in more detail in the discussion section 3.1.

2.2.2 ERP Data

In Figure 4, ERP plots for midline electrodes of words in focus position are depicted. For the analysis of the mean voltage changes, comparisons between correctly and incorrectly stressed words were calculated for each word position and word type separately. Furthermore, for each word type two time-windows were chosen to identify violation effects.

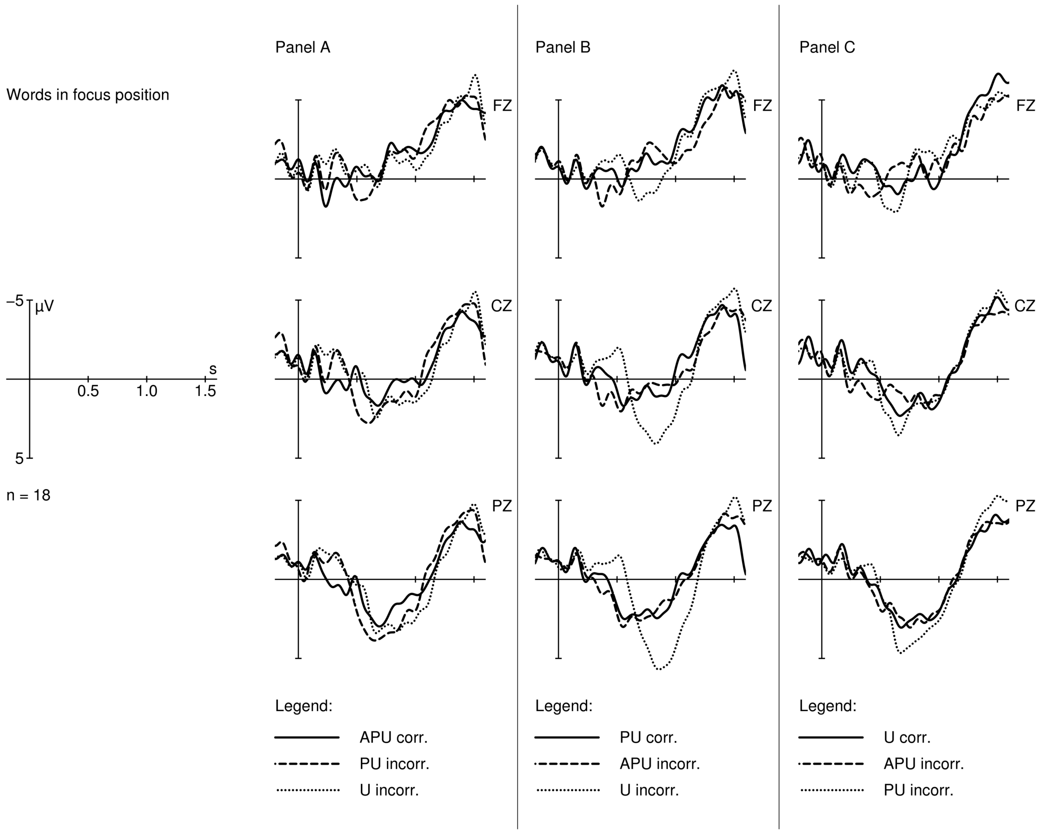

Figure 4: *Grand Averages of event-related potentials (ERPs) measured at the midline electrodes (Fz, Cz, Pz) obtained for words with antepenultimate stress (e.g. ˈLexikon, panel A), penultimate stress (e.g. Biˈkini, panel B), and final stress (e.g. Vitaˈmin, panel C). The correct conditions (solid lines) are plotted against the incorrect conditions (dashed and dotted lines). In panel A violations with penultimate stress yield a positivity effect between 450 to 1000 ms post word onset and violations with final stress between 630 to 1200 ms. In panel B violations with final stress produce a positivity between 640 to 1130 ms, and in panel C violations with penultimate stress between 470 to 710 ms.*

As shown by the grand average plots by the statistical analyses summarised in Table 3, incorrectly stressed words evoke late positive components as found in Knaus et al. (2007) and Domahs et al. (2008). For words with canonical antepenultimate stress (panel A), we observe that both violations with penultimate and final stress produce a positivity effect (for statistical analyses see Table 3). In words with canonical penultimate stress (panel B) only violations with final stress yield a positivity effect. Also in words with canonical final stress (panel C), asymmetrical results are obtained for the two violation conditions; only incorrect penultimate stress evoked a positivity.

Table 3: *Results of statistical analyses of mean voltage changes with the accounted factors StressPosition (antepenult, penult and final) and Region (frontal: F3, Fz, F4; central: C3, Cz, C4; parietal: P3, Pz, P4). P-values are Huynh-Feldt-corrected.*

Comparisons for words in focus position

Compared conditions	Time window	Factor	Statistics		
antepenult corr. vs. penult incorr.	450 – 1000 ms Positivity	StressPosition	$F(1, 17) =$	4.38,	$p = .052$
		Region	$F(2, 34) =$	134.08,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	7.48,	$^{**}p = .009$
		frontal	$F(1, 17) < 1$		
		central	$F(1, 17) =$	4.67,	$^{*}p = .045$
		parietal	$F(1, 17) =$	8.53,	$^{**}p = .010$
antepenult corr. vs. final syllable incorr.	630 – 1200 ms Positivity	StressPosition	$F(1, 17) =$	11.40,	$^{**}p = .004$
		Region	$F(2, 34) =$	45.96,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	4.97,	$^{*}p = .034$
		frontal	$F(1, 17) =$	4.30,	$p = .054$
		central	$F(1, 17) =$	9.99,	$^{**}p = .006$
		parietal	$F(1, 17) =$	14.31,	$^{**}p = .002$
penult corr. vs. antepenult incorr.	300 – 540 ms Positivity	StressPosition	$F(1, 17) < 1$		
		Region	$F(2, 34) =$	50.41,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	7.29,	$^{**}p = .009$
		frontal	$F(1, 17) < 1$		
		central	$F(1, 17) < 1$		
		parietal	$F(1, 17) =$	3.09,	$p = .097$
penult corr. vs. final syllable incorr.	640 – 1130 ms Positivity	StressPosition	$F(1, 17) =$	7.68,	$^{*}p = .013$
		Region	$F(2, 34) =$	105.71,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	30.10,	$^{***}p = .000$
		frontal	$F(1, 17) < 1$		
		central	$F(1, 17) =$	10.09,	$^{**}p = .006$
		parietal	$F(1, 17) =$	33.96,	$^{***}p = .000$
final syllable corr. vs. antepenult incorr.	160 – 520 ms Positivity	StressPosition	$F(1, 17) < 1$		
		Region	$F(2, 34) =$	27.01,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	2.93,	$p = .090$

final syllable corr. vs. penult incorr.	470 – 710 ms Positivity	StressPosition	$F(1, 17) =$	1.25,	$p = .279$
		Region	$F(2, 34) =$	89.43,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	17.66,	$^{***}p = .000$
		frontal	$F(1, 17) < 1$		
		central	$F(1, 17) =$	1.62,	$p = .220$
		parietal	$F(1, 17) =$	6.63,	$^{*}p = .020$

Comparisons for words in non-focus position

Compared conditions	Time window	Factor	Statistics		
antepenult corr. vs. penult incorr.	360 – 590 ms Positivity	StressPosition	$F(1, 17) < 1$		
		Region	$F(2, 34) =$	79.79,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	2.29,	$p = .137$
antepenult corr. vs. final syllable incorr.	870 – 1180 ms Positivity	StressPosition	$F(1, 17) =$	10.43,	$^{**}p = .005$
		Region	$F(2, 34) =$	18.11,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) < 1$		
penult corr. vs. antepenult incorr.	550 – 800 ms Positivity	StressPosition	$F(1, 17) < 1$		
		Region	$F(2, 34) =$	172.60,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	2.30,	$p = .142$
		frontal	$F(1, 17) =$	1.78,	$p = .200$
		central	$F(1, 17) < 1$		
		parietal	$F(1, 17) < 1$		
penult corr. vs. final syllable incorr.	590 – 1180 ms Positivity	StressPosition	$F(1, 17) =$	30.32,	$^{***}p = .000$
		Region	$F(2, 34) =$	112.23,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) =$	8.53,	$^{**}p = .008$
		frontal	$F(1, 17) =$	5.04,	$^{*}p = .038$
		central	$F(1, 17) =$	30.53,	$^{***}p = .000$
		parietal	$F(1, 17) =$	63.57,	$^{***}p = .000$
final syllable corr. vs. antepenult incorr.	740 – 1020 ms Positivity	StressPosition	$F(1, 17) < 1$		
		Region	$F(2, 34) =$	30.26,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) < 1$		
final syllable corr. vs. penult incorr.	500 – 750 ms Positivity	StressPosition	$F(1, 17) =$	2.53,	$p = .130$
		Region	$F(2, 34) =$	62.81,	$^{***}p = .000$
		StressPosition × Region	$F(2, 34) < 1$		
		frontal	$F(1, 17) =$	1.47,	$p = .242$
		central	$F(1, 17) =$	2.12,	$p = .164$
		parietal	$F(1, 17) =$	2.49,	$p = .133$

580 – 980 ms Positivity	StressPosition		$F(1, 17) < 1$		
	Region		$F(2, 34) =$	94.88,	$^{***}p = .000$
	StressPosition × Region		$F(2, 34) =$	11.93,	$^{**}p = .002$
		frontal	$F(1, 17) < 1$		
		central	$F(1, 17) < 1$		
		parietal	$F(1, 17) =$	4.88,	$^{*}p = .041$
700 – 1100 ms Positivity	StressPosition		$F(1, 17) < 1$		
	Region		$F(2, 34) =$	54.81,	$^{***}p = .000$
	StressPosition × Region		$F(2, 34) =$	11.84,	$^{**}p = .002$
		frontal	$F(1, 17) =$	1.74,	$p = .206$
		central	$F(1, 17) < 1$		
		parietal	$F(1, 17) =$	2.84,	$p = .110$

As for words in non-focus position, the midline electrodes presented in Figure 5 demonstrate that the effect size is generally smaller in comparison to effects evoked by violations of words in focus position. Besides the overall decrease of mean voltage changes, violation effects do not necessarily occur for all conditions that produced effects when presented in focus position. For words with canonical antepenultimate stress (panel A), again only incorrect final stress produced a positivity effect. The same is observed for words with canonical penultimate stress (panel B). In words with canonical final stress (panel C), a moderate parietal effect is found for penultimate stress between 580 to 980 ms.

Although the violation-to-expectation effects are less pronounced for words in non-focus position, the effect patterns observed in both sentence types are generally comparable. However, the fact that participants had to cope with two different intonation patterns seems to have distracted their attention from the actual task to judge word stress patterns. Given the error rates and the brain responses to different stress violations, the data indicate that some errors were more salient to the participants than others. Words incorrectly stressed on the antepenult or penult were more error-prone and produced fewer and only moderate effects in comparison to words with incorrect final stress. This holds in particular for violations involving antepenultimate and penultimate stress in non-focus position. An analysis of intonation contours and phonetic parameters suggest that tonal patterns and the different phonetic realisations of the three tested stress patterns might be responsible for the observed effects.

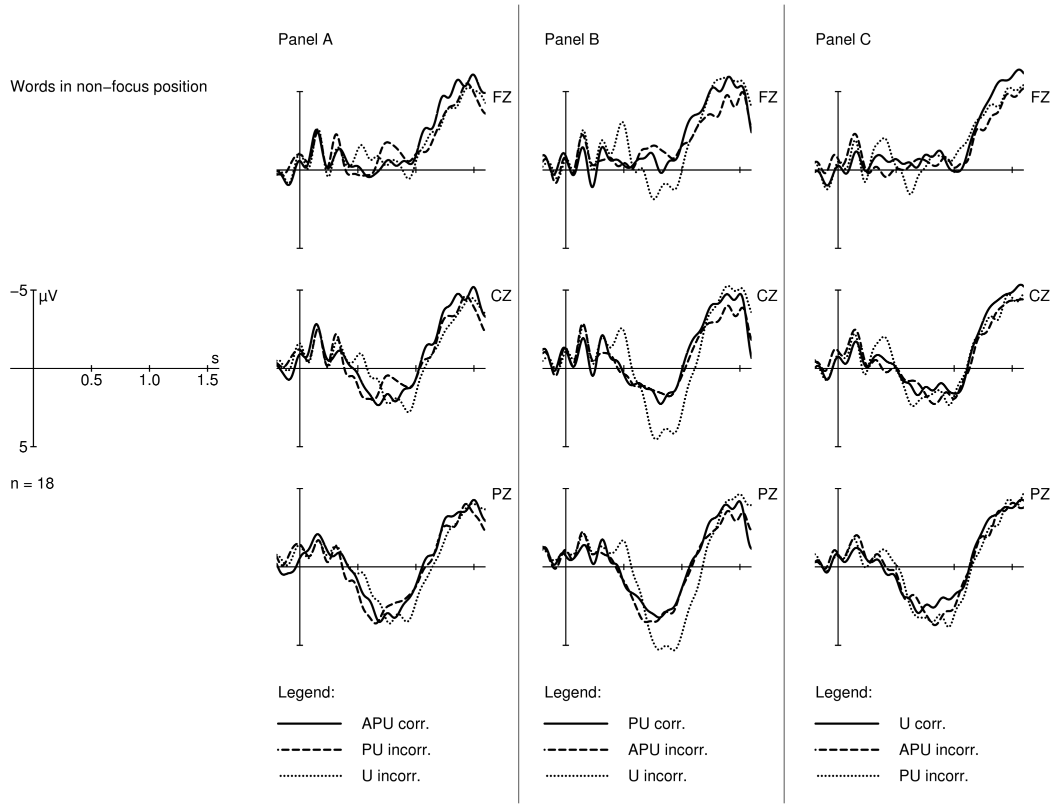

Figure 5: *Grand Averages of event-related potentials (ERPs) measured at the midline electrodes (Fz, Cz, Pz) obtained for words with antepenultimate stress (e.g. 'Lexikon, panel A), penultimate stress (e.g. Bi'kini, panel B), and final stress (e.g. Vita'min, panel C). The correct conditions (solid lines) are plotted against the incorrect conditions (dashed and dotted lines). In panel A, violations with final stress yield a positivity effect between 870 to 1180 ms post word onset, in panel B, violations with final stress between 590 to 1180 ms, and in panel C violations with penultimate stress between 580 to 980 ms.*

3. Discussion

The experiment reported in this article addressed the question whether and to what extent stress positions within words depend on the overall rhythmical distribution of stresses in sentences. To test this, stress manipulations of words were contrasted in two different positions within sentences: i) in focus position and ii) in non-focus position. A comparison of ERPs revealed that, irrespective of the position of the manipulated words, similar patterns of positivity effects occur. As in similar earlier experiments (Magne et al., 2007; Domahs et al., 2008;

Marie et al., 2010), we found positivity effects for stress violations that were related to the evaluation of stress patterns. In Domahs et al. (2008), such a positive component was interpreted to reflect an evaluation process, indicating to what extent a specific expectation was violated, and how easily participants could reject an incorrect stress pattern. The evaluation process produces enhanced positivity effects in conditions with a clear stress violation. This is the case in violations involving the reorganisation of syllables into feet (e.g. bi(ki.ni)$_F$ changed to *(bi.ki)$_{Fw}$(ni)$_{Fs}$) However, in the present study some of the effects patterned differently. In the following two sections the role of the intonation contours in the evaluation of word stress manipulations will be examined in detail. This will provide answers to the question why some of the results found are different from the ones reported in Domahs et al. (2008).

3.1. Comparison of stress shifts in focus and non-focus positions

Word stress manipulations yield violation effects in focus and non-focus position: for final stress in words with antepenultimate stress (e.g. **Lexiˈkon*), for final stress in words with penultimate stress (e.g. **Bikiˈni*), and for penultimate stress in words with final stress (e.g. **Viˈtamin*). Furthermore, violations presented in focus position yield an additional P300 effect in the condition in which stress was shifted from antepenultimate position to penultimate position (e.g. *ˈLexikon* changed to **Leˈxikon*). The strong overlap of effect patterns and the similar effect sizes and effect distributions between both sentence types suggest that the identification of stress violations is mostly independent from the intonational patterns the critical words are embedded in. In this respect word prosodic aspects of speech processing are largely autonomous from higher prosodic properties. However, the stress shift from antepenult to penult evoked a positivity in focus position only. Thus, in this case intonational properties influence the word processing. Why does this happen in this specific context?

A comparison of the mean phonetic values for duration, F0, and intensity for the antepenultimate and penultimate syllables in both intonational contexts reveals that the differences (Δ) in duration are less pronounced in the second sentence compared to the first one. Figure 6 shows these differences grouped according to the relevant stress conditions. A paired t-test on the durational difference of antepenultimate and penultimate syllable in focus and non-focus context confirms the visual impression. In most conditions with antepenultimate and penultimate stress, the length differences between first and second syllable are significantly larger when presented in focus position in comparison to non-focus position (apu corr.: $t(29) = 3.11$, $p < .004$; pu corr.: $t(29) = 2.67$, $p < .012$; pu incorr.: $t(29) = 1.93$, $p = .064$).

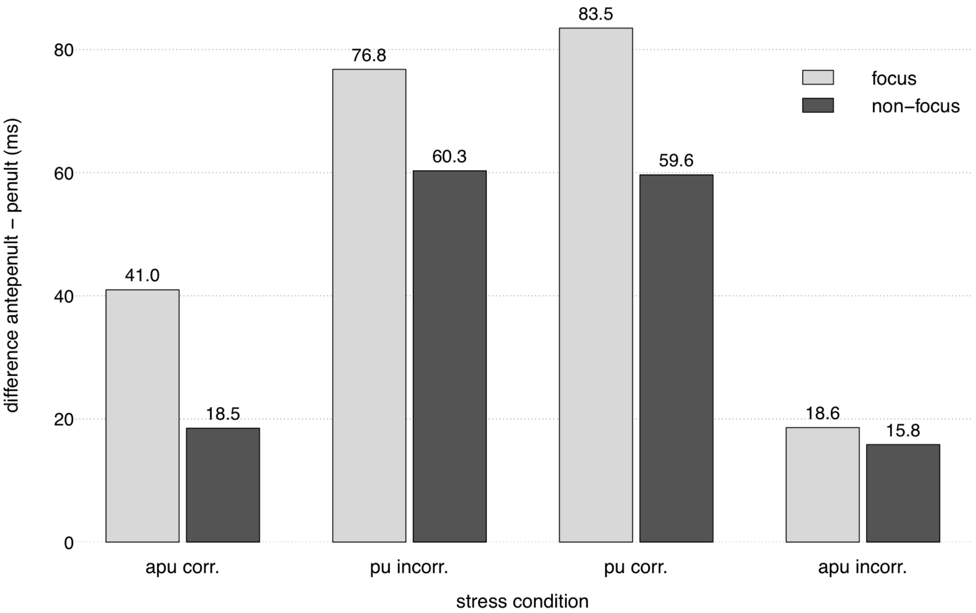

Figure 6: *Differences of antepenultimate and penultimate syllables for experimental conditions with correct antepenultimate stress (apu corr.), incorrect penultimate stress shifted from the antepenult (apu incorr.), correct penultimate stress (pu corr.), and incorrect antepenultimate stress shifted from the penult (pu incorr.). Light bars indicate sentence 1 (focus), dark bars sentence 2 (non-focus).*

Since such differences in the phonetic parameter duration are smaller in the second intonational context compared to the first, participants may have difficulties to reject the incorrect pattern. This is confirmed by the error rates for incorrectly stressed words on the antepenult in words with canonical penultimate stress: such words led to increased error-rates in the second sentence type compared with the first one (see Table 2a and b).

Note further that in non-focus context (see Figure 2b), the critical word is preceded by an L*H accent (realised over "*nur noch*") whereby the high pitch level might be perceptually aligned with the onset of the critical word. In conditions with a stress shift from the antepenultimate syllable to the penultimate syllable, the destressing of the first syllable may therefore be less perceivable due to the fact that a high tone precedes. The analysis of the phonetic parameters summarised in Table 1 shows that the three different stress patterns in the critical words are realised by different phonetic parameters. For instance, antepenultimate stress is mainly expressed by a relatively high pitch value in comparison to the two other syllables, penultimate stress by pitch rise and increased duration, and final stress mainly by an increase of duration. Taken these phonetic properties of stress in certain positions, words with an ill-formed destressed antepenultimate in non-focus position, which are preceded by the pitch rise of the L*H nuclear stress (see intonation contour of the second sentence in Figure 2b), could be perceived as stressed initially, i.e., correctly.

The present example shows that the serialisation of pitch accent and word stress can lead to interferences of phonetic properties within different prosodic domains. In particular, the pitch rise of an L*H accent appears to extend its pitch value to the following element and makes the destressing of the initial syllable of the following word less perceivable than in other pitch contexts. Thus, rhythm beyond the word level has the capacity to override actual prominence relations measured at the word level.

3.2 How do the present results relate to previous findings?

The stress manipulations presented in focus position are analogous to manipulations studied in previous experiments (Domahs et al. 2008) and yield similar components. However, comparing the effect patterns for words in focus position, the question arises why some violation effects for manipulations that produced enhanced positivity effects in the previous study (Domahs et al., 2008) were not found in the present study. In particular, this is the case for incorrect antepenultimate stress in words with canonical penultimate stress (e.g. *ˈBikini). The previous experiment suggested that the enhanced P300 reflects a severe structural violation because both stress patterns call for different internal foot parsing (e.g. bi(ˈki.ni) vs. *(ˈbi.ki)(ni:) and *(bi.ki)(ˈni:)). However, in the present experiment we find only a marginal parietal positivity effect for violations with antepenultimate stress ($F(1, 17)$, $p = .097$). In addition, for a manipulation that did not evoke a positivity in the previous experiment, an effect occurs presently. This is the case for violations with final stress in words with canonical antepenultimate stress. The absence of this effect in the previous experiment was interpreted as a consequence of an identical foot parsing underlying both stress patterns (e.g. (ˈle.xi)(kon) vs. *(le.xi)(ˈkon)). Does the failure to replicate the previous result mean that the previous interpretation was premature and not appropriate?

In the present study a very general effect pattern occurs: violations with antepenultimate stress produce less pronounced effects and violations with final stress produce stronger effects than in the experiment reported by Domahs et al (2008). A comparison of phonetic stress realisations (see Table 1) with those in Domahs et al. (2008) reveals that the speaker of the present experimental stimuli produced generally shorter syllables than the speaker of the previous experiment. Especially the length contrast between first and second syllables in words with incorrect antepenultimate stress is less pronounced in the present experiment compared to the previous one (APU in mean 7 ms shorter than PU (236 ms vs. 243 ms) in the present experiment and APU in mean 35 ms longer than PU (289 ms vs. 254 ms) in the previous experiment; see also the reduced length contrast for incorrect APU in words with target penultimate stress in Figure 6), whereas final syllables are longer. Previous phonetic analyses of German word stress showed duration to be the crucial phonetic parameter of word stress (Dogil & Williams 1999). It is likely that the positivity effect for incorrect antepenultimate stress failed to occur in the present experiment due to the lack of the duration cue.

The pronounced P300 effect for final stress, in contrast, indicates that this pattern can be identified as incorrect more easily than the other patterns. Note that the P300 component does not directly reflect the acceptability of a certain stress pattern but rather how easy it is to judge a perceived pattern as correct or incorrect. In the present experiment, the P300 effect seems to be most pronounced for words with clear stress patterns, i.e., with final stress.

3.3 Interplay between word and sentence prosody

Domahs et al. (2008) report separate ERP effects for distinct stress violations, namely pronounced P300 effects for violations involving restructuring of feet and no or reduced P300 effects for violations maintaining the foot structure. In this respect, the parsing of syllables into feet determines which syllables of a word are stressable and which are not. The current findings support this interpretation and add that the perceptual saliency of violations is furthermore modulated by the position of words within higher prosodic structure. Following the present findings, the placement of manipulated words into focus position seems to be the most promising prerequisite for the investigation of word prosodic structures. A further important observation is that individual phonetic realisations of prominence relations may lead to different results in stress perception.

Coming back to the question raised in the introduction whether words are simply part of the overall rhythmical pattern of sentences (e.g. van der Hulst 1996, 1997, 2009; Noel Aziz Hanna 2003) or have their own prosodic structure determining primary and secondary stress positions (Liberman & Prince 1977; Nespor & Vogel 1986; Hayes 1995; Alber 2005; Knaus & Domahs 2009), we come to the following conclusion.

The overlap of effect patterns in focus and non-focus position supports the assumption that words have their own structure irrespective of their contextual embedding. However, as the asymmetrical effects between focus and non-focus position show, pitch accents of higher prosodic units can interfere with the prominence relations within prosodic words. In particular, word onsets are prone to be misinterpreted both as unstressed (in the stress shift from penultimate to antepenultimate syllable: *Biˈkini* to **ˈBikini*) or stressed (in the stress shift from antepenultimate to penultimate syllable: *ˈLexikon* to **Leˈxikon*). In such cases the local prominence relations – which have been shown to produce enhanced P300 effects if violated in previous experiments – are levelled in perception. Hence, the basic process of stress assignment proceeds bottom-up starting with foot construction, but can be influenced by higher-level prosodic cues.

4. Conclusion

Taken together, our findings suggest that rhythm above the word level can have an impact on the perception of prominence relations between elements at word level. This is especially the case when the word-internal prosodic structure on the one hand and higher prosodic structure on the other hand are not congruent or even conflicting, as for example in weak syllables of words immediately following high tone elements at the intonational level. Since phonetic parameters as cues for word stress vary across the word (initial stress by pitch, medial stress by pitch and length, and final stress by length mainly), initial syllables are prone for being misinterpreted as stressed in cases where they follow a pitch rise in intonation.

The present findings are important for psycho- and neurolinguistic research on word prosody in showing that word-prosodic aspects have to be carefully controlled for their intonational embedding.

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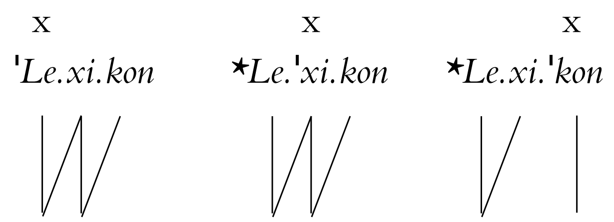
5 Outlook – implications for models of metrical stress and remarks on the role of the foot in other languages

The neurolinguistic studies presented in this dissertation have shown that the proposed experimental approach is a fruitful way to investigate prosodic structures and parameters involved in word stress processing that are otherwise empirically hard to determine. In particular, the data show that the foot is a real prosodic category and plays an important role in German word stress assignment. The foot is therefore not just an epiphenomenon. As the foot takes an intermediate position in the prosodic hierarchy and thus somewhat hidden from direct observation, the use of very sensitive methods such as EEG with its high temporal precision is necessary for examining the processing of prosodic information.

The empirical foundation of the foot is an important finding for phonological theory and, more specifically, optimality theoretic modeling. It complements findings from earlier approaches that use large typological data sets or corpora on single languages.

In addition to providing evidence for existing assumptions, the experimental findings also provide a test case for existing theoretical proposals. As an example, I briefly discuss some aspects of optimality theoretic proposals that

Figure 5.1: Foot structures for a critical stimulus from the study of trisyllabic words according to Hyde's (2002) proposal



assume slightly different foot shapes (Hyde, 2002) or stress the role of general rhythmical patterns (Kager, 2001, 2005).

Hyde (2002) proposes a concept of the metrical foot that allows for ambipodality, i.e., a syllable can belong to two feet. Similar to the proposal discussed previously, Hyde's parsing algorithm requires an exhaustive parsing of syllables. However, in contrast to the standard accounts and the OT approach suggested in this dissertation, this requirement is not achieved by a constraint ranking but is part of the non-violable Gen component of the OT grammar.

In the light of the findings from the experimental study on trisyllabic words (see chapter 2; Knaus and Domahs, 2009; Domahs et al., 2008) it becomes obvious that the suggested "intersecting" trochaic foot shapes (Hyde, 2002: 315-317) cannot explain the distribution of the positivity effects found. As can be seen in the foot structures for a stimulus from the study of trisyllabic German words presented in figure 5.1, Hyde's proposal predicts easier shifts, i.e., fewer processing difficulties, from antepenultimate to penultimate stress. This would predict exactly the opposite of the ERP effects found here.

As explicated in chapter 1, Kager's (2001; 2005) Rhythmic Licensing Theory emphasizes general rhythmic patterns by assuming markedness constraints that ban deviations from the Principle of Rhythmic Alternation (see definition on page 30) and constraints that license these deviations in specific contexts. Figure 5.2 shows experimental conditions with correct stress on the antepenult violate *LAPSE. The shifts to the final syllable that did not evoke positivity effects (or just reduced ones) violate not only *LAPSE but also the rhythmic licensing constraint Lapse-At-End. The shifts to the penult that evoked a pronounced P3 are rhythmically wellformed. Again, this would predict the opposite of the ERP effects found. Rhythmic alternation alone thus cannot explain the experimental findings from the studies presented in the previous chapters.

Figure 5.2: Evaluations of rhythmic markedness and licensing constraints on correct stress on the antepenult and stress shifts to the final and penultimate syllable

pronounced P3

no/reduced P3

ˈσσσ	*σσˈσ	*σˈσσ
*Lapse violation	*Lapse violation	perfect rhythm
	Lapse-At-End violation	

Recent studies investigated the word stress systems of Turkish (Domahs et al., 2012a) and Polish (Domahs et al., 2012b) using the same experimental paradigm as the studies on German word stress. However, the observed ERP effects for stress violations are different from those revealed for German. The distribution of effects is explained best if we assume a default stress pattern (final stress for Turkish and penultimate stress for Polish) and a number of lexicalized exceptional stress patterns. The default stresses are not processed explicitly or less consciously and the evaluation of shifts to positions of default stress is much harder for participants than shifts to positions of lexicalized stress.

Clearly, there are languages in which word internal prosodic structures play a lesser role. On the other hand there are languages like German, which utilize feet extensively for the assignment of word stress and in which the distribution of word stress is explainable only when we are looking at feet.

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Appendix

1 List of stimuli used in study on pentasyllabic words

Stimulus (stimulus type, correct stress pattern)

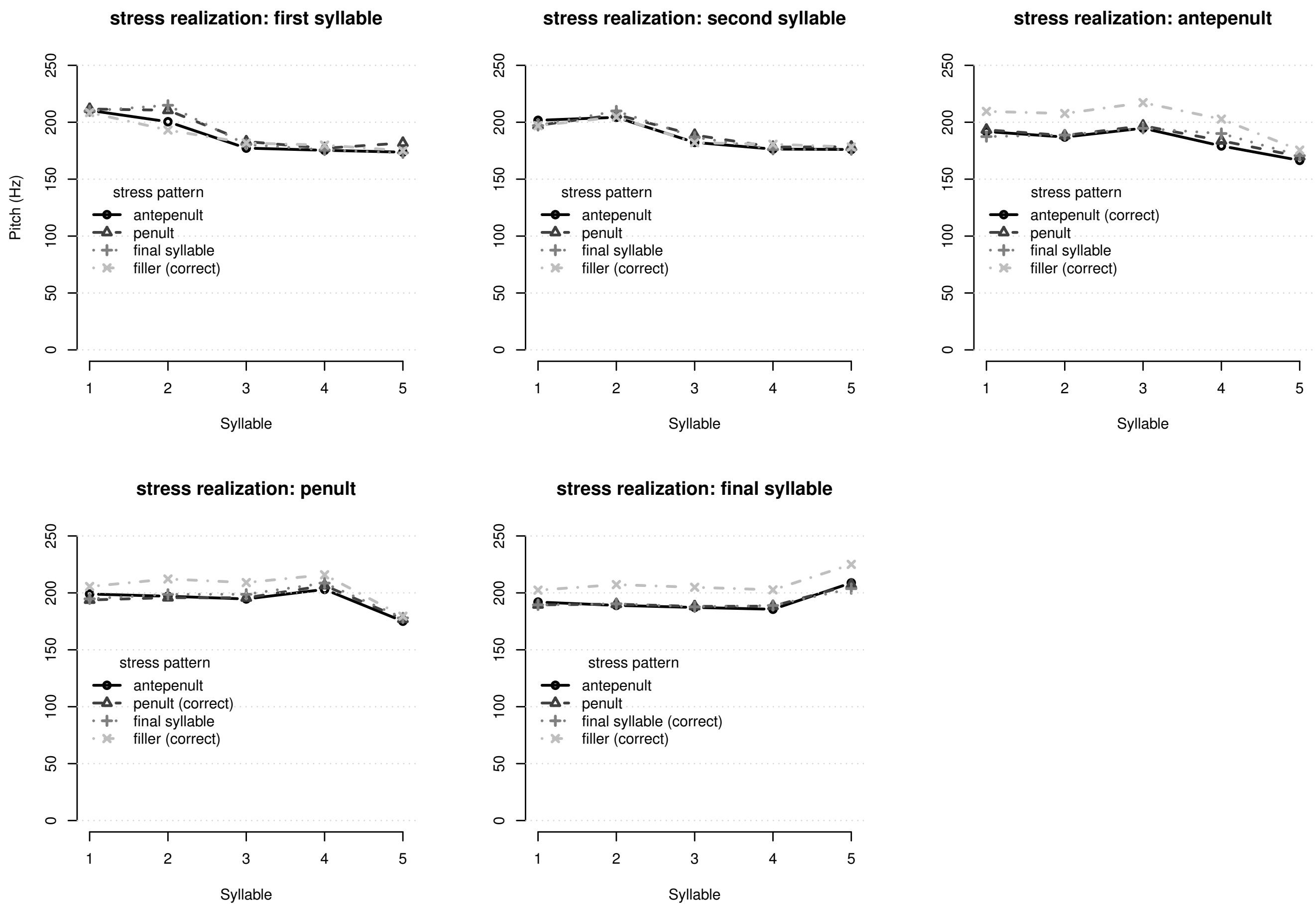
1. Annullierbarkeit (item, antepenult)
2. Finanzierbarkeit (item, antepenult)
3. Hinterlassenschaft (item, antepenult)
4. Ignorantentum (item, antepenult)
5. Kandidatenschaft (item, antepenult)
6. Kompostierbarkeit (item, antepenult)
7. Kontrollierbarkeit (item, antepenult)
8. Konvertierbarkeit (item, antepenult)
9. Parasitentum (item, antepenult)
10. Produzierbarkeit (item, antepenult)
11. Professorenschaft (item, antepenult)
12. Reformierbarkeit (item, antepenult)
13. Respektierbarkeit (item, antepenult)
14. Überlegenheit (item, antepenult)
15. Übertragbarkeit (item, antepenult)
16. Absolutismus (item, penult)
17. Afrikanistik (item, penult)
18. Artikulator (item, penult)
19. Charakteristik (item, penult)
20. Dilettantismus (item, penult)
21. Enthusiasmus (item, penult)
22. Immunisierung (item, penult)
23. Implementierung (item, penult)
24. Kodifizierung (item, penult)
25. Legitimierung (item, penult)
26. Lokalisierung (item, penult)
27. Modifizierung (item, penult)
28. Parallelismus (item, penult)
29. Synchronisierung (item, penult)
30. Zivilisiertheit (item, penult)
31. Anonymität (item, final syll.)
32. Anthropologie (item, final syll.)
33. Antiquariat (item, final syll.)
34. Archäologie (item, final syll.)
35. Enzyklopädie (item, final syll.)
36. Flexibilität (item, final syll.)
37. Karikaturist (item, final syll.)
38. Kreativität (item, final syll.)

39. Parallelogramm (item, final syll.)
40. Popularität (item, final syll.)
41. Scharlatanerie (item, final syll.)
42. Sensibilität (item, final syll.)
43. Spiritualist (item, final syll.)
44. Stereotypie (item, final syll.)
45. Terminologie (item, final syll.)
46. Ausgelassenheit (filler, first syll.)
47. Aussichtslosigkeit (filler, first syll.)
48. Einzigartigkeit (filler, first syll.)
49. Heimatlosigkeit (filler, first syll.)
50. Rückversicherung (filler, first syll.)
51. Unabhängigkeit (filler, first syll.)
52. Unaufrichtigkeit (filler, first syll.)
53. Unempfindlichkeit (filler, first syll.)
54. Unentschiedenheit (filler, first syll.)
55. Unentschlossenheit (filler, first syll.)
56. Unterverzeichnis (filler, first syll.)
57. Urbevölkerung (filler, first syll.)
58. Widerspiegelung (filler, first syll.)
59. Widersprüchlichkeit (filler, first syll.)
60. Zuversichtlichkeit (filler, first syll.)
61. Amoralismus (filler, first syll.)
62. Grenzenlosigkeit (filler, first syll.)
63. Überdosierung (filler, first syll.)
64. Urproduktion (filler, first syll.)
65. Aufgeblasenheit (filler, first syll.)
66. Obdachlosigkeit (filler, first syll.)
67. Unerfahrenheit (filler, first syll.)
68. Angelegenheit (filler, first syll.)
69. Teilnahmslosigkeit (filler, first syll.)
70. Unbequemlichkeit (filler, first syll.)
71. Ruhelosigkeit (filler, first syll.)
72. Teleobjektiv (filler, first syll.)
73. Hoffnungslosigkeit (filler, first syll.)
74. Zuverlässigkeit (filler, first syll.)
75. Unwahrscheinlichkeit (filler, first syll.)
76. Beaufsichtigung (filler, second syll.)
77. Beeinträchtigung (filler, second syll.)
78. Belanglosigkeit (filler, second syll.)
79. Benachrichtigung (filler, second syll.)
80. Entschlusslosigkeit (filler, second syll.)
81. Erweiterbarkeit (filler, second syll.)
82. Geruchlosigkeit (filler, second syll.)
83. Gesetzlosigkeit (filler, second syll.)
84. Gesichtslosigkeit (filler, second syll.)
85. Veranschaulichung (filler, second syll.)
86. Vervielfältigung (filler, second syll.)
87. Vernachlässigung (filler, second syll.)
88. Vervollständigung (filler, second syll.)
89. Zuvorkommenheit (filler, second syll.)
90. Zuwiderhandlung (filler, second syll.)
91. Beeinflussbarkeit (filler, second syll.)
92. Gehörlosigkeit (filler, second syll.)
93. Geringfügigkeit (filler, second syll.)
94. Zufriedenstellung (filler, second syll.)
95. Absonderlichkeit (filler, second syll.)

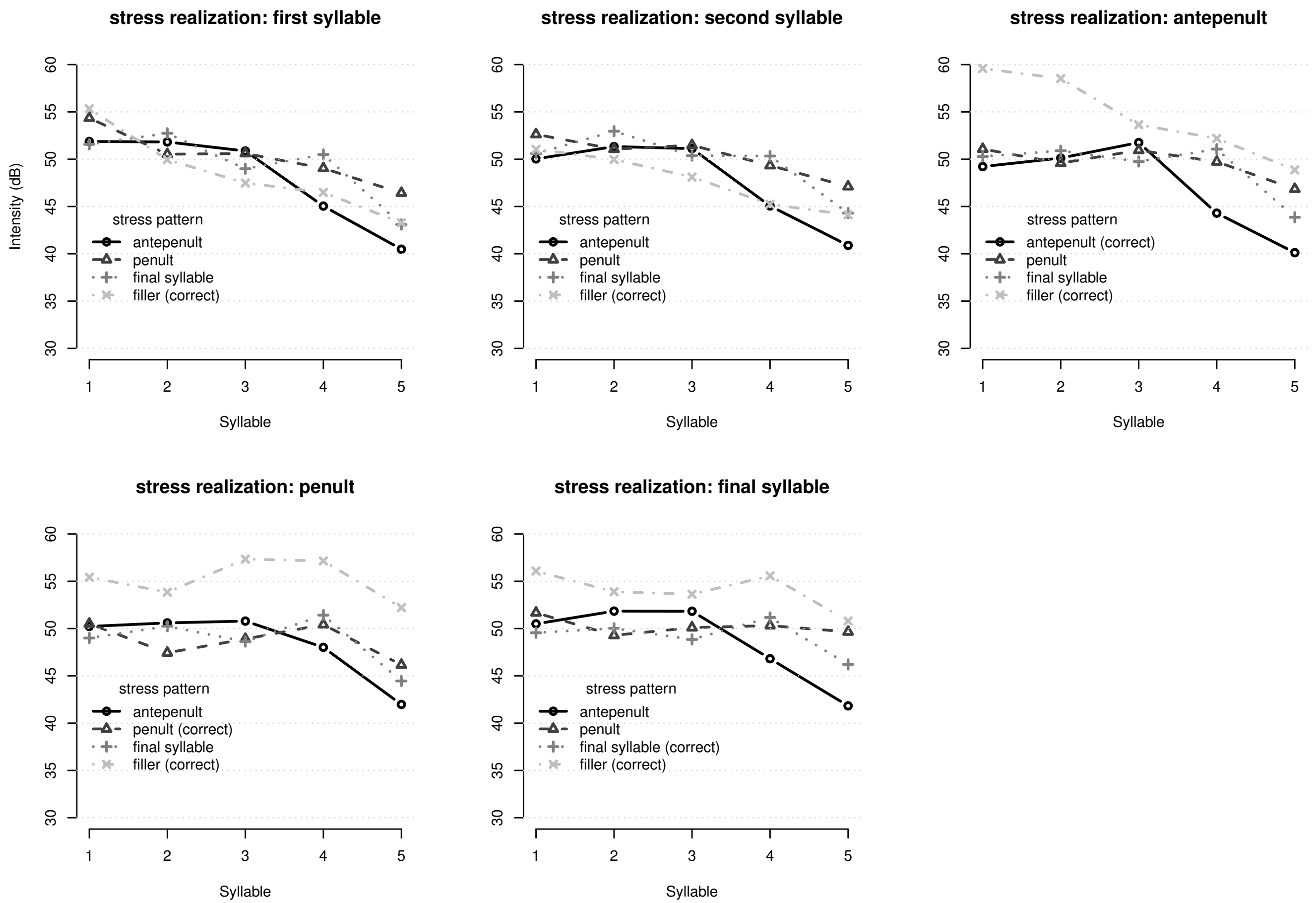
96. Veränderlichkeit (filler, second syll.)
97. Verinnerlichung (filler, second syll.)
98. Erfolglosigkeit (filler, second syll.)
99. Bewusstlosigkeit (filler, second syll.)
100. Benachteiligung (filler, second syll.)
101. Beeinflussbarkeit (filler, second syll.)
102. Verunreinigung (filler, second syll.)
103. Gesetzmäßigkeit (filler, second syll.)
104. Berücksichtigung (filler, second syll.)
105. Veröffentlichung (filler, second syll.)
106. Antiseptikum (filler, antepenult)
107. Übersteuerung (filler, antepenult)
108. Unabwendbarkeit (filler, antepenult)
109. Unausstehlichkeit (filler, antepenult)
110. Unerklärbarkeit (filler, antepenult)
111. Ungenießbarkeit (filler, antepenult)
112. Übertriebenheit (filler, antepenult)
113. Unentbehrlichkeit (filler, antepenult)
114. Überrumpelung (filler, antepenult)
115. Übersetzerin (filler, antepenult)
116. Unerbittlichkeit (filler, antepenult)
117. Überlagerung (filler, antepenult)
118. Überforderung (filler, antepenult)
119. Aristoteles (filler, antepenult)
120. Überlieferung (filler, antepenult)
121. Abrakadabra (filler, penult)
122. Alkoholismus (filler, penult)
123. Substantivierung (filler, penult)
124. Kristallisierung (filler, penult)
125. Neologismus (filler, penult)
126. Verifizierung (filler, penult)
127. Vulkanisierung (filler, penult)
128. Akkumulator (filler, penult)
129. Klassifizierung (filler, penult)
130. Föderalismus (filler, penult)
131. Katalysator (filler, penult)
132. Modernisierung (filler, penult)
133. Organisator (filler, penult)
134. Normalisierung (filler, penult)
135. Kapitalismus (filler, penult)
136. Ägyptologie (filler, final syll.)
137. Lexikologie (filler, final syll.)
138. Ambiguität (filler, final syll.)
139. Attraktivität (filler, final syll.)
140. Nitroglyzerin (filler, final syll.)
141. Eigenbrötelei (filler, final syll.)
142. Relativität (filler, final syll.)
143. Choreographie (filler, final syll.)
144. Bibliographie (filler, final syll.)
145. Aktualität (filler, final syll.)
146. Subjektivität (filler, final syll.)
147. Effektivität (filler, final syll.)
148. Solidarität (filler, final syll.)
149. Universität (filler, final syll.)
150. Arachnophobie (filler, final syll.)

2 Stress realizations in pentasyllabic words – plots of phonetic parameters

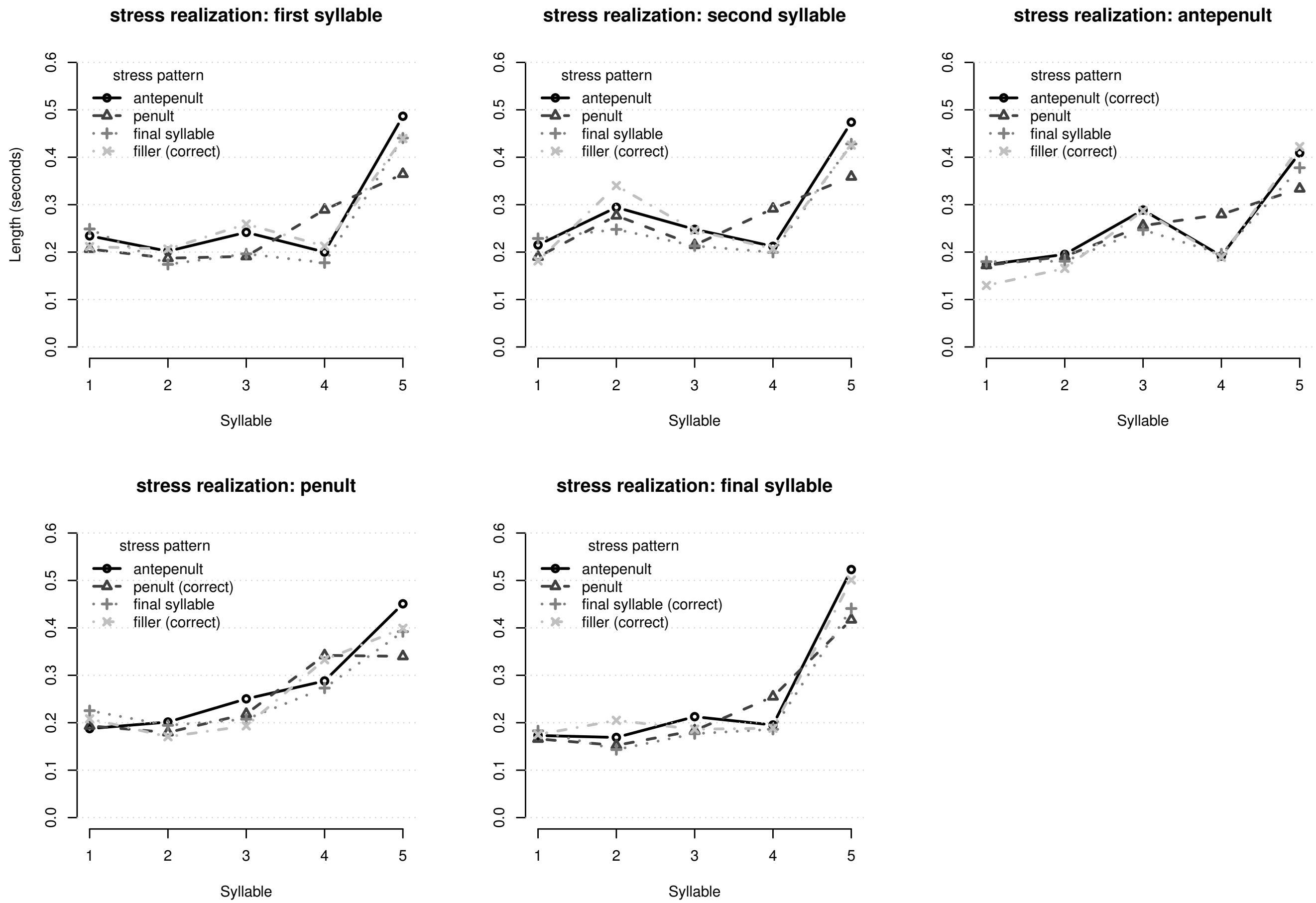
2.1 Mean pitch per syllable



2.2 Mean intensity per syllable

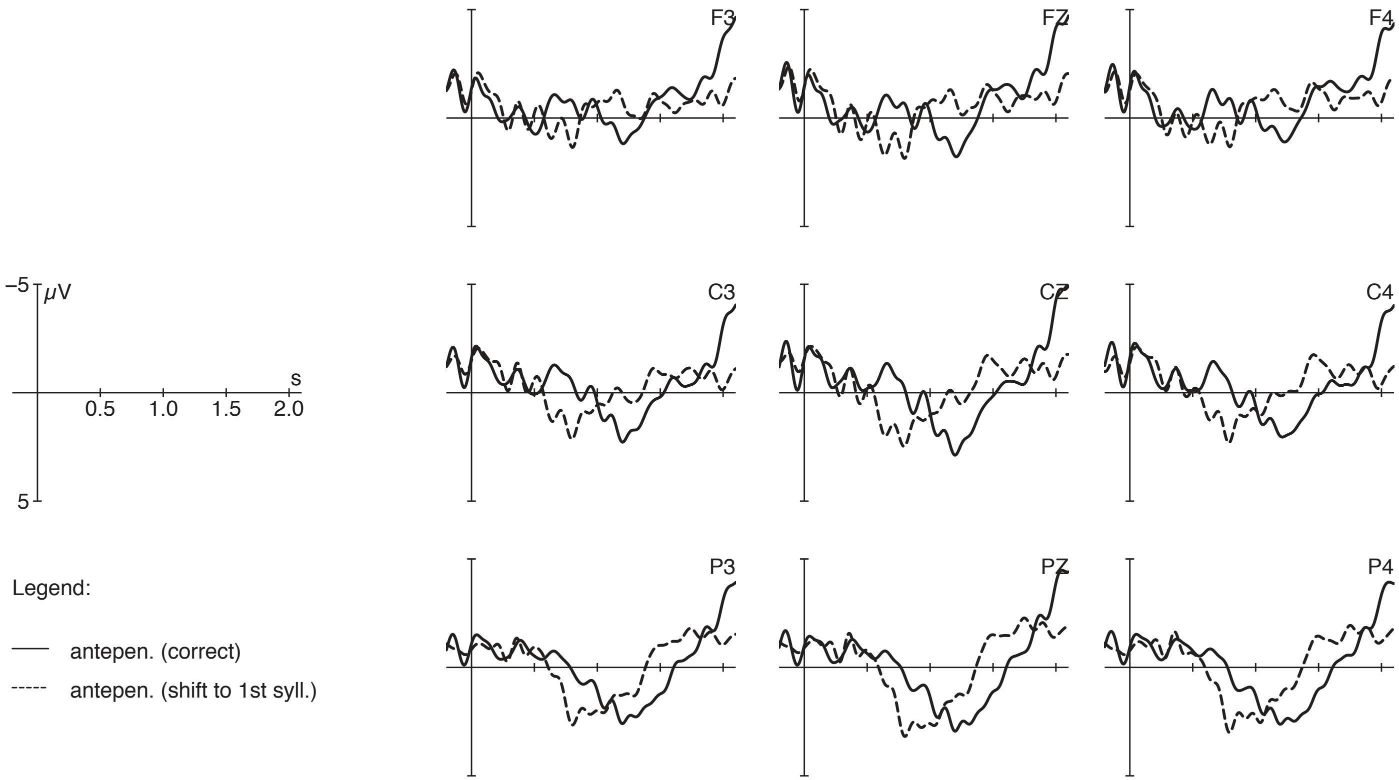


2.3 Mean length per syllable

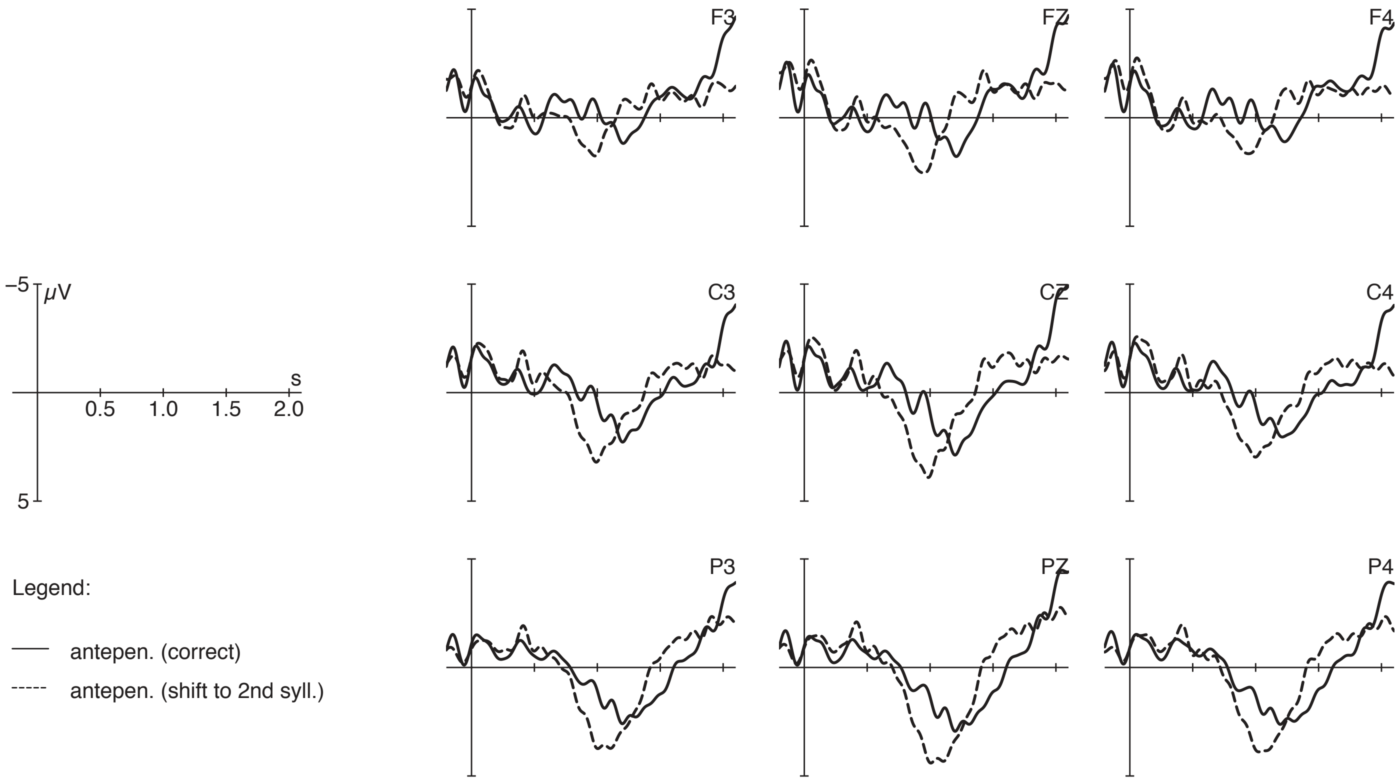


3 Grand average ERP Plots of pentasyllabic words

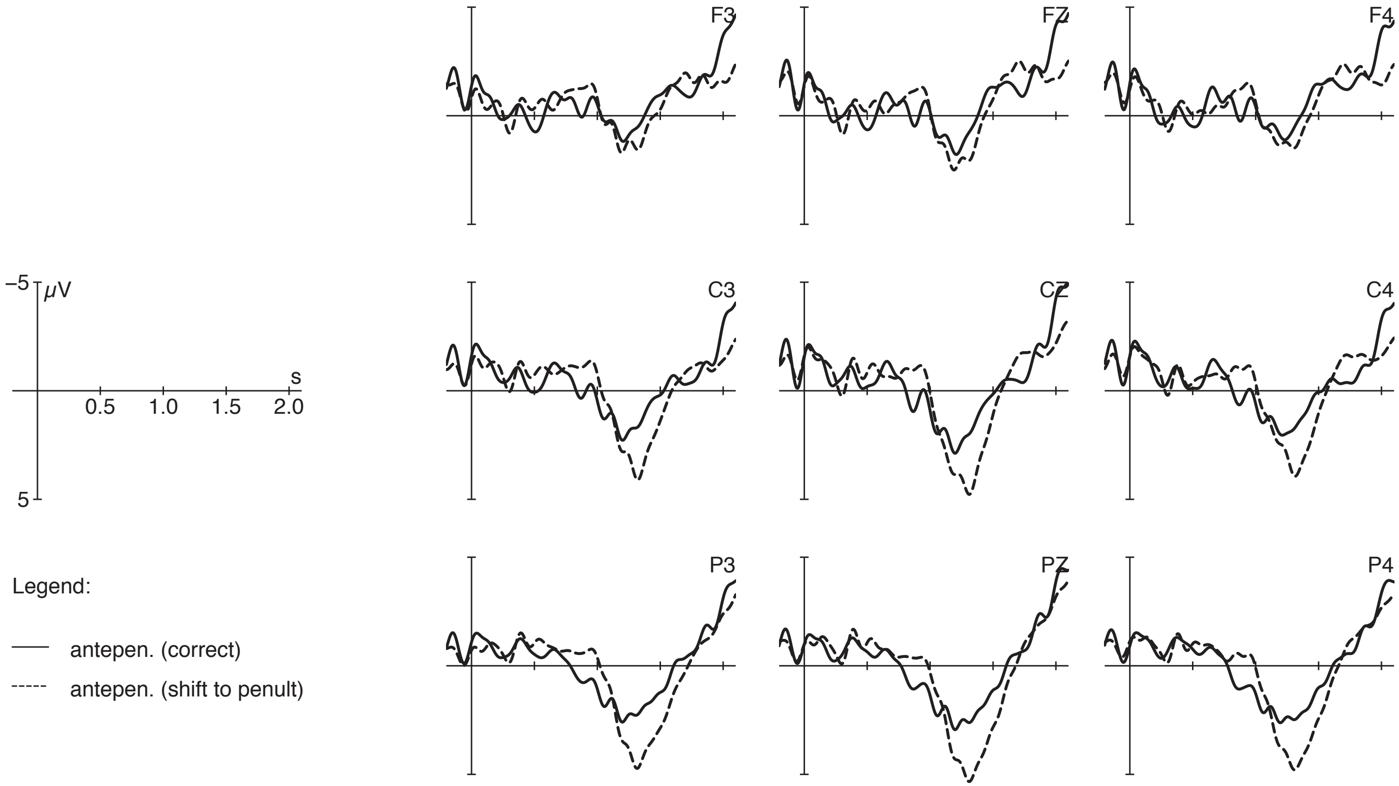
3.1 Correct antepenultimate stress vs. shifted to first syllable



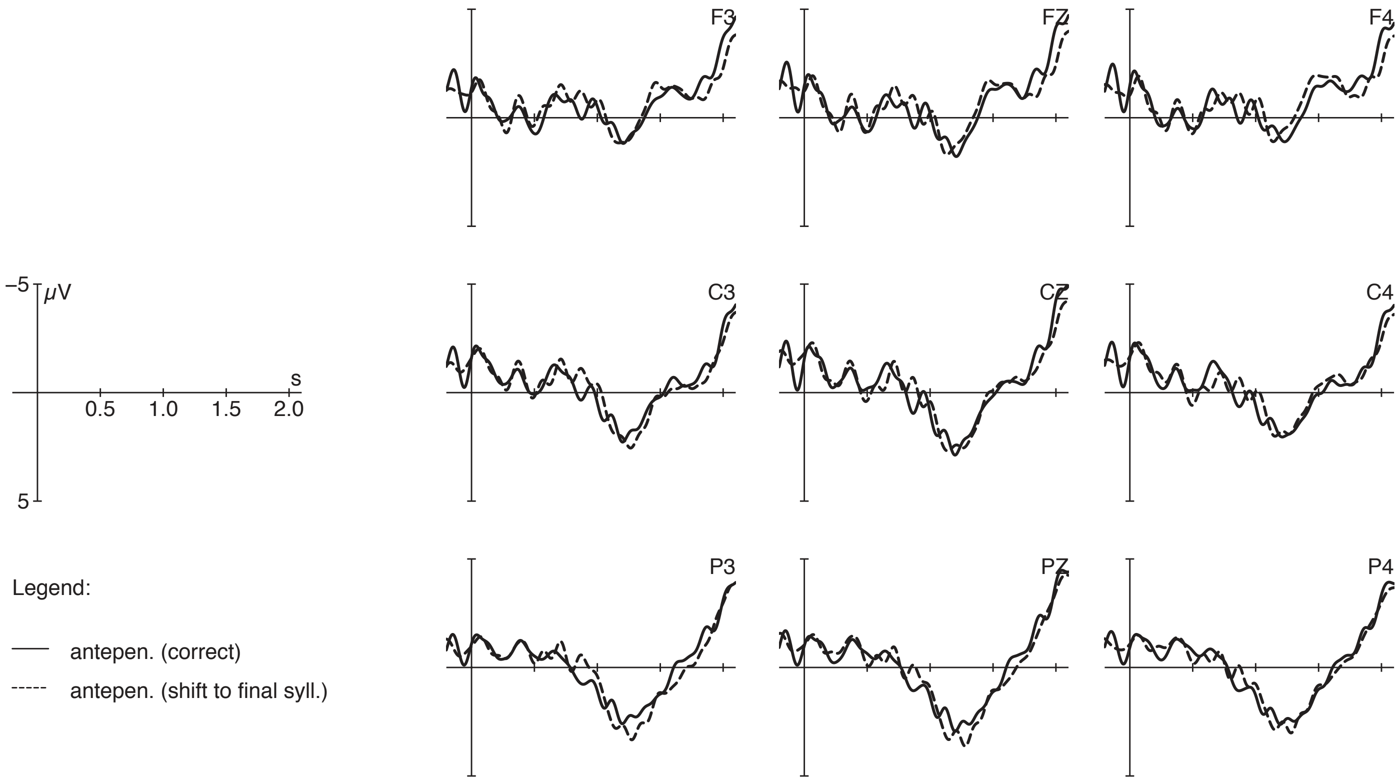
3.2 Correct antepenultimate stress vs. shifted to second syllable



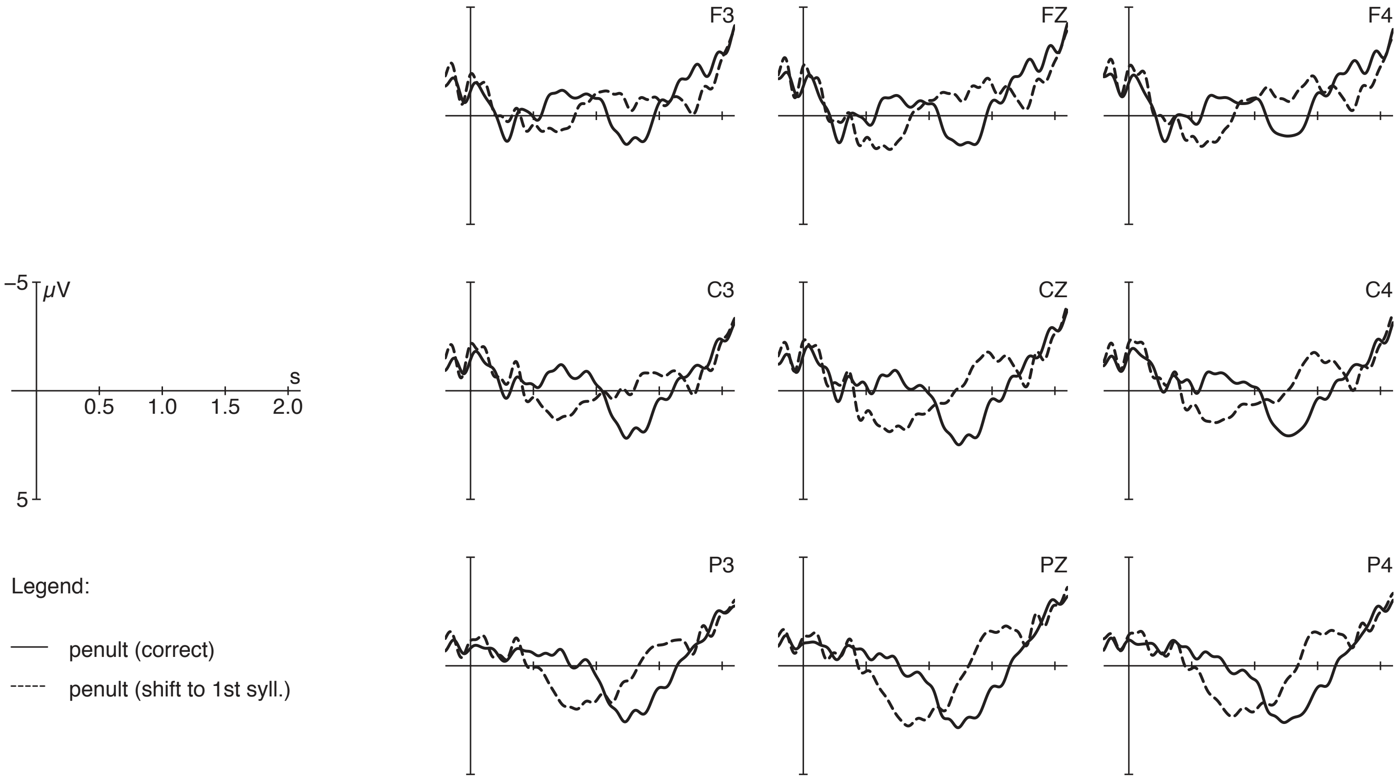
3.3 Correct antepenultimate stress vs. shifted to penultimate syllable



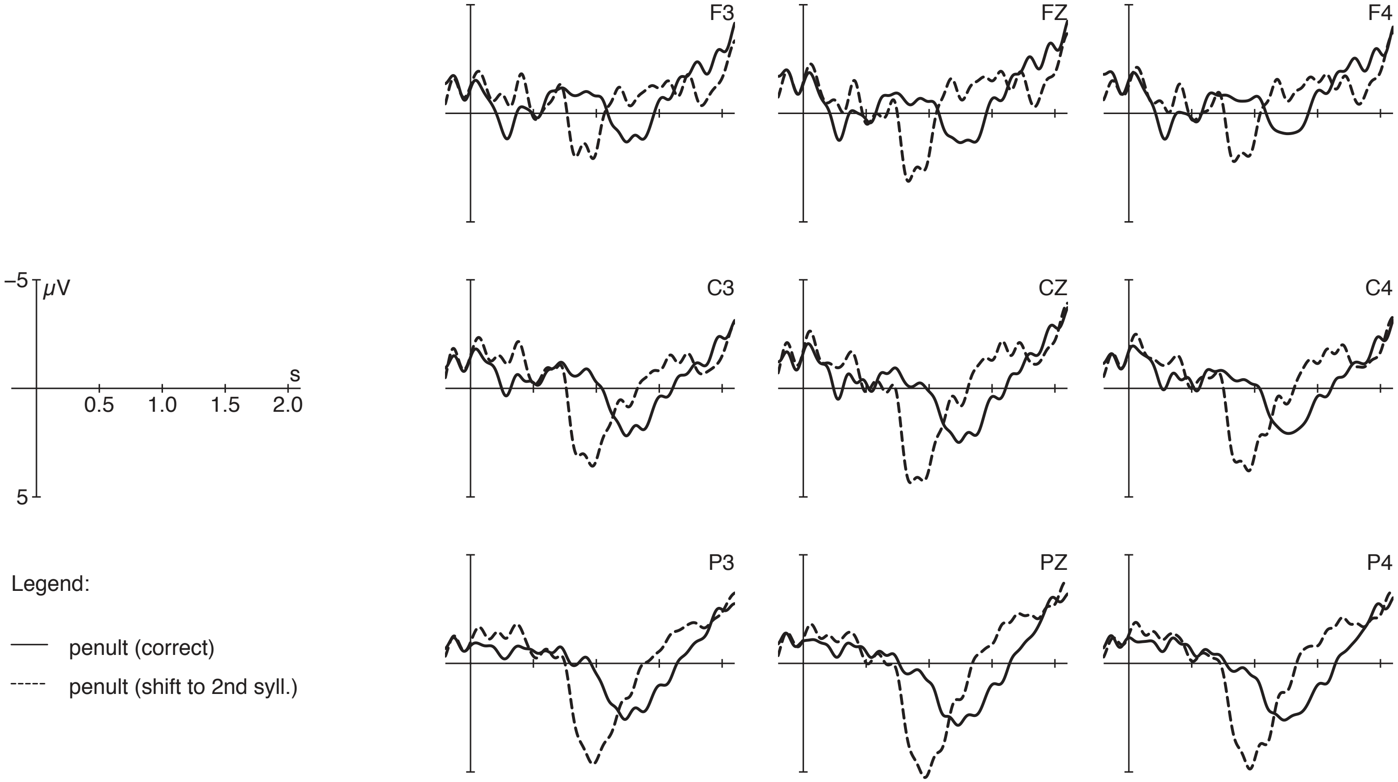
3.4 Correct antepenultimate stress vs. shifted to final syllable



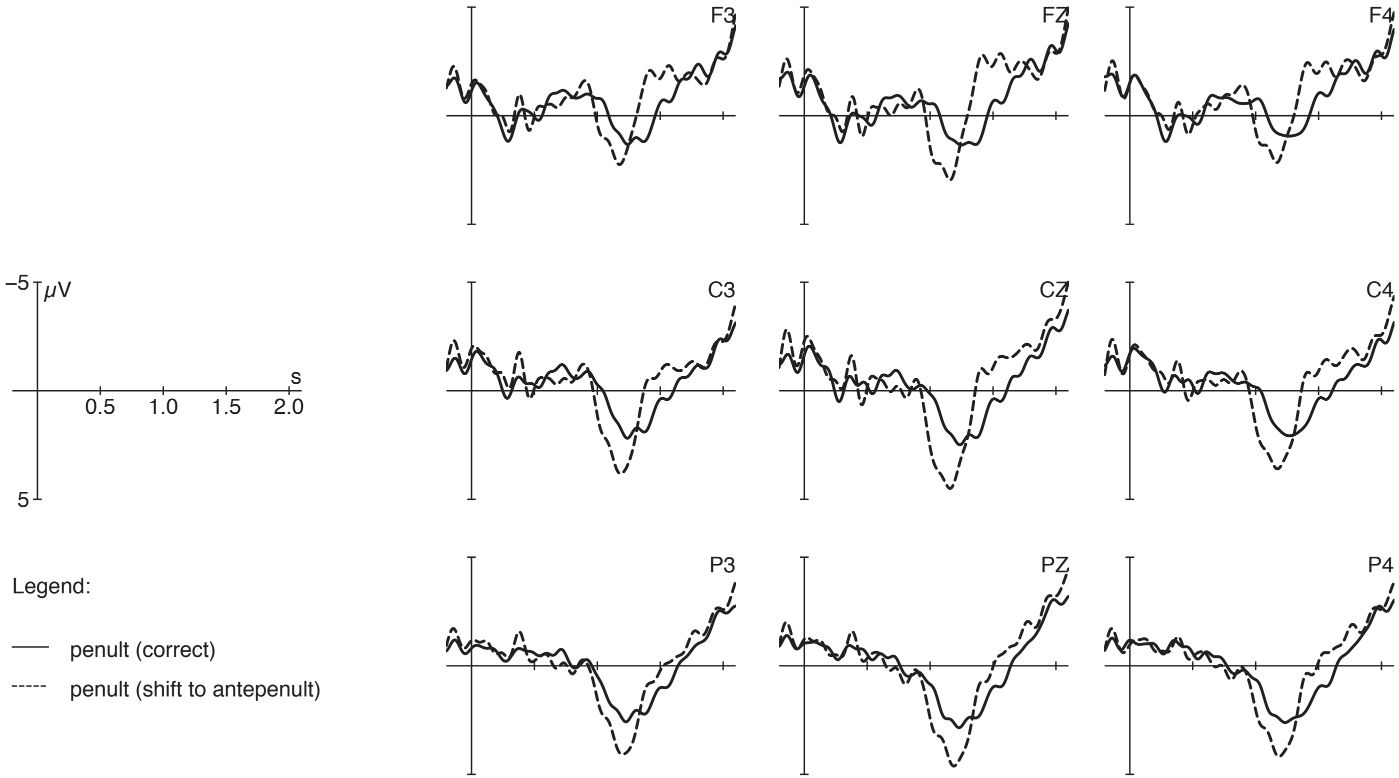
3.5 Correct penultimate stress vs. shifted to first syllable



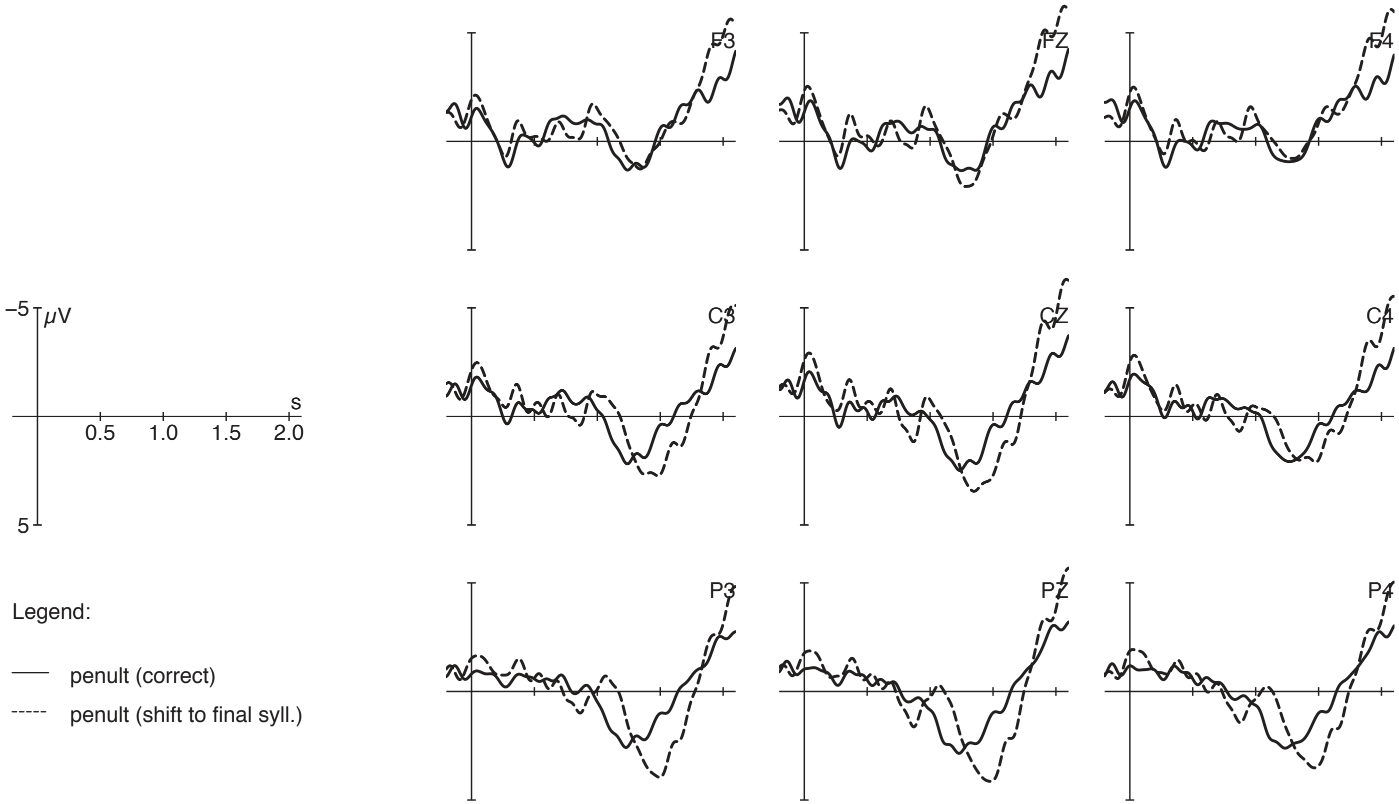
3.6 Correct penultimate stress vs. shifted to second syllable



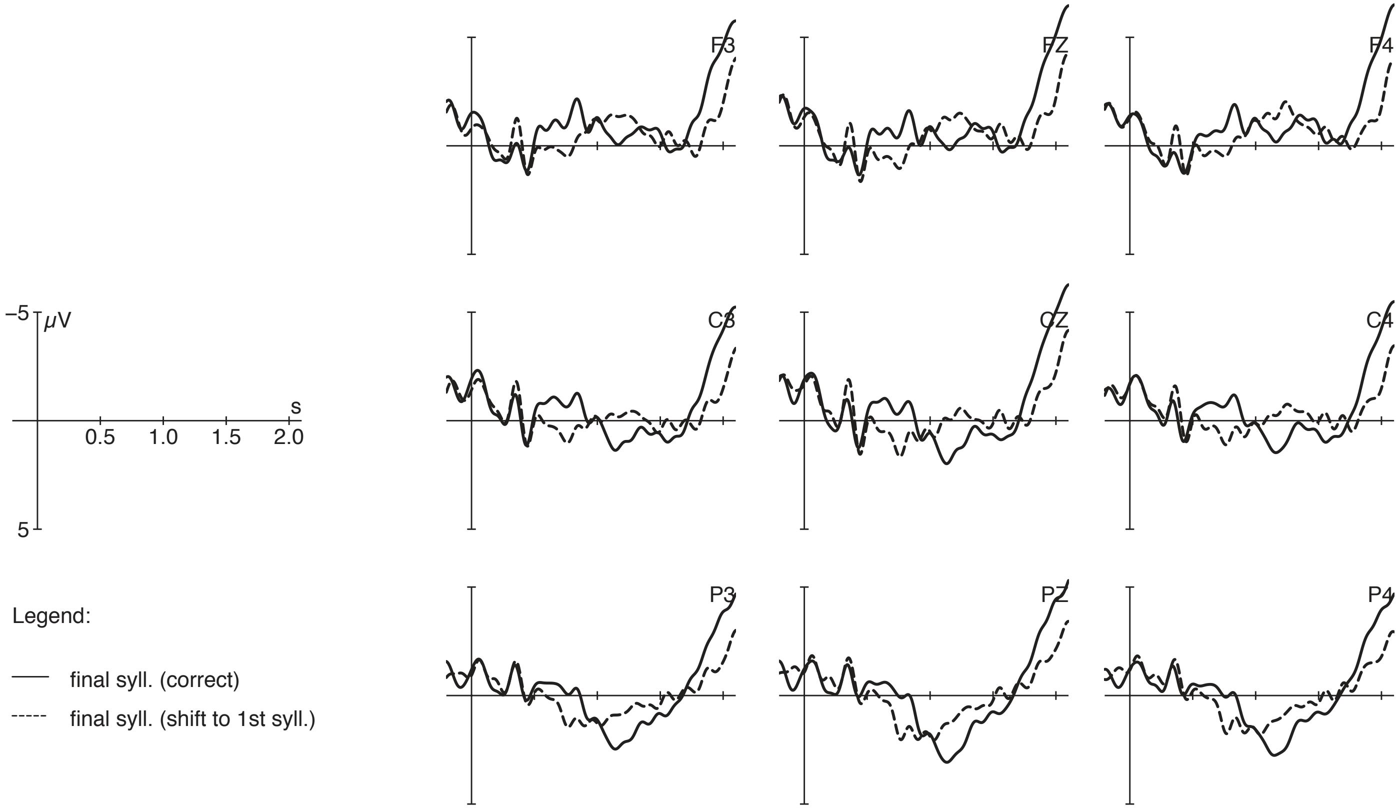
3.7 Correct penultimate stress vs. shifted to antepenultimate syllable



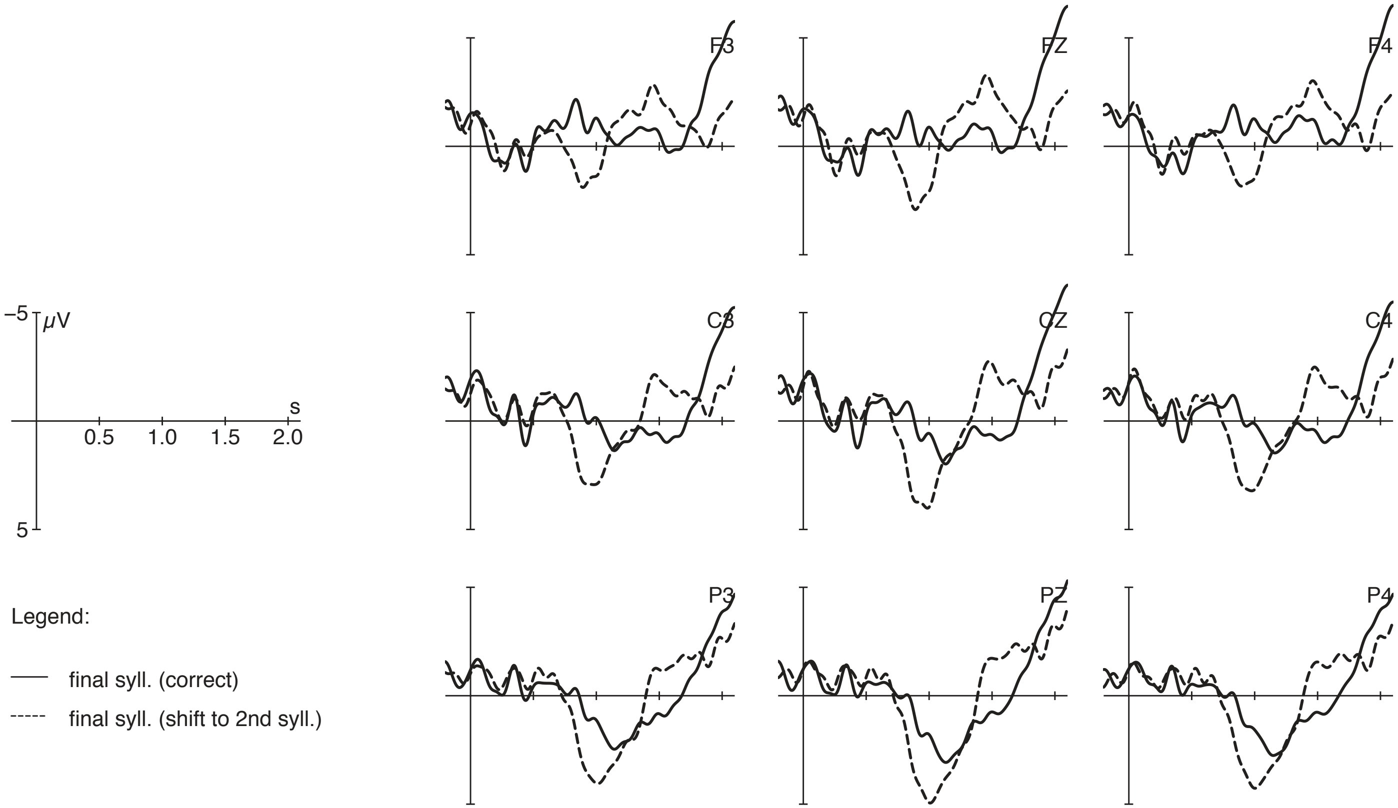
3.8 Correct penultimate stress vs. shifted to final syllable



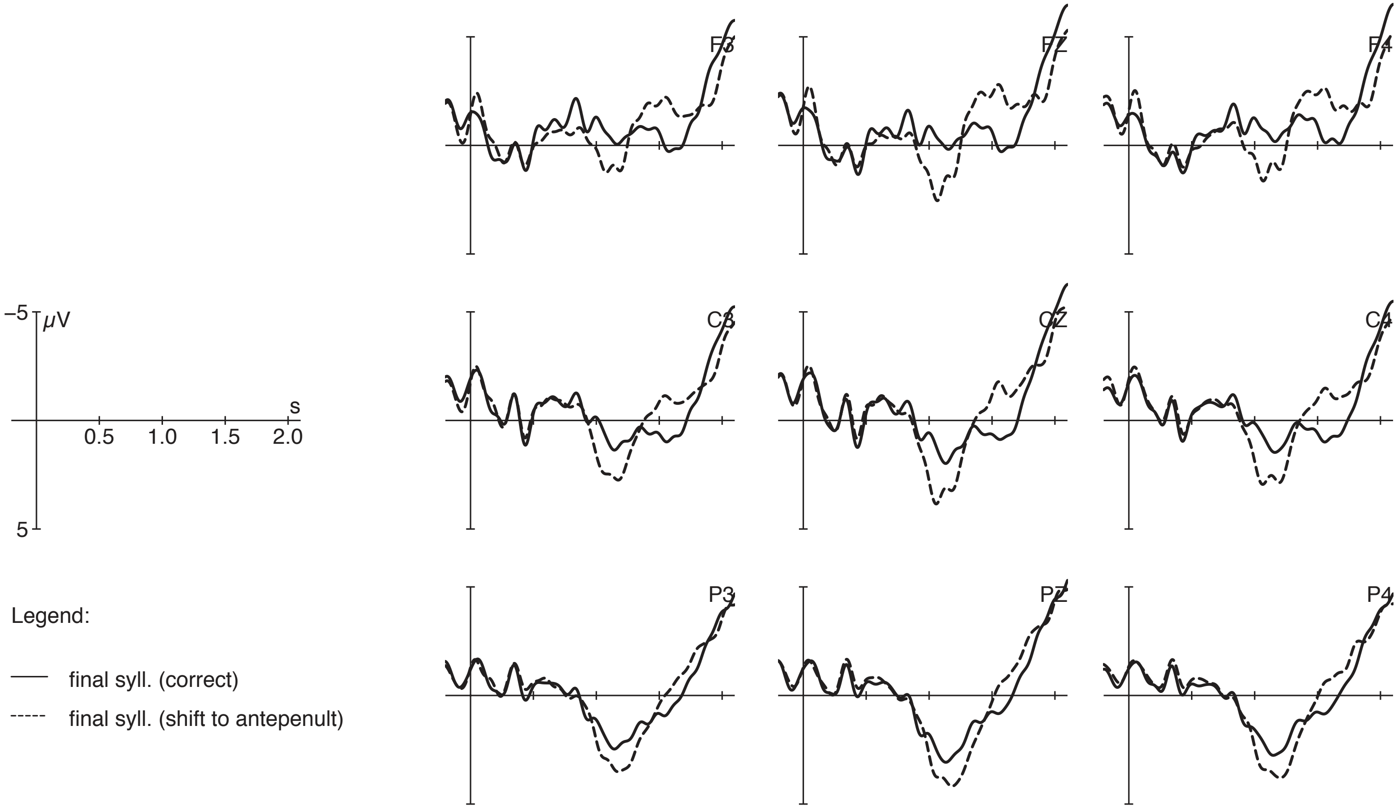
3.9 Correct final stress vs. shifted to first syllable



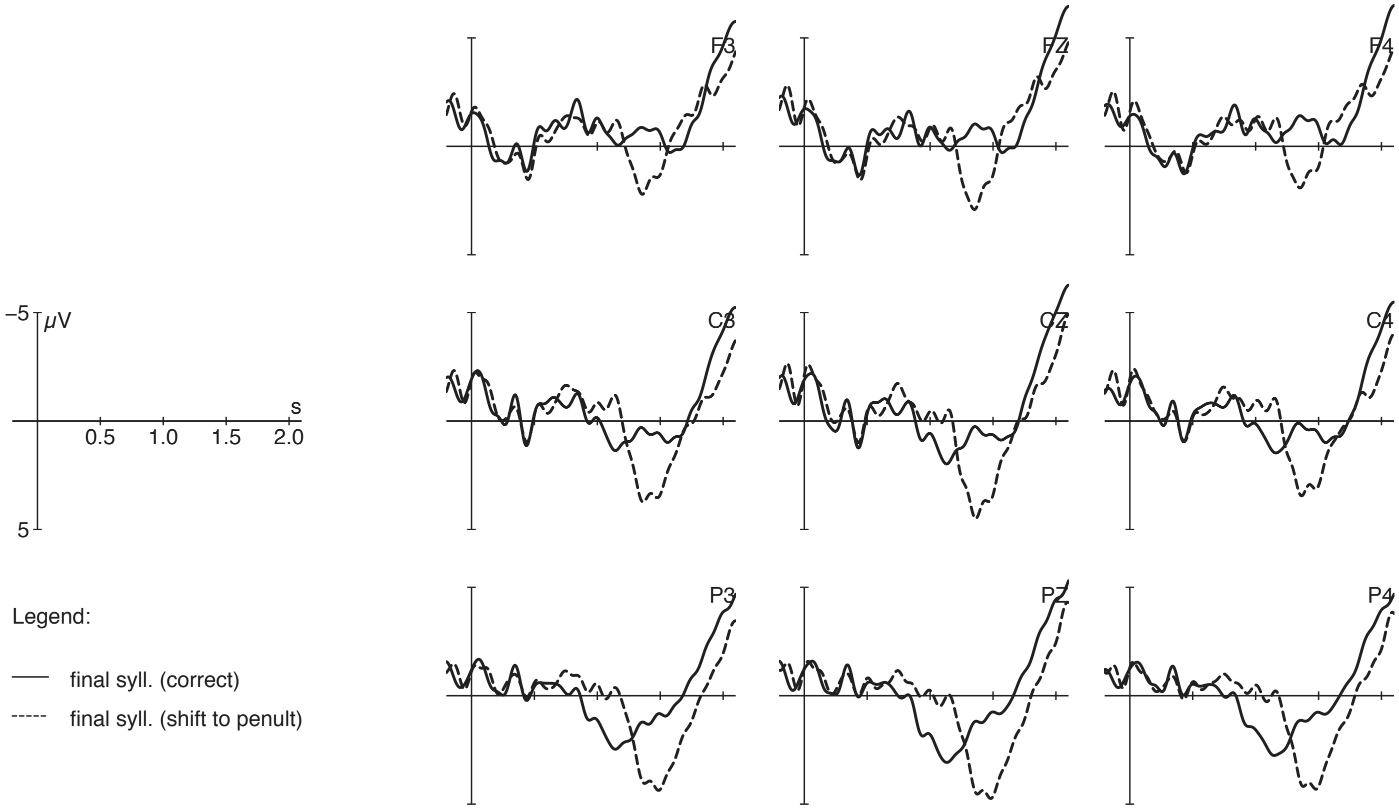
3.10 Correct final stress vs. shifted to second syllable



3.11 Correct final stress vs. shifted to antepenultimate syllable



3.12 Correct final stress vs. shifted to penultimate syllable



Liste der in der Dissertation "Looking at feet. A neurolinguistic and constraint-based analysis of German word stress" von Johannes Knaus enthaltenen Publikationen und Darstellung des Eigenanteils

Knaus, Johannes, Richard Wiese, and Ulrike Janßen (2007) The processing of word stress: EEG studies on task-related components. In Jürgen Trouvain and William J. Barry (eds.) *Proceedings of the 16th International Congress of Phonetic Sciences (ICPhS XVI)*, Paper ID 1209, Saarbrücken: Universität des Saarlandes, 709–712, URL http://www.icphs2007.de/conference/Papers/1209/1209.pdf

Verantwortlich für die Auswertung und Durchführung statistischer Analysen, maßgeblich verantwortlich für die Interpretation der Ergebnisse, das Erstellen des Manuskripts und dessen Endredaktion

Knaus, Johannes and Ulrike Domahs (2009) Experimental evidence for optimal and minimal metrical structure of German word prosody. *Lingua* **119, 10**, 1396–1413, doi:10.1016/j.lingua.2008.04.002

Unter Zugrundelegung der experimentellen Studien und deren Analyse maßgeblich verantwortlich für die Erstellung der den Kern der Publikation darstellenden modelltheoretischen Analyse und für die Diskussion linguistischer Theorien

Domahs, Ulrike, Richard Wiese, and Johannes Knaus (to appear) Word prosody in focus and non-focus position: An ERP-study on the interplay of prosodic domains. In Ralf Vogel and Ruben van de Vijver (eds.) *Rhythm in phonetics, grammar and cognition*, Trends in Linguistics. Studies and Monographs, Mouton de Gruyter

Maßgeblich verantwortlich für die Konzeption der Studie, deren Vorbereitung und Durchführung, der statistischen Auswertung und Analyse sowie der Interpretation der Ergebnisse und das Erstellen des Manuskripts und dessen Endredaktion

Knaus, Johannes, Richard Wiese, and Ulrike Domahs (2011) Secondary stress is distributed rhythmically within words: An EEG study on German. In Wai-Sum Lee and Eric Zee (eds.) *Proceedings of the 17th International Congress of Phonetic Sciences (ICPhS XVII)*, Hong Kong, China: City University of Hong Kong, 1114–1117, URL http://www.icphs2011.hk/resources/OnlineProceedings/RegularSession/Knaus/Knaus.pdf

Maßgeblich verantwortlich für die Konzeption der Studie, deren Vorbereitung und Durchführung, der statistischen Auswertung und Analyse sowie der Interpretation der Ergebnisse und das Erstellen des Manuskripts und dessen Endredaktion

Erklärung

Hierdurch erkläre ich,
dass ich meine Dissertation „ Looking at feet. A neurolinguistic and constraint-based analysis of German word stress"
selbständig ohne unerlaubte Hilfe angefertigt, keine anderen als die angegebenen Hilfsmittel verwendet und alle Stellen, die anderen Quellen dem Sinn nach entnommen sind, durch Angabe der Herkunft kenntlich gemacht habe. Alle wörtlich entnommenen Stellen habe ich als Zitate gekennzeichnet.
Die Dissertation hat in ihrer jetzigen oder einer ähnlichen Form weder ganz noch in Teilen einer in- oder ausländischen Hochschule zu Prüfungszwecken vorgelegen.

Marburg, den 10. Juli 2013

(Unterschrift)