It’s all about the rhythm – A neurocognitive approach towards the Rhythm Rule in German and English

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Zusammenfassung

Die vorliegende Dissertation widmet sich der kognitiven Verarbeitung rhythmischer Irregularitäten in Form von sogenannten Akzentzusammenstößen (*stress clashes*) und Akzentauslassungen (*stress lapses*) im Deutschen und Englischen. Mithilfe psycholinguistischer und neurolinguistischer Methoden wird gezeigt, welche Unterschiede bei der Verarbeitung dieser rhythmisch markierten Formen im Vergleich zu wohlgeformten Strukturen auftreten und wie sich diese bemerkbar machen. Bei Akzentzusammenstößen und -auslassungen handelt es sich um erlaubte jedoch rhythmisch markierte Formen. In dieser Hinsicht unterscheiden sie sich von anderen Formen rhythmischer Abweichungen, die bisher in der Psycho- und Neurolinguistik untersucht wurden. Sie sind markiert, da sie gegen das Prinzip der rhythmischen Alternation (PRA) verstoßen. Wie wichtig die Einhaltung dieses Prinzips im Deutschen und Englischen ist, wurde bisher nur in wenigen Perzeptions- und Produktionsstudien und ausschließlich an Komposita zu rhythmisch motivierten Akzentverschiebungen (*stress shifts*) untersucht. Das Phänomen der Akzentverschiebung, ausgelöst durch die sogenannte *Rhythm Rule*, wurde für die vorliegende Dissertation daher zusätzlich auf Phrasenebene untersucht. Diese Art der Verschiebung kann in akzentzählenden Sprachen wie dem Deutschen und Englischen dann erfolgen, wenn das PRA ansonsten durch einen Zusammenstoß von Haupt- und Nebenakzent innerhalb einer phonologischen Phrase verletzt würde. In beiden Sprachen wird dabei der Nebenakzent verschoben, um eine rhythmisch wohlgeformte Struktur zu erhalten (z.B. *Terˈmin ˌabsagen → Terˈmin abˌsagen*; *chamˌpagne ˈcocktails → ˌchampagne ˈcocktails*).

In insgesamt fünf Studien wurde untersucht, wie rhythmisch markierte sowie wohlgeformte Strukturen auf Wort- und Phrasenebene realisiert, wahrgenommen und verarbeitet werden. Zudem wurden Faktoren wie Aufmerksamkeit und Informationsstruktur und deren Einfluss auf die kognitive Verarbeitung rhythmischer Abweichungen näher beleuchtet. Die Ergebnisse zeigen, dass selbst feine rhythmische Abweichungen vom Gehirn wahrgenommen werden können und mit erhöhten Kosten in der Sprachverarbeitung verbunden sind. Die vorliegende Dissertation verdeutlicht zudem, dass die *Rhythm Rule* sowohl auf der Wort- als auch der Phrasenebene eine wichtige Rolle spielt.

1 Introduction

In recent years, various psycholinguistic and neurolinguistic studies have provided evidence for the theoretical proposition of lexical stress independent from contextual influences like e.g. phrasal stress distribution. Deviations and violations from lexical stress result in increasing costs for lexical retrieval (cf. e.g. Knaus et al., 2007; Magne et al., 2007; Domahs et al., 2008). The compliance with correct lexical stress is thus advantageous for language processing as it helps identifying and finding the correct word form in the mental lexicon. Therefore, lexical word stress is preserved under embedding, i.e. syllables which receive higher level accents are usually the same syllables that also bear lexical stress on the word level (Liberman & Prince, 1977; Giegerich, 1985; Truckenbrodt, 2006).

However, when particular words are combined to larger constituents, an adjustment of lexical stress can be observed, especially in compounds or phrases. In German, secondary stress can be moved rightwards in compounds (*ˈHauptˌbahnhof* → *ˈHauptbahnˌhof* 'main train station') but also in phrases containing phrasal verbs (*Terˈmin ˌabsagen* → *Terˈmin abˌsagen* 'to cancel an appointment'). A similar distribution of secondary and primary stress with a leftward shift of secondary stress is found in English compounds (*chamˌpagne ˈcocktails* → *ˌchampagne ˈcocktails*) and phrases (*thirˌteen ˈmen* → *ˌthirteen ˈmen*). In these cases the relative prominence pattern of the included words is not preserved under embedding, as the lexical stress of the word bearing secondary stress is shifted to another stressable syllable within the lexical item. Although described as being optional, such stress shifts appear very often and operate highly systematically in stress-timed languages like English and German. With regard to German, Wiese (1996) states that stress shifts appear to be optional in phrases but obligatory in compounds. Therefore, there seem to be factors which override the stress preservation rule.

The phenomenon of shifted stress distribution is discussed especially in the theoretical framework of Metrical Phonology (Liberman & Prince, 1977; Hayes, 1984; Selkirk, 1984; Nespor & Vogel, 1989). The pioneering work which tried to explain such stress shifts was provided by Liberman and Prince (1977) in their article "On stress and Linguistic Rhythm". In this article, stress shifts were acknowledged as highly systematic operations in the English language for the first time. In contrast, previous articles (Gimson, 1962; Bresnan; 1972; Goldsmith, 1976) which reported about this phenomenon, classified them as exceptional, as neither the occurrence nor the clearly systematic appearance of stress shifts can be explained in the traditional segmental approach to stress in the generative *Sound Patterns of English* account (SPE) (Chomsky & Halle, 1968). Liberman and Prince (1977) developed a formal approach based on a new relational, suprasegmental stress definition, i.e. the prominence of a syllable is always relative to the prominence of another syllable. Hence, stress is defined by the relation of strong and weak syllables to each other within a word or also on a phrasal level. The introduction of relative prominence as well as the representation of metrical strength within metrical grids had an important impact for phonology in general and for rhythmic phenomena as stress shifts in particular. Liberman and Prince (1977) described stress shift as a means of avoiding so-called stress clashes of two stressed adjacent syllables placed next to each other in certain instances of embedding. In order to avoid such clashes, the stress pattern of the word carrying secondary stress can be reversed (*thirˈteen* → *ˌthirteen ˈmen*) so that the clashing secondary stress is moved away from primary stress onto another close-by stressable syllable within the same lexical item. In this way, an alternating pattern is restored. The avoidance of stress clashes is most often needed in phrases and compounds since clashes most commonly appear when particular words are combined, as mentioned above. The framework provided not only a clear definition of a stress clash but also and more importantly the rules for, and mechanisms of, when and how such a clash can be avoided in the English language. The rule, labelled *Iambic Reversal*, is especially remarkable since it can be – together with other generated mechanisms – adapted to other stress-timed languages in which such shifts appear. Due to syntax, stress shifts in English operate exclusively leftwards, whereas in other languages like German stress can also be shifted rightwards (see examples above). Therefore, the more universal term *Rhythmic Reversal* is also used (Wiese, 1996). Independent of the direction of shift, it can only operate within the domain of the phonological phrase (Nespor & Vogel, 1986) in all languages.

Several other approaches try to give an adequate framework and explanation for the orderly occurrence of stress shifts (Prince, 1983; Selkirk, 1984; Hayes, 1984, 1995). Eventually and despite more or less fine-grained differences, all these approaches share the assumption that stress shifts appear in language in order to create an even, alternating sequence of stressed and unstressed syllables. The importance of alternating strong and weak elements in language was stated as the so-called *rhythmic law* in the early beginning of the 20^{th} century (Ries, 1907). Hence, stress shifts seem to operate due to the pursuit of *eurhythmy*, i.e. rhythmically well-formedness by rhythmical alternation and periodicity, in different languages. Hence, the trigger seems to be of universal rather than language-specific origin, namely of universal rhythmical nature. Therefore, the application of stress shifts and other strategies to prevent stress clashes are often subsumed under the term *Rhythm Rule* (Liberman & Prince, 1977). The output of the Rhythm Rule (RR) is a harmonic sequence of alternating strong and weak units. This resembles the alternating beat sequences in musical structures. The rhythmical organisation of the prosodic structure of language seems therefore to be comparable to the rhythmical ideal of music, determined by the *Principle of Rhythmic Alternation* (Sweet, 1875/76; Jespersen, 1933; Cooper & Meyer, 1960; Abercrombie, 1967; Selkirk, 1984). The Rhythm Rule represents a linguistic repair strategy to avoid sequences of stressed or unstressed syllables and to follow the demands of the general Principle of Rhythmic Alternation (PRA) whenever possible.

Not only stress clashes, but also the juxtapositions of unstressed syllables, so-called stress lapses, contravene the Principle of Rhythmic Alternation (Selkirk, 1984). According to the PRA, a stress lapse is built up by at least two adjacent unstressed syllables, although there is some dispute whether only two adjacent unstressed syllables can be interpreted as a real lapse (cf. Selkirk, 1984; Nespor & Vogel, 1989; Plag, 1999). However, there is some consensus that deviations in form of stress clashes are less well-formed than stress lapses (Nespor & Vogel, 1989; Kager, 1995).

The strong influence of rhythm and its pursuit of regularity, especially in languages like German and English, is further driven by the fact that both languages belong to the group of stress-timed languages. In these languages, the distance between stressed syllables has to be kept isochronous, whereas in syllable-timed languages as French, all syllables are distributed isochronously (Pike, 1945; Abercrombie, 1965, 1967). Although this classification has turned out to be phonetically and physically untenable (e.g. Bolinger, 1965; Roach, 1982; Beckman, 1992), it has been maintained with exclusively stress-timed and syllable-timed languages viewed as extreme points in a continuum (Roach, 1982; Auer & Uhmann, 1988). Independent of physical or psychological isochrony, the concept of rhythmic alternation plays an important role in classical stress-timed languages like English and German (cf. Liberman & Prince, 1977; Selkirk, 1984; Hayes, 1984; Couper-Kuhlen, 1986).

Although the PRA reflects an ideal state of rhythm and can thus – as strict regularity cannot be given in natural language – only be fulfilled to a certain degree, several studies (Cutler & Foss, 1977; Grosjean & Gee, 1987; Cutler & Norris, 1988; Pitt & Samuel, 1990; Mattys, 2000; Rothermich et al., 2013) have been able to show that rhythmic alternations constitute an important and valuable factor in language processing: A regular pattern of rhythmically alternating structures is not only advantageous in speech perception for adults (Cutler & Foss, 1977), and for infants in early language acquisition (Jusczyk, 1999; Nazzi & Ramus, 2003), but also in speech segmentation (Cutler & Norris, 1988; Pitt & Samuel, 1990). The reason for this is that it leads attention to stressed syllables (*attentional bounce hypothesis*; Pitt & Samuel, 1990) and helps to build up expectations when the next stressed syllable might appear. Deviations from rhythmic regularity, on the other hand, slow down speech production and increase the speech error probability (Tilsen, 2011).

Various studies have provided electrophysiological evidence that the brain not only reacts to clear metrical and lexical violations (e.g. Steinhauer et al., 1999; Knaus et al., 2007; Magne et al., 2007; Domahs et al., 2008; Domahs et al., 2013b), but also to even small deviations in language (Schmidt-Kassow & Kotz, 2009b; Rothermich et al., 2010, 2012) as well as in musical structures (Koelsch et al., 2000; Koelsch & Sammler, 2008; Geiser et al., 2009). The on-line processing of rhythmic deviations has thus been given some attention in psycholinguistic and neurolinguistic research in recent years. However, little is known yet about the influence of the Rhythm Rule on rhythmic regularity, i.e. the presence or absence of rhythmically induced stress shifts. Thus, the importance of the RR in stress-timed languages like German and English remained to be tested using the event-related potentials (ERP) technique.

The aim of the present doctoral thesis is to gain deeper insight into the cognitive processing of rhythmically irregular structures in form of stress clashes and stress lapses in comparison to structures that follow the Rhythm Rule. Although stress clashes and stress lapses are allowed and hence present in speech, they are nonetheless marked as rhythmically ill-formed. Hence, since rhythmically induced stress shifts appear often in languages like German, and especially English, it was decided to investigate how the brain reacts to structures that do not meet with rhythmic expectations but are allowed in the investigated language. In this respect, this rhythmic phenomenon differs from the rhythmic deviation types that have been investigated to date. Four studies comprising five experiments using the ERP technique were conducted within the scope of the present thesis. In order to support and complement the findings of the ERP studies, an additional production and perception study and two reaction time studies were designed and undertaken on German rhythmic irregularities.

Three ERP studies were conducted on the cognitive processing of rhythmic irregularities in German phrases (Studies 2 and 4) and compounds (Study 5). Due to the given task settings in the ERP studies, measured reaction times were not meaningful. Therefore, independent reaction time studies with the identical set of stimuli from Studies 2 and 5 were performed and are reported with the corresponding ERP studies. Based on the findings of the first ERP experiment on German phrases (Study 2), a follow-up study was conducted in which the sensitivity towards attentional and contextual influences was further tested by using modified task settings and adjusted stimuli presentation modalities (Study 4). The study on German compounds (Study 5) consists of two experiments which tried to shed further light on the task-sensitivity of the ERP components found in Studies 2 and 4 on German phrases.

A further ERP study was set up in order to compare the influence of the RR on processing in German and English by using similar deviations in English. Therefore, English compounds were tested either obeying or deviating from this rule (Study 3). Moreover, due to the aforementioned syntactic differences between stress shift targets in German and English, this study allowed for a combined yet disentangled investigation of rhythmical and lexical influences on speech processing.

In previous research, the application of the RR in speech production was mainly investigated on English data and exclusively in compound structures in German. Therefore, an additional production and perception study (Study 1) was used as a pre-test for the planned ERP studies on German. Investigating the application and perception of the RR should deliver further insights into its importance in German not only on the word level (in compounds) but also on the phrasal level and therefore complement and extend the findings of previous studies.

The main part of this thesis consists of four research articles based on Studies 1 to 4 described above. The original research articles are presented in Chapter 8 of this thesis. Their most important findings are illustrated in a summarised and interconnected form in the chronological order of publication in Chapters 2 to 5. Chapter 6 presents the research questions and preliminary results of Study 5, as the manuscript on this study has not yet been submitted for publication. Finally, the most important findings of the studies and future directions that result from them are discussed and outlined in Chapter 7.

2 The status of the Rhythm Rule within and across word boundaries in German

The aim of the first study was to gain more insight into the acoustic correlates of the applied Rhythm Rule and its perception by German native speakers. This is important as rhythmic irregularities in form of clashes and lapses are subtle and therefore possibly hard to perceive. Moreover, since the RR is described as an optional process and supposed to be only potentially obligatory for German compounds but not for phrases (Wiese, 1996), this study compared the production and perception of secondary and primary stress distribution in noun compounds as well as in phrases. By including potential stress shift targets in form of phrases, this study is the first production and perception study including larger phrases as stimuli.

So far, the few previous studies which investigated the role of the RR in German (Mengel, 2000; Wagner & Fischenbeck, 2002), have concentrated exclusively on noun compounds of the A(BC) type (e.g. $Haupt_A$-$bahn_B$-hof_C ‘main station’) in which the A constituent carries primary stress. When this first constituent is monosyllabic or carries stress on its final syllable, secondary stress has to be shifted from the B constituent rightwards to the C constituent, according to the RR.

Regarding their results, the occurrence and importance of stress shifts in German compounds seems to be inconclusive. Mengel (2000) classifies the RR as a primarily perceptual phenomenon. Using synthesised and delexicalised trisyllabic structures carrying primary stress on the first constituent, he states that the listener automatically perceives an alternating pattern in the two final syllables due to the preceding triggering initial constituent. No shift is perceived when this triggering context is not given. The important role of the triggering context is also found in a study by Wagner and Fischenbeck (2002) which investigated delexicalised as well as naturally occurring A(BC) compound structures. They showed that the perception of clearly produced stress shifts in the (BC) part of compounds is strongly impaired when presented without the triggering A constituent, but only when all constituents are monosyllabic. In compounds consisting of four syllables due to a disyllabic C constituent, stress shift is still perceivable indicating that the foot structure and the number of syllables has an important impact on stress shift perception. However, it has to be kept in mind that solely one token of a trisyllabic compound was tested against the tokens of four different quadrisyllabic compounds.

Moreover, the results show that stress shifts are not only perceived but also produced by German speakers, even though rather rarely. Hence, it was suggested by Wagner and Fischenbeck (2002) that stress clashes are rather unproblematic for German speakers and listeners, as they seem to be produced and thus perceived rather frequently.

The rating of perceived stress patterns also shows that speakers tend to use two different strategies in order to fulfil the RR: It is either possible to shift secondary stress rightwards onto the next stressable syllable, hence to produce a real stress shift, or to destress the syllable carrying secondary stress. Both options obtain a rhythmically alternating sequence of stressed and unstressed syllables and have been described as the two main strategies in order to avoid stress clashes in English (*Reversal Analysis* vs. *Deletion Analysis*) (Selkirk, 1984; Vogel et al., 1995).

Indeed, destressing seems to be the dominant production strategy in English (Horne, 1990; Vogel et al., 1995). In a study on English compounds, Vogel et al. (1995) showed that the final syllable of a potential shift target word like *thirteen* is significantly reduced in its duration and fundamental frequency (F_0) in contexts producing a stress clash (e.g. *thirˌteen ˈmen*) compared to non-clash contexts (e.g. *thirˌteen caˈdets*). Hence, instead of reversing the stress pattern in the target word, the prominence of the clashing syllable is reduced. Listeners are nonetheless able to hear stress shifts, which is due to the weakening of the final syllable making the initial syllable of the disyllabic target word perceptually stronger. Comparable to the German results, various studies investigating the RR (Cooper & Eady, 1986; Grabe & Warren, 1995; Vogel et al., 1995; Tomlinson et al. 2014), have demonstrated the important influence of the triggering context on the perception of stress shifts in English, often leading to the assumption that stress shifts are rather a purely perceptual phenomenon than an option in language production.

Although previous studies do not fully agree on matters of the realisation of the RR, they all concur on the view that it does exist – albeit optional and speaker-dependent – not only on a perceptual level but also to a certain extent on an articulatory level, and thus plays an important role in English as well as in German.

The present study therefore was designed to explore whether the occurrence of stress shifts in German compounds and phrases is in fact a purely perceptual phenomenon or reflected by phonetic alternations in German speech production. Since the appearance of stress shifts is also described beyond external word boundaries (Kiparsky, 1966; Nespor & Vogel, 1986; Wiese, 1996) but so far has only been tested within compounds, the investigation was extended to the phrasal level to find experimental support for the application of the RR within and beyond word boundaries. It was designed to replicate the study by Wagner and Fischenbeck (2002) by including the same set of trisyllabic and quadrisyllabic A(BC) compounds but to extend their investigation regarding the differences between these compound types by including more compounds in the different perception experiments. Moreover, phonological phrases consisting of a disyllabic noun and a following trisyllabic phrasal verb carrying lexical stress on its initial syllable (e.g. *Terˈmin ˌabsagen* ‘to cancel an appointment’) were used as stimuli. These phrases either contained a clash context triggering stress shift or a non-clash context.

Thirteen native German speakers (seven female) were asked to read short newspaper sections that contained four different trisyllabic (e.g. $Haupt_A$-$bahn_B$-hof_C ‘main station’) and seven different quadrisyllabic (e.g. $Fach_A$-$hoch_B$-$schu_C$-le_C ‘technical college’) A(BC) compounds as well as four phonological phrases as described above. They either included a stress clash (e.g. *Terˈmin ˌabsagen* ‘to cancel an appointment’) or a non-clash context (e.g. *ˈFeier ˌabsagen* ‘to cancel a party’). These compounds and phrases served as stimuli in two perception experiments and the four phonological phrases of each condition were further phonetically analysed.

Due to the comparably high number of speakers, a set of 52 phonological phrases per condition, 43 trisyllabic, and 65 quadrisyllabic compounds were included in the first perception experiment (for detailed information about the stimuli and method see Chapters 8, 10.1.1 and 10.1.2).

In the first perception task, all critical stimuli were presented in isolation, i.e. extracted from their carrier sentence. Per speaker, the evaluation by four linguistically trained listeners was surveyed. This way, four independent evaluations regarding the stress distribution in the stimuli of one speaker could be analysed. The results of the overall evaluation of all tested stimuli show a consistent picture regarding the perceivable application of the RR within as well as beyond word boundaries in German: The majority of phonological phrases that contain a stress clash context were perceived with shifted stress within the included phrasal verb. In total, less than 4 per cent of all evaluated phrases containing a clash context were perceived with an actual clash of primary and secondary stress. The evaluation of the two compound types showed that the number of syllables does not play a crucial role in the perception of stress shifts, at least when the compound is presented and evaluated with the triggering A constituent: Over 56 per cent of the trisyllabic and 68 per cent of the quadrisyllabic compounds were perceived with primary stress on the A constituent and secondary stress on the C constituent.

The perception of stress shifts in the two compound types might change when evaluated without the triggering context, as it was shown for English as well as for German compounds (Grabe & Warren, 1995; Wagner & Fischenbeck, 2002). Nevertheless, Wagner and Fischenbeck (2002) found that German listeners are still able to correctly perceive stress shifts in quadrisyllabic compounds presented without the A constituent. This proposition was tested in a second perception experiment comparing the detection of stress shifts in compounds consisting of three and four syllables.

In this experiment, only compounds perceived with a clear shift in experiment 1 were included. Therefore, the syllable of the A constituent was deleted from the remaining 24 trisyllabic (*Hauptbahnhof* → *Bahnhof* 'main station' → 'station') and 44 quadrisyllabic (*Fachhochschule* → *Hochschule* 'technical college' → 'college') compounds. The same listeners as in experiment 1 were asked to evaluate the stress distribution in the remaining (BC) compounds. However, the listeners were not told that the compounds originally contained a preceding constituent so they were asked to identify the distribution of primary and secondary stress.

The results revealed a clear difference between the two compound types and showed that the context-independent perception of stress shifts depends on syllable number. While the disyllabic structure of the C constituent in originally quadrisyllabic compounds is advantageous for the correct perception of shifts (perception of primary stress on the C constituent in 68 per cent), the evaluation is more complicated when the (BC) compound consists of only two syllables (perception of primary stress on the C constituent in only 42 per cent, in comparison to 37 per cent on the B constituent). The results therefore support the findings of Wagner and Fischenbeck (2002) and extend them regarding the context-independent perception of stress shift in trisyllabic compounds.

The third and last part of this study consisted of a phonetic analysis of all phrasal verbs from the tested phonological phrases that were evaluated as shifted when presented in a clash context in perception experiment 1. The corresponding verbs which were produced in a non-clash context were acoustically analysed as a comparison. This analysis was conducted in order to find out whether the perception of stress shifts in the two perception experiments was mainly motivated by rhythmic expectancies and thus indeed just a perceptual phenomenon as supposed by different studies (Grabe & Warren, 1995; Mengel, 2000) or whether there is acoustic evidence which attests the usage of stress reversal or destressing in order to fulfil rhythmic demands.

The results of the statistical analysis (for more details see Chapter 8) show that the first syllable of the phrasal verbs produced in non-clash condition is realised significantly longer in comparison to the first syllable of phrasal verbs embedded in a clash context. No significant differences were found for F_0 or intensity. Syllable duration thus seems to be the decisive factor in German phrasal verbs for the production and perception of stress shift. This finding is in line with studies which highlight the importance of syllable duration for prominence perception in German (Dogil, 1999; Jessen et al., 1995; see also Chapter 3). However, descriptive statistics for each speaker and for the different stimuli types suggest a great variability in the realisation of the RR in German. This makes a conclusive decision regarding the dominant production strategy particularly difficult.

The overall results of this production and perception study support the assumption that stress shifts are regular and maybe even mandatory in German compounds (cf. Wiese, 1996). The fact that stress shifts are regularly perceived in noun compounds as well as in larger phrases beyond single word boundaries is contrary to the findings by Wagner and Fischenbeck (2002) which describe the appearance and perception of stress shifts in German compounds as a rather rare phenomenon. However, the present study supports their finding that especially quadrisyllabic compounds are context-independently perceivable as shifted. The acoustic analysis provides insight into the phonetic correlates of the RR in German, showing that syllable duration is the main cue for its realisation and perception and that the RR hence indeed possesses not only a perceptual but also an articulatory expression.

Based on these findings, the question arises what role this form of rhythmical alternation plays in cognitive processing. To this end, an ERP study was conducted in which the RR was either applied or not, leading to stress clashes as well as stress lapses, structures that can both occur in German. This study is presented in the following chapter.

3 The influence of rhythmic (ir)regularities on speech processing: evidence from an ERP study on German phrases

This study concentrates on the question how rhythmic irregularities which violate the demands of the RR as well as the PRA but potentially occur in natural speech are cognitively processed. Therefore, possible differences in the processing of these rhythmically marked structures and rhythmically well-formed structures in accord with the PRA and following the RR were explored.

As reported in Chapter 2, there have been several off-line production and perception studies which cannot draw a fully conclusive picture of this topic but show that stress shifts are an optional and possibly even rare strategy used in German (cf. Wagner and Fischenbeck, 2002). However, no on-line study looked at direct brain responses to these structures. The present study was planned to show the importance of this special form of rhythmic regularities and irregularities. It should deliver a clearer picture of the acceptability of stress clash structures in language processing. Moreover, due to the RR's optional character, a further question was whether well-formed and ill-formed structures are processed differently in any way. This point is even more important as several studies claim shifts to be non-existent but rather a purely perceptual phenomenon (cf. Chapter 2). If so, no processing differences should be found for well-formed structures and rhythmic deviations. However, since the study described in Chapter 2 could show that the RR possesses – at least to a certain degree – articulatory reality in German, it was assumed that stress clashes as well as stress lapses are processed differently from well-formed control conditions. As mentioned in the Introduction, stress lapses are described as being less problematic than stress clashes, therefore differences between the two ill-formed structures in form of stronger reactions to stress clashes were expected, as well.

To investigate these research questions, the event-related potentials (ERP) technique was used. Event related potentials are derived from the recording of an electroencephalogram (EEG) which is measured non-invasively from electrodes that are applied to the surface of the scalp. This electrophysiological technique holds the advantage to show otherwise invisible processes of language processing by measuring the brain's electrical activity in response to a sensory stimulus. Moreover, due its high temporal resolution (in the range of milliseconds) this method is especially beneficial in reflecting these stimulus-triggered changes in real time, time-locked to the event which causes this signal. Event-related potentials elicited by a critical experimental stimulus are always interpreted in relation to a control condition to show which effects are solely due to the relative difference between those two conditions. These effects, so-called ERP components, are defined along four dimensions: latency (their temporal appearance, measured in milliseconds (ms)), polarity (positive vs. negative deflection of the critical condition in comparison to its control condition), amplitude (their intensity or 'strength', measured in microvolt (µV)), and topography (their scalp distribution, detected from the electrode sites at which the effect is measured most significantly). Regarding their nomenclature, ERP components are usually labelled according to their polarity ('N' and 'P', for 'negativity' or 'positivity') and their timing (the effect's approximate peak latency relative to its onset, in ms) (Coles & Rugg, 1995; Luck, 2005). With respect to the topography of a component, it has to be stated that the spatial resolution of this technique is rather poor, i.e. the measurement of an effect on the scalp surface cannot directly be associated with the exact, underlying location eliciting this effect, also known as the so-called 'inverse problem'. Therefore, the topographic distribution of an elicited ERP component has to be seen as roughly rather than exactly accurate and the spatial distribution of a component is described in regional dimensions (e.g. frontal vs. central vs. parietal or anterior vs. posterior) by putting together several electrodes of a particular site to a so-called *Region of Interest* (ROI). Regarding the research question of the studies in the present dissertation, the excellent temporal resolution of this technique is most important, as it can deliver a finer-grained picture of the question when exactly special events, e.g. rhythmic irregularities, are encountered and processed in the human brain.

There have been several studies using the ERP technique which were able to show the importance of rhythmic regularity in language as well as in musical processing (Magne et al., 2007; Schmidt-Kassow & Kotz, 2009a, 2009b; Rothermich et al., 2010, 2012; Marie et al., 2011; Koelsch et al., 2000; Koelsch & Sammler, 2008; Geiser et al., 2009). Their findings prove that the brain clearly responds to rhythmic irregularities, even to small deviations (Schmidt-Kassow & Kotz, 2009b). This is most often reflected by a biphasic pattern consisting of an (early) negativity and a late positive component (LPC). However, as was already stated in the Introduction, deviations from the correct lexical stress pattern also lead to increasing costs in processing, which is reflected by an N400 (e.g. Knaus et al. 2007; Domahs et al., 2009, 2013a). The cited studies reveal the importance of both, rhythmical and lexical well-formedness for language processing.

The distinctiveness of this study lies in the fact that both types of deviations are included in the investigated set of stimuli: stress shifts fulfil demands of rhythmical well-formedness but simultaneously violate the lexical stress pattern. Stress clashes, on the other hand, keep the correct lexical stress pattern but therefore violate rhythmic demands. Finally, stress lapses include both, a rhythmical as well as a lexical deviation. Combining lexical and rhythmical deviations made it possible for this study to further clarify the nature of their functional components as well as the question which deviation is more costly and hence less acceptable.

In this study, phonological phrases in the same form as in Study 1 were used as stimuli. Moreover, phonological phrases containing clear lexical violations were included as filler items to shed further light on the processing of lexical violations. The presented stimuli are given in an exemplar fashion in Table 1.

Condition	*Example*
Correct SHIFT	Sie soll den **Terˈmin abˌsagen**, wie besprochen. *She is supposed to cancel the appointment, as discussed.*
Correct NO SHIFT	Sie soll die **ˈFeier ˌabsagen**, wie besprochen. *She is supposed to cancel the party, as discussed.*
CLASH	Sie soll den **Terˈmin ˌabsagen**, wie besprochen. *She is supposed to cancel the appointment, as discussed.*
LAPSE	Sie soll die **ˈFeier abˌsagen**, wie besprochen. *She is supposed to cancel the party, as discussed.*
Filler correct	Sie soll die **ˈPreise reduˌzieren**, wie immer. *She is supposed to reduce the prices, as usual.*
Filler incorrect	*Sie soll die **ˈPreise reˌduzieren**, wie immer. *She is supposed to reduce the prices, as usual.*

Table 1. Experimental Conditions and filler Items.

An acoustic analysis on the phrasal verbs revealed that the speaker produced real stress shifts in the SHIFT condition by shortening the initial syllable of the phrasal verb and lengthening the penultimate syllable (see also Chapter 10.2.4). This finding is in line with the results of the acoustic analysis of Study 1, supporting the claim that syllable duration is the dominant cue in the realisation of the RR as well as with previous studies which showed that duration is the most decisive factor for the prominence perception of a syllable, followed by intensity and F_0 (Jessen et al., 1995; Dogil, 1999; Mengel, 2000).

The stimuli (see also Chapters 10.2.1 – 10.2.3) were presented to the participants together with the task to evaluate the sentences' overall prosodic naturalness, i.e. attention was not explicitly directed towards the critical rhythmical conditions within the carrier sentences. Moreover, the carrier sentences were kept as natural as possible, i.e. not strictly rhythmically regular. This way, the critical rhythmical structures were processed in a maximally natural metric context. This should make it possible to map the processing of these structures in natural language as authentically as possible. These two points are in contrast to previous studies investigating subtle rhythmically irregular structures (Schmidt-Kassow & Kotz, 2009a, 2009b; Rothermich et al., 2010; 2012).

The overall results of the study show that in fact two types of negativities are elicited by stress clash structures and stress lapse structures, differing in topography and latency. The difference in latency could be explained by the fact that the stressed syllable is the reference point for word recognition and thus violation detection within a word (Cutler & Norris, 1988: *Metrical Segmentation Strategy*; cf. Domahs et al., 2008). In words containing a shift, as in stress lapses, the second syllable carries stress, therefore the dependent effects can only occur with the beginning of this syllable and not with the verb's onset as in structures containing no stress shift. However, the spatial distribution of the two negativities found for clash and lapse is very different, therefore it is more likely that these two effects reflect different functional processes. The more frontally distributed early negativity found for clash is interpreted to reflect an error-detection mechanism activated by the contained rhythmic deviation, i.e. a subcomponent of the left anterior negativity (LAN) (Hoen & Dominey, 2000). This interpretation is in line with several studies which found a negativity effect with a similar temporal and spatial distribution (cf. Koelsch et al., 2000; Schmidt-Kassow & Kotz, 2009a; Rothermich et al., 2010, 2012). This finding is especially remarkable since it shows that even subtle rhythmic deviations in contexts which do not contain strong cues of rhythmic regularity can be detected and that this component can thus be elicited even if no strong expectations regarding the overall rhythmical structure are built up.

The negativity elicited by lapse, on the contrary, is distributed in the centro-parietal region and peaks about 400 ms post-onset. Therefore, it most likely reflects an N400. Although stress lapses do also contain a rhythmic irregularity, this deviation seems not to be entirely responsible for the elicited effect. Due to the included stress shift, lapse structures additionally contain a deviation from the lexical stress pattern, opposed to the phrasal verbs in the control condition. As stated above, previous studies showed that the deviation from lexical stress patterns increases costs in lexical retrieval (Friedrich et al., 2004; van Donselaar et al., 2005; Knaus et al., 2007; Magne et al., 2007). This interpretation is further supported by the fact that lapse structures still elicit this component when compared to verbs containing a stress shift but no rhythmical deviation. This finding suggests that the double deviation in LAPSE leads to this strong effect. Interestingly, no effect was elicited by stress shift structures alone in comparison to structures without a shift. The lexical deviation in rhythmically well-formed structures is thus licensed by rhythmic demands. The results of this study might therefore explain why stress shifts operate under embedding despite lexical stress normally being preserved (cf. Introduction).

In all comparisons, these negative components are followed by a late positive component. This component reflects the same underlying functional process for both deviations, namely the evaluation process related to the task requirements. Thus, the positivity is interpreted as a member of the P300 family, as the P300 is described as being task-sensitive and task-specific (cf. Picton, 1992; Coulson et al., 1998; Knaus et al., 2007; Magne et al., 2007; Domahs et al., 2008, 2009, 2013a; Schmidt-Kassow & Kotz, 2009a, 2009b; Marie et al., 2011).

Regarding the latency of this component in the different comparisons, it provides further support for the Metrical Segmentation Strategy (Cutler & Norris, 1988) as its latency is dependent from the detection of the stressed syllable in the different conditions. This result further contributes to the findings of previous studies which described the dependency of the P300's latency on the position of the stressed syllable in the speech signal (Magne et al., 2007; Knaus et al., 2007; Domahs et al., 2008). The amplitude of this component is very pronounced for stress lapses but reduced for stress shifts. This asymmetry is interpreted to reflect the resolvability of the given task, with the amplitude being its indicator. Stress lapses contain an accumulation of lexical and rhythmical deviations and are thus easier to detect and evaluated as more unnatural than the subtle rhythmical deviation within stress clash structures. The amplitude of the positivity elicited by stress lapses is more pronounced than the one elicited by stress clashes. The more pronounced amplitude thus reflects the facilitated evaluation process. This interpretation is further supported by various ERP studies which found similar amplitude asymmetries in the P300 depending on task-resolvability (cf. Domahs et al., 2009, 2013a; Schwartze et al., 2011).

To further extend the findings on the processing demands of these structures, a reaction time study was carried out, in addition, using the identical set of stimuli. This was done in order to further reveal the temporal organisation of mental processes underlying the processing of rhythmical irregularities. In this study, stimuli were presented in isolation rather than embedded into a carrier sentence. For the interpretation of reaction times (RTs), it is assumed that the easier the identification of a stimulus, the faster the response, and vice versa, the harder the evaluation, the slower the response. The time between the onset of a stimulus and the onset of the response to it can thus give an important insight in the question of how long it takes a listener to process, identify and evaluate a structure with regard to its rhythmicity in this case.

Its results in fact support and complete the findings of the ERP study. Stress clashes, which are interpreted to be harder to detect and to cause higher costs in processing, need more time to be evaluated than rhythmically regular structures but also compared to structures containing stress lapses. Stress lapses are detected faster due to the stronger violations. Stress clashes are thus an obstacle in language processing as they require more complex processing. Stress lapses are even less acceptable than stress clashes as they not only deviate from rhythmic expectations but also increase the costs for lexical retrieval due to their deviation from lexical stress. However, deviations from lexical stress are only problematic in this context when they are rhythmically unlicensed. Thus, harmonious rhythmical stress seems to be more important than the strict compliance with lexical stress. The overall findings of the present study show that rhythmically alternating structures are in fact distinguished and processed differently from rhythmically irregular structures, as the brain reacts sensitively to even small rhythmic deviations which can potentially be produced and perceived by German native speakers.

Since the RR is supposed to operate more frequently in English, these conclusions may be generalisable to English as well as other stress-timed languages in which rhythmical adjustments on lexical stress patterns are observed (Liberman & Prince, 1977; Grabe & Warren, 1995; Vogel et al., 1995; see Introduction). This was investigated in a further study on English compounds which is summarised in the next chapter.

4 The relevance of rhythmical alternation in language processing: An ERP study on English compounds

The objective of this study was to test whether the results found for rhythmic irregularities in form of stress clashes and stress lapses in German could also be found in English. Moreover, the fact that rhythmically induced stress shifts operate leftwards in English provides a further advantage: As the shift occurs in the word preceding the shift-trigger, it is not yet rhythmically licensed when the shifted word is encountered. Thus, it is possible to disentangle lexical and rhythmical influences on language processing. Therefore an ERP study was conducted investigating the processing of English compounds either obeying or deviating from the RR.

It has been shown that rhythmic preferences shaped the English grammar and its prosodic structure and that the pursuit of rhythmic alternation heavily influences speech production and perception (Kelly, 1988; Kelly & Bock, 1988; Schlüter, 2005; Vogel et al., 1995; Tilsen, 2011; Breen & Clifton, 2011; Tomlinson et al., 2014). Moreover, the trochaic foot consisting of a strong-weak syllable pattern is the preferred structure in English (Shapiro & Beum, 1965; Selkirk, 1984; Dresher & Lahiri, 1991). Therefore, the application of the RR can be considered as an aspired strategy to avoid stress clashes and to turn the less frequent iambic weak-strong pattern into a trochaic one by stress reversal (e.g. *chamˌpagne ˈcocktails* → *ˌchampagne ˈcocktails*). However, several production and perception studies stated the optionality of its application as well as the possibility that stress shifts are not articulated but a perceptual repair strategy in order to perceive rhythmical alternations (e.g. Grabe & Warren, 1995; Tomlinson et al., 2014). Other authors argue that stress shifts apparently triggered by rhythmic factors are in fact just due to the tendency to generally place a pitch accent at the beginning of an intonational or phonological phrase (*Early pitch accent account*; Bolinger, 1958, 1965; Shattuck-Hufnagel, 1995).

The results of the phonetic analysis on the stimuli used in this study (see also Chapter 10.3.4) speak against these assumptions, showing that the speaker produced real stress shifts in the tested disyllabic words in potential clash contexts: phrases like e.g. *iˌdeal ˈpartners* were realised as *ˌideal ˈpartners*. This was obtained by reversing the F_0 pattern and an additional shortening of the final syllable. Hence, pitch and duration can be stated as the most important cues for the realisation of the RR. The results show that the RR is not only a perceptual repair strategy but also produced in (British) English. The same set of disyllabic nouns was realised with higher F_0 on the significantly longer final syllable in non-clash contexts (e.g. *iˌdeal traiˈnees*). This finding is important regarding the early pitch accent account, as it shows that higher pitch is not generally positioned on the first syllable in potential shift target words but in fact only when positioned adjacently to a strong syllable carrying primary stress.

Another proposition by Grabe and Warren (1995) regarding the lexical status of potential disyllabic stress shift targets (e.g. *thirteen*; *ideal*; *champagne*) claims that these words do not possess fixed lexical stress on the final syllable but that stress is assigned context-dependently. Thus, the first syllable is stressed in potential stress clash contexts and the final syllable in all other positions. This proposition should also be inspected within the present study.

Due to the clear articulatory stress shifts included in the stimuli, it was expected to find processing differences between rhythmically well-formed and ill-formed structures, as well as between the two deviation types, comparable to Study 2 on German. Moreover, the disentanglement of lexical and rhythmical influences on the nature of the reported negativity effect (LAN vs. N400), especially in stress lapse structures, should be explored. This intention is particularly promising in this study because of the aforementioned word order in phonological phrases including a potential stress shift item in English. The stress shift item precedes the trigger word, therefore its legitimacy is not clear when the shift is perceived (e.g. *ˌchampagne ˈcocktails*). The deviation from lexical stress can hence be investigated uncoupled from the rhythmical trigger of this shift and should evoke an N400 effect due to the more costly lexical retrieval process. If, however, the proposal of context-dependent stress assignment (Grabe & Warren, 1995) is correct, no N400 effect should be found. The perception of a stress shift raises the predictions regarding the rhythmical structure of the following word. Rhythmic deviations which can then be detected in the following word might be reflected by an LAN-like component as in Study 2. The present experiment can thus provide further insight into the question how rhythmic predictability and violations of these predictions influence language processing.

The design of stimuli, task and procedure was comparable to the design of Study 2 (for further details see also Chapters 8 and 10.3). The presented stimuli are given in an exemplar fashion in Table 2.

Condition	*Example*
Correct SHIFT	The ˌ**champagne** ˈ**cocktails** are very pricey.
Correct NO SHIFT	The **chamˌpagne deˈsserts** are very delicious.
CLASH	The **chamˌpagne** ˈ**cocktails** are very pricey.
LAPSE	The ˌ**champagne deˈsserts** are very delicious.
Filler correct	I like to **inˈvite** good friends.
Filler incorrect	*I like to ˈ**invite** good friends.

Table 2. Experimental Conditions and filler Items.

The results of the study provide important answers to the aforementioned research questions. First of all, important processing differences between shifted and unshifted words were found in form of a centro-parietal N400 effect. In line with previous findings, it most likely reflects the deviation from the correct lexical stress pattern. This result delivers clear evidence against the assumption that potential stress shift targets receive their stress pattern from context as assumed by Grabe and Warren (1995) and shows that these word types contain fixed lexical stress, as well. Moreover, this effect for the differential processing of shifted and unshifted word forms confirms that English listeners do not automatically perceive initial stress in potential stress shift targets. This is further complemented by the behavioural data, showing that stress clashes are evaluated as least natural. If potential stress shift items were automatically and unconsciously repaired, stress clash structures should not be perceived as prosodically unacceptable but as equally acceptable as structures containing real stress shifts.

Regarding the processing of stress clash and stress lapse structures in comparison to rhythmically well-formed structures, the obtained results show that both deviation types elicited a pronounced late positivity effect, again reflecting the resolvability of the given task to evaluate the prosodic naturalness of the overall sentence (cf. Study 2). Differing from the results found for German rhythmical deviations, the amplitude is more pronounced for lapse as well as for clash structures in comparison to their correct control conditions. This suggests that the evaluation was comparably resolvable for both deviation types and that stress clashes and stress lapses are thus equally ill-formed and unacceptable for English listeners.

The detection of the rhythmically deviation types is again reflected by different components for stress clashes and stress lapses. Stress lapses elicited an early negativity comparable to the LAN-like effect found in Study 2 for stress clashes. This effect is interpreted to reflect the detection of irregularity in the rhythmical structure, i.e. the violation of the PRA. Since the preceding word contained a stress shift, a following unstressed syllable completely contradicts the expectations raised by this preceding shift which is then rhythmically unlicensed in the lapse context. The recognition of this double deviation is mirrored by this early negative component which is generally described as a reflection of an error-detection mechanism (cf. Koelsch et al., 2000; Geiser et al., 2009; Schmidt-Kassow & Kotz 2009a; Rothermich et al., 2010, 2012).

The same component was expected to be found for English stress clashes. However, the negativity effect elicited by stress clashes was not statistically significant, possibly overridden by the occurrence of a preceding enhanced positivity effect elicited by the clash condition. This positivity is evoked by the strong initial syllable carrying primary stress, leading to the stress clash (e.g. *cham*ˌ*pagne* ˈ*cocktails*). It most likely reflects the unexpected deviation of signal properties as the preceding final stress fostered the expectation of an unstressed syllable to follow. Due to the pitch information of the strong syllable, phonetic as well as rhythmical expectations are violated, resulting in a P200 component which is described as a reflection of unfulfilled predictions in auditory stimuli, especially influenced by the pitch contour of initial syllables (Friedrich et al., 2001; Böcker et al., 1999; Neuhaus & Knösche, 2006; Marie et al., 2011).

The present study demonstrates that English listeners are very sensitive to rhythmic deviations violating the (optional) RR. It could be shown that rhythmical expectancies can be built up by one single word, even when the overall sentential context does not contain strong rhythmical cues about the incoming speech signal. The N400 effect found for stress shifted words documents that these words in fact contain fixed lexical stress, stored in the mental lexicon. The fact that an N400 was found for lexical stress violations on the one hand and an LAN-like component for rhythmical deviations on the other hand, helps to further define the nature of these components and contributes to their characteristic features.

5 How information structure influences the processing of rhythmic irregularities: ERP evidence from German phrases

The two ERP studies on deviations from the RR in German and English illustrated the importance of rhythmical as well as lexical well-formedness for language processing. The components obtained for these two deviation types represent their functional processing: Lexical stress deviations result in an N400 effect due to the higher costs for lexical retrieval while rhythmical deviations elicit an LAN-like effect reflecting the error detection in the rhythmical structure. These findings are in line with previous studies on lexical and rhythmical processing (Knaus et al., 2007; Magne et al., 2007; Schmidt-Kassow & Kotz, 2009a; Rothermich et al., 2010, 2012).

However, in the study on German phrasal verbs (Study 2, see Chapter 3), an N400 effect was found for lexical violations which also contain a rhythmical deviation, i.e. in stress lapse structures (e.g. *Sie soll die ˈFeier abˌsagen* 'She is supposed to cancel the party'), but not if the deviation from lexical stress is rhythmically well-formed (e.g. *Sie soll den Terˈmin abˌsagen* 'She is supposed to cancel the appointment'). In contrast, maintained lexical stress leading to a rhythmical irregularity is perceived as unacceptable and erroneous. The pursuit of rhythmical well-formedness hence seems to be the triggering factor for the effects found but is reflected by two different components. In order to further investigate the two negative components found in Study 2, a follow-up study was conducted which used the identical set of auditory stimuli but whose design was adapted and extended in order to answer this and further questions concerning the components found.

To verify that the effect found for stress lapses is in fact an N400, the critical phrasal verb was presented visually prior to the auditory presentation of the critical stimuli, integrated into a wh-question. Other studies were able to show that the N400 is absent in this design set-up due to the accomplished lexical retrieval when the deviating structure is presented auditorily (cf. Knaus et al., 2007; Domahs et al., 2015). If the negativity effect elicited by stress lapses mainly reflects lexical retrieval costs, it should be absent in the present study.

The stimuli in form of different types of question-answer pairs are illustrated in Table 3 (see also Chapter 10.4).

Condition	*Example*
Wh question (presented visually)	**WAS** soll sie **absagen**? *What is she supposed to cancel?*
Correct SHIFT	Sie soll den **Terˈmin abˌsagen**, wie besprochen. *She is supposed to cancel the appointment, as discussed.*
Correct NO SHIFT	Sie soll die **ˈFeier ˌabsagen**, wie besprochen. *She is supposed to cancel the party, as discussed.*
CLASH	Sie soll den **Terˈmin ˌabsagen**, wie besprochen. *She is supposed to cancel the appointment, as discussed.*
LAPSE	Sie soll die **ˈFeier abˌsagen**, wie besprochen. *She is supposed to cancel the party, as discussed.*
Filler type questions (presented visually)	Soll sie das **ANGEBOT reduzieren**? *Is she supposed to reduce the offer?*
Filler correct	Sie soll die **ˈPreise reduˌzieren**, wie immer. *She is supposed to reduce the prices, as usual.*
Filler incorrect	*Sie soll die **ˈPreise reˌduzieren**, wie immer. *She is supposed to reduce the prices, as usual.*

Table 3. Experimental conditions and filler items. Words in bold letters indicate the critical phonological phrase, words in capital letters indicate the word bearing nuclear stress.

The additional presentation of a wh-question included two further advantages. First, due to the included shift of attention from the overall sentence (≙ wide focus as in Studies 2 and 3) to the object noun phrase which replaces the wh-phrase in the following answer sentence (≙ narrow focus), the critical phrasal verb is standing in post-focus position. This way it could be investigated whether the rather subtle rhythmical deviations are still detectable if unfocused. If the early negativity elicited by stress clashes is indeed an LAN-like component, it should be evoked irrespective of attentional focus (cf. Rothermich et al., 2010) and thus also be found in the present study. If the negativity found for stress lapses is exclusively generated by the contained rhythmic deviation, after all, it should be elicited in this study, as well.

Second, the manipulation of focus can clarify the task-sensitivity of the late positive component found in the preceding studies, as this component is described as being only detectable and assessable if focus is directed towards the critical structure (e.g. Knaus et al., 2007; Magne et al., 2007; Schmidt-Kassow & Kotz, 2009b; Marie et al., 2011). Information which is not perceived in focus position is less attended to and hence processed less accurately (Cutler & Fodor, 1979; Birch & Rayner, 1997; Wang et al., 2011, 2012; Domahs et al., 2015). Therefore, only very salient violations can be detected in non-focus position. The late positive component is therefore expected to be absent in the present study.

The data of this follow-up study in fact reveal a negativity effect for stress clashes in the identical time window as in the previous study (see Figure 1). In contrast to the preceding study, no negativity effect was found for structures containing stress lapses (see Figure 2). These results confirm and strengthen the interpretation for the two components reflecting different processes for these two deviation types.

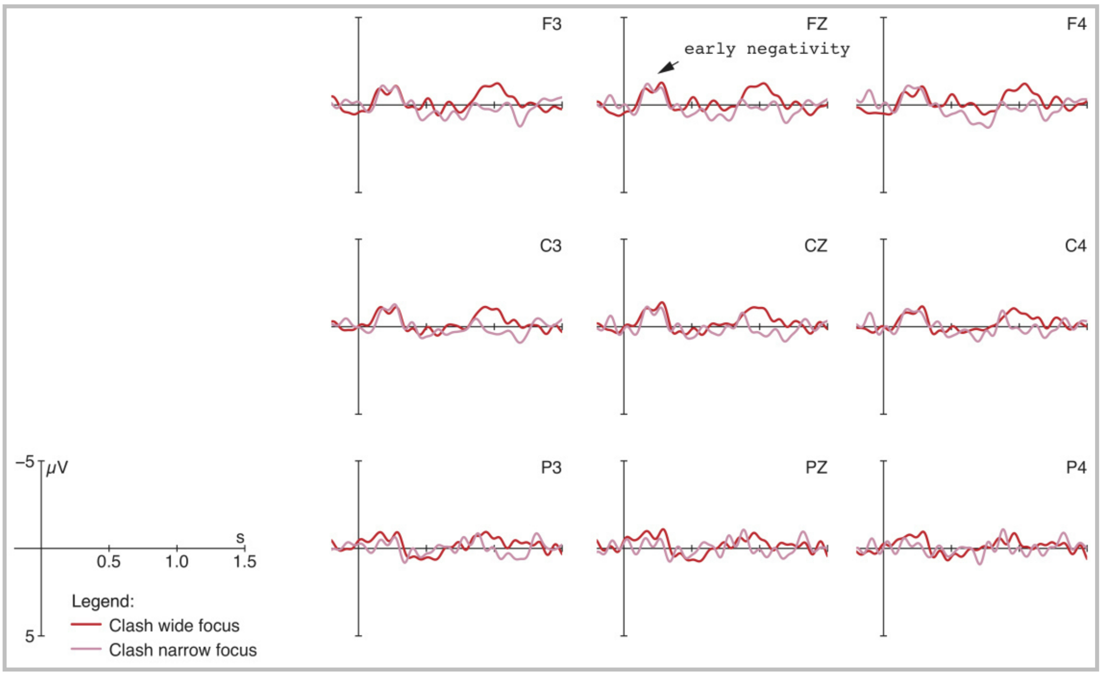

Figure 1. ERP difference waves show the similarity in latency and topography of the negativity effect found for CLASH and control condition SHIFT in wide focus (red line) and narrow focus (pink line).

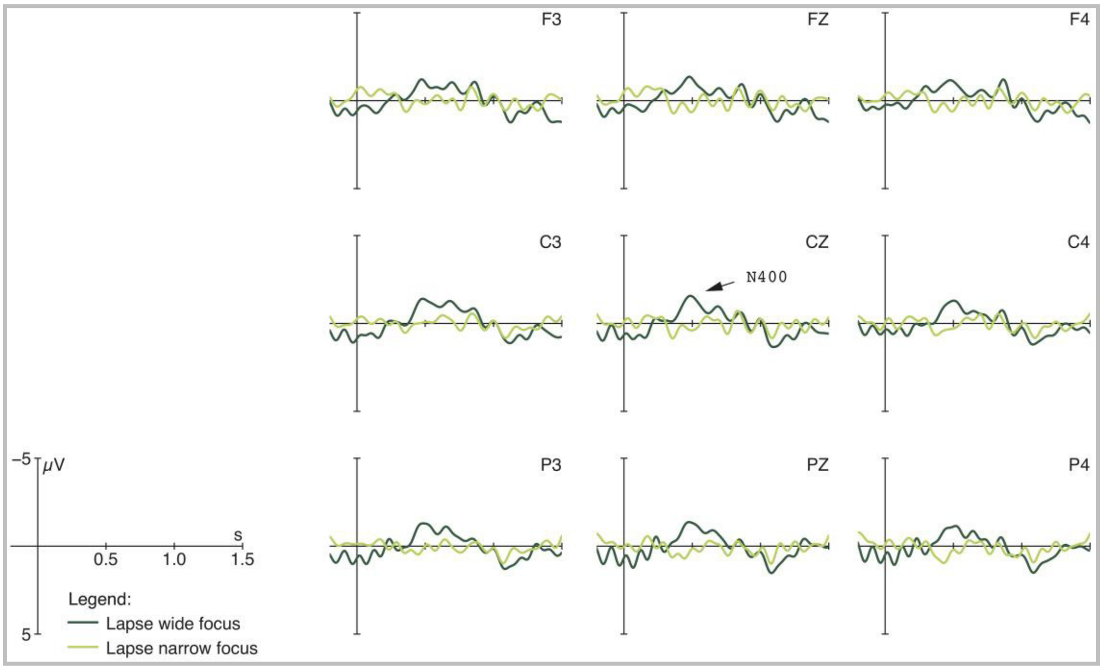

Figure 2. ERP difference waves show the difference of the negativity effect found for LAPSE and control condition NO SHIFT in wide focus (dark green line) and the missing negativity effect in narrow focus (lime green line).

Although the listeners' attention was redirected towards the semantics of the preceding noun phrase, an early anterior negativity was found for stress clashes in comparison to their correct control condition SHIFT. In contrast, the behavioural data show that sentences containing clashes were evaluated as equally natural as the control sentences. This illustrates that the perception and detection of this rhythmical deviation type proceeds rather unconsciously and automatically and supports the component's independency from attention and focus on the rhythmical structure.

Due to the preceding visual presentation of the critical verb, higher costs for lexical retrieval could be excluded as a factor for a potential negativity elicited by stress lapses. The absence of a negativity effect for this deviation type supports the assumption made in the preceding study that the negativity effect found there is in fact an N400 caused by increased costs in lexical retrieval. It thus seems as if the rhythmical deviation alone is not salient enough in order to be detected if attention is not explicitly directed towards the metrical structure.

As expected, no late positive component was found for the critical conditions in this study, supporting the description of this component as being task-sensitive as well as attention-sensitive. Regarding the processing of the subtle rhythmic deviations, this result suggests that they are less perceivable and detectable when presented in non-focus position and attention is additionally directed away from them. The evaluation of the sentences including rhythmical deviations is thus equally unproblematic as the evaluation of the well-formed sentences. This in line with the behavioural data which show that all conditions are generally evaluated as more natural in comparison to the evaluation data of the previous study. In contrast, the filler items which contain clear lexical stress violations independently from a rhythmical purpose elicited an enhanced late positivity. Hence, these violations were salient enough to be recognised. This shows that an attentional shift makes the subtle rhythmic deviations investigated in this study even less salient and supports the assumption that only clear and salient errors result in a late positive component (cf. Wang et al., 2012; Domahs et al., 2015).

The present study further disentangles the influence of rhythmical and lexical deviations in stress clash and stress lapse structures and shows that both deviation types are processed differently. This was done by adopting the necessary design set-up by Knaus et al. (2007) and Domahs et al. (2015) to evoke or suppress an N400 effect. The data confirm that the two negativity effects measured in the preceding study reflect in fact two distinct processes. With respect to rhythmic irregularities in form of stress clashes, it shows the brain’s ability to detect them automatically, independently of attention, even if the critical deviation is rather subtle and embedded into a rhythmically natural, i.e. not strictly alternating context. However, the results also illustrate that cognitive responses to subtle rhythmic deviations are affected and reduced by an attentional shift towards the meaning of another item included in the presented structure, making them less salient and perceptible. This study thus extends previous findings as it shows that an attentional shift induced by information structure influences not only the degree of semantic (Wang et al., 2011), syntactic (Wang et al., 2012) and lexical (Domahs et al., 2015) processing but also the depth of rhythmic processing.

6 Quantity counts: evidence from an ERP study on rhythmic deviations in German trisyllabic and quadrisyllabic compounds

The last study conducted within the scope of this dissertation concentrates once more on the processing of stress clashes and lapses in German. This time, noun compounds instead of phrasal verbs were used as stimuli. This was done in order to investigate possible processing differences of violations from the RR beyond word boundaries (as investigated in Study 2) and within word boundaries. Moreover, due to the results obtained in the perception study (Study 1, see Chapters 2 and 8) on this type of compounds, the usage of A(BC) noun compounds provides the possibility to look further into the role of the number of syllables and to see whether differences in syllable numbers also affect their processing. Due to the topographic differences of the negativity effects obtained for the two rhythmical deviation types in Study 2 (i.e. a fronto-central negativity for stress clashes vs. a centro-parietal negativity for stress lapses; see Chapters 3 and 8) another aim of this study was to shed further light on the distribution and thus the nature of these components. Therefore, ERPs were recorded from 64 electrodes in this study instead of 32 electrodes as in the previous ERP studies. The increased number of electrodes offers the possibility to locate the topographic distribution of the separate components even more precisely.

Since the perception study described in Chapter 2 as well as the perception study by Wagner and Fischenbeck (2002) showed that stress shifts and stress clashes are more easily perceived in quadrisyllabic than in trisyllabic compounds, 30 A(BC) compounds with a monosyllabic C constituent (e.g. *Haupt*$_A$*-bahn*$_B$*-hof*$_C$ 'main station') and 30 A(BC) compounds with a disyllabic C constituent (e.g. *Fach*$_A$*-hoch*$_B$*-schu*$_C$*-le*$_C$ 'technical college') were used as stimuli in the experiments of the present study (see Table 4). It was hypothesised that rhythmical deviations in longer compounds are detected more easily due to their foot structure in comparison to shorter compounds. This could be seen in clearer evaluation ratings in the behavioural data and in earlier and more pronounced ERP effects for the rhythmical deviations in the compounds consisting of more syllables. Moreover, results of an additional reaction time study on the identical set of compounds should show faster reactions for longer compounds.

Condition	Example
Correct SHIFT monosyllabic C	Sie soll den neuen ˈ**Hauptbahnˌhof** ansehen *She is supposed to view the new main station.*
Correct SHIFT disyllabic C	Sie soll die neue ˈ**Stadtsparˌkasse** umbauen. *She is supposed to rebuild the new municipal savings bank.*
Correct NO SHIFT monosyllabic C	Sie soll den neuen ˈ**Güterˌbahnhof** ansehen. *She is supposed to view the new goods station.*
Correct NO SHIFT disyllabic C	Sie soll die neue ˈ**Landesˌsparkasse** umbauen. *She is supposed to rebuild the new Landessparkasse.*
CLASH monosyllabic C	Sie soll den neuen ˈ**Hauptˌbahnhof** ansehen *She is supposed to view the new main station.*
CLASH disyllabic C	Sie soll die neue ˈ**Stadtˌsparkasse** umbauen. *She is supposed to rebuild the new municipal savings bank.*
LAPSE monosyllabic C	Sie soll den neuen ˈ**Güterbahnˌhof** ansehen. *She is supposed to view the new goods station.*
LAPSE disyllabic C	Sie soll die neue ˈ**Landessparˌkasse** umbauen. *She is supposed to rebuild the new Landessparkasse.*
Filler correct	Sie soll die neue ˈ**Armbanduhr** einstellen. *She is supposed to set the new wrist watch.*
Filler incorrect	*Sie soll die neue **Arm**ˈ**banduhr** einstellen. *She is supposed to set the new wrist watch.*

Table 4. Experimental Conditions and filler Items.

All compounds, either obeying or deviating from the Rhythm Rule, were presented in two consecutive EEG sessions with different task settings. Implicit and explicit tasks were created in order to further inspect the critical role of attention and task relevance of the components obtained in the previous studies on German phrasal verbs. It was expected that components reflecting automatic processes should not be affected by different task settings and therefore be elicited in both sessions irrespective of an implicit or explicit task, whereas attention-controlled components like the P300 (labelled as LPC in the previous studies) should only be found in the session including an explicit task.

In the first experimental session, all stimuli were presented without the evaluation task used in the previous studies (see Chapters 3 – 5) but with an implicit task directing the participants' attention away from the prosodic structure of the sentences. Participants were instructed to listen to the presented sentences, to try to memorise as many words from the sentences as possible and to tick them off on a word list including 10 words in total. This list was handed out in the short breaks between experimental blocks, i.e. after the presentation of approximately 60 sentences each. All participants were told that this experiment investigated the unconscious memorability of words and addressed the natural memory capacity. This way, it was ensured that the participants listened to each sentence without paying attention to the metrical structure of the presented sentences.

Regarding the early negativity obtained for clash structures in Study 2, related studies were able to show that this negativity is elicited for rhythmical irregularities irrespective of a matching rhythmical task, i.e. independent of attentional focus towards the rhythmical structure (Schmidt-Kassow & Kotz, 2009a; Rothermich et al., 2010). These findings confirm the independent processing of metric and rhythmic structures during speech processing and suggest that this negativity should also be elicited in the present study for clash sentences. This hypothesis is further supported by the results for stress clashes in the follow-up study on German phrasal verbs (Study 4), i.e. the fact that an attentional shift did not suppress this effect. However, the participants' attention was at least directed in the general direction of rhythm and meter, especially in the first study. The present study should therefore clarify whether even very subtle irregularities can be detected automatically irrespective of task requirements and any attention to prosody.

With respect to the N400 effect, previous studies showed that lexical retrieval is hindered by deviating stress patterns irrespectively of implicit or explicit task settings (Friedrich et al., 2004; van Donselaar et al., 2005; Knaus et al., 2007; Magne et al., 2007). These findings suggest that lexical retrieval is an automatic process. Hence, this component should also be elicited when an implicit task is used and it is expected to find an N400 effect for stress lapses but still no N400 effect for rhythmically licensed stress shifts. This task setting thus helps to investigate the N400's task-dependency. This is even more interesting as this question could not be addressed in Study 4 due to the visual presentation of the critical phrasal verb.

The late positive component found in Studies 2 and 3 is expected to be absent in the first experiment as the task setting does not involve an evaluation process (cf. Knaus et al., 2007; Magne et al., 2007; Domahs et al., 2008, 2009, 2013a; Schmidt-Kassow & Kotz, 2009b; Marie et al., 2011).

To compare the impact of an implicit and a more explicit task on the identical set of stimuli, the second experimental session included the same evaluation task used in Studies 2 and 3 (cf. Chapters 3 and 4). This session was undertaken at least four weeks after the first session had been accomplished as the same group of participants took part in both sessions. Only participants that completed both experimental sessions were included for data analysis.

The carrier sentences for the critical compounds were again kept as natural as possible, i.e. not strictly rhythmically regular. As filler items, correctly and incorrectly stressed forms of trisyllabic (AB)C noun compounds with primary stress on the initial syllable (e.g. *Arm*$_A$-*band*$_B$-*uhr*$_C$) were included (see Table 4 and Chapter 10.5). For the clear lexical stress violations in these sentences, an N400 effect was expected to be found in both sessions. All stimuli were spoken by the same female native speaker who had also recorded the stimuli for Study 2. This way, it was possible to control for potential speaker-dependent effects. The stimulus preparation procedure was kept identical to the one used in the previous studies (for more details see Chapter 8).

A phonetic analysis (see Chapter 10.5.6) on the different compound types revealed that the speaker produced real stress shifts in compounds with a monosyllabic C constituent in the SHIFT condition by shortening the initial syllable of the B constituent and lengthening the syllable of the C constituent. Hence, compounds like e.g. ˈ*Haupt*ˌ*bahnhof* were realised as ˈ*Hauptbahn*ˌ*hof* ('main train station'). In compounds with a disyllabic C constituent, the syllable of the B constituent in shift condition was significantly shorter than the B constituent in non-shift condition but not significantly shortened in comparison to the first syllable of the C constituent. Hence, the acoustic impression of a stress shift was induced by duration levelling. This impression was strengthened by higher intensity on the first syllable of the C constituent in shifted compounds (e.g. ˈ*Stadtspar*ˌ*kasse*) in comparison to the first C constituent syllable in unshifted compounds (e.g. ˈ*Landes*ˌ*sparkasse*). The findings on shorter compounds are in line with the acoustic analyses of the previous studies and support the importance of syllable duration as a decisive factor in the realisation of the RR. The results for longer compounds further illustrate the variability of strategies in order to avoid stress clashes in different word structures.

The overall preliminary results show that the predictions are only partially fulfilled. The behavioural data reveal that stress clashes were evaluated as significantly less natural than the control condition only in quadrisyllabic but not in trisyllabic compounds. This result shows that stress clashes are indeed easier to detect in longer compounds. Regarding the ERP results for stress clashes, an early negativity effect was found for this deviation type in trisyllabic as well as in quadrisyllabic compounds when attention was generally directed towards the prosodic structure of the sentences heard. The number of syllables thereby had an influence on the component's onset: Stress clashes in quadrisyllabic compounds were detected faster and therefore lead to an earlier onset of the negativity effect in comparison to trisyllabic compounds. Surprisingly, the early negativity was absent in the results from session 1. According to previous studies, rhythmical irregularities should be found and processed irrespectively of attention and task settings. Moreover, it was also found for stress clashes in Study 4 (see Chapter 5) despite an attentional shift. In these studies, however, clear rhythmical violations were presented in strictly regular structures (cf. Schmidt-Kassow & Kotz, 2009a; Rothermich et al., 2010) or attention was at least supposed to be directed towards prosodically well-formedness by the given task (cf. Study 4, Chapter 5). This leads me to the assumption that stress clashes which are a potentially occurring structure in German and then presented embedded in a rather rhythmically natural context, are too subtle rhythmical deviations in order to elicit an early negativity effect when attention is completely directed away from the prosodic structure. Thus, the deviation's saliency might play a role for the elicitation of this negative component in different task settings.

Stress lapses elicited an N400 in comparison to the control condition in both sessions, i.e. irrespective of task and attention. This is in line with the prediction based on findings from previous studies (cf. Knaus et al., 2007; Magne et al., 2007) and supports this component's task-independency. Thus, rhythmically unlicensed stress shifts are detectable irrespectively of attention. Regarding the factor number of syllables, the results for stress lapses show an earlier effect onset in compounds consisting of more syllables in session 2.

An enhanced late positive component was found for stress lapses in the second session, again showing an earlier onset of the effect for longer compounds. However, no significant differences could be found in the positive-going grand average waves for stress clashes and their control condition. This suggests that the given evaluation task is in fact reflected by a late positive component, but that there is no significant difference effect between stress clashes and their correct control condition. It thus seems as if the detection of this form of deviation is either too hard to detect and therefore eliciting a reduced positivity or not detected at all and thus no difference can be found between the grand averages of the ill-formed structures and the control structures. Support for the latter interpretation comes from the aforementioned behavioural data which show that there is no significant difference in the evaluation of sentences containing trisyllabic compounds with stress clashes and trisyllabic compounds containing stress shifts. Only in quadrisyllabic compounds, sentences containing stress clashes are evaluated as less natural than stress shifts. In this case, the number of syllables does in fact help the evaluation process but it is not reflected in a late positivity effect, unlike the findings for stress lapses. This asymmetric result of the ERP data has to be further examined and will be discussed in more detail in the upcoming research article on this study. An overview of the preliminary ERP results found for both task setting types and the main comparisons CLASH & SHIFT and LAPSE & NO SHIFT is given in Table 5.

Experimental design	*Comparison*	*Negativity*	*Positivity*	*Critical compounds*
Memory task (Session 1)	CLASH & SHIFT monosyllabic C	180 – 380 ms n.s.	---	ˈHauptˌbahnhof vs. ˈHauptbahnˌhof
	CLASH & SHIFT disyllabic C	180 – 380 ms n.s.	900 – 1100 ms *(right anterior)	ˈStadtˌsparkasse vs. ˈStadtsparˌkasse
	LAPSE & NO SHIFT monosyllabic C	350 – 650 ms *	1100 – 1300 ms **	ˈGüterbahnˌhof vs. ˈGüterˌbahnhof
	LAPSE & NO SHIFT disyllabic C	---	---	ˈLandessparˌkasse vs. ˈLandesˌsparkasse
Evaluation task (Session 2)	CLASH & SHIFT monosyllabic C	250 – 500 ms ** (left posterior)	---	ˈHauptˌbahnhof vs. ˈHauptbahnˌhof
	CLASH & SHIFT disyllabic C	180 – 380 ms *	1100 – 1350 ms n.s.	ˈStadtˌsparkasse vs. ˈStadtsparˌkasse
	LAPSE & NO SHIFT monosyllabic C	350 – 650 ms *	1100 – 1300 ms ***	ˈGüterbahnˌhof vs. ˈGüterˌbahnhof
	LAPSE & NO SHIFT disyllabic C	250 – 650 ms *	750 – 1150 ms *	ˈLandessparˌkasse vs. ˈLandesˌsparkasse

Table 5. Different types of ERP effects in different time windows for the critical comparisons in both task setting types. Statistical significance is indicated by * ($p < .05$), ** ($p < .01$), *** ($p < .001$). Underlined words (bahnhof) indicate the critical word's onset for average calculation.

So far, the preliminary results show that the number of syllables in fact influences the detection and perception of rhythmical irregularities: Stress lapses and stress clashes in longer compounds are perceived more easily, i.e. the brain reacts faster to deviations in compounds that contain a larger number of syllables. This is further supported by the results of the reaction time study which reveals a main effect for the factor syllable number as well as a significant interaction of the factors syllable number and well-formedness. It shows that rhythmically deviating words can be evaluated faster in comparison to their well-formed control compounds the more syllables are available for this evaluation process. These findings thus complement the results of the production and perception study of this thesis.

7 Conclusion and future directions

The research conducted within the scope of this doctoral thesis supports and complements the findings of previous studies and furthermore shows that the Rhythm Rule plays an important role in stress-timed languages like German and English. With regard to the acoustic correlates of the Rhythm Rule, the production data reveal that there are various possibilities in producing rhythmically regular structures, either by levelling or shifting secondary stress. Moreover, the implementation is also language-dependent. For German, syllable duration was determined as the decisive factor. In order to obtain a perceptible shift, the potentially clashing syllable is shortened and the duration is transferred to a following stressable syllable, leading to a real reversal of prominence. For English, on the contrary, reversing the prominence of F_0 and an additional shortening of a potentially clashing syllable leads to perception of stress shifts.

The overall data reveal neuronal reflections of rhythmical processes during language processing. They confirm that rhythmically regular structures are advantageous as regularity is an important factor for the ability to build up predictions about the prosodic structure of the following speech signal. The conducted ERP data also give an important insight into the weighting of lexical violations and rhythmical deviations. Normally, deviations from lexical stress lead to higher processing costs. However, no reflections of these costs are found when these shifts are rhythmically licensed. In contrast, compliance with lexical stress leads to more costly processing if this adherence leads to a deviation from rhythmic regularity. Thus, deviation from lexical stress seems to be acceptable when this results in a harmonious rhythmical structure. Regarding the different types of rhythmic irregularities, either containing an additional lexical stress deviation or not, the ERP studies on German were able to show that stress clashes and stress lapses are in fact processed differently as they are reflected by two distinct negative components, due to the double violation (lexical and rhythmical deviations) in stress lapse structures versus rhythmical deviation only in stress clash structures.

The results of the ERP study on English compounds shed further light on the lexical status of potential targets of the Rhythm Rule. The finding of an N400 effect for stress shifted words, reflecting higher costs in lexical retrieval, are in opposition to the proposition that these words might not possess lexical default stress but context-dependent stress. Moreover, the results from this study further show that these shifts have to be rhythmically licensed in order to be acceptable. This is in line with the results from the German ERP studies, complementing and supporting the importance of rhythmical compliance in stress-timed languages.

Overall, the results of the ERP and the reaction time studies could show that the processing of rhythmically irregular structures is associated with higher costs as they are processed differently from well-formed structures. This is not only true for salient violations but also for rather subtle and allowed rhythmical deviations, even in natural contexts. These findings contradict the proposition that rhythmical regularity as well as the Rhythm Rule can be ascribed to a purely perceptual repair phenomenon. The compliance with rhythmical predictions and thus the application of the Rhythm Rule is beneficial and desirable for language processing. The results therefore show that the phenomenon of rhythmically induced stress shifts plays indeed an important role in the processing of English and German and that English as well as German listeners are sensitive to rhythmic deviations even if these are allowed forms in the respective language.

Due to the optionality of the Rhythm Rule, the analysis of more natural production data is of particular interest for future investigation. By inspecting spontaneous and thus more natural speech with regard to rhythmic regularity, the articulatory reality of the RR might be illuminated. To this end, a corpus study on the audio edition of the Spoken British National Corpus (Coleman et al., 2012) would enable us to gain deeper insight in which way and how regularly the Rhythm Rule is actually applied in the English language.

Since rhythm is a key element in language as well as in music and both domains follow the Principle of Rhythmic Alternation, future studies are planned to further highlight the relationship between music and language with regard to rhythmic processing. As a first step, a follow up study on the German stimuli (i.e. phrasal verbs & compounds) with musicians as participants will be realised in the near future (in cooperation with Sonja Kotz, Richard Wiese and Ulrike Domahs).

Based on the findings by previous studies which showed an increased sensitivity of musicians to even subtle deviations in rhythmic and metric structures in comparison to non-musicians (cf. Koelsch et al., 2002; Schön et al., 2004; Tervaniemi et al., 2009; Marie et al., 2011), this study should deliver a finer-grained picture of the processing of these subtle rhythmic deviations in language processing. It can further give a deeper insight into the influence of musical expertise on language processing, i.e. the transfer of training effects on musical rhythm to language prosody.

With regard to the processing of stress clash structures in German, it was assumed that their particular difficulty might arise from the tension of lexical stress compliance and the concurrent rhythmical deviation. It was hypothesised that stress clashes are not directly and consciously recognised as deviations, leading to higher processing costs. Due to the fronto-central occurrence of the early negative component for stress clashes, it was assumed that they are kept longer in the auditory working memory for inspection and evaluation, which is described to be located in the fronto-central area (e.g. Kaiser & Lutzenberger, 2004; Eulitz & Obleser, 2007). Support for this assumption comes from a study using the functional magnet resonance imaging (fMRI) method on different types of deviations from the prosodic foot structure in German nouns (Domahs et al., 2013b). It showed that mild prosodic violations lead to a stronger activation in frontal areas such as the inferior frontal gyrus (IFG), reflecting longer retention in the working memory due to higher demands for deviation detection in comparison to more severe violation types (Domahs et al., 2013b). In order to further test this localisation hypothesis for subtle rhythmic deviations, a follow up study using the fMRI technique has just recently been conducted (in cooperation with Katerina Kandylaki, Arne Nagels, Tilo Kircher, Ina Bornkessel-Schlesewsky, Ulrike Domahs and Richard Wiese). The high spatial resolution of this method makes it possible to review this hypothesis and to further investigate the connection between the pronounced ERP effects in certain regional areas and the actual localisation of rhythmical processing in the brain. This way, the two distinct processes reflected by different ERP components for stress clashes and stress lapses can be further disentangled and located.

8 Research articles

1. Bohn, K., Wiese, R., Domahs, U. (2011). The status of the Rhythm Rule within and across word boundaries in German. *Proceedings of the 17th International Congress of Phonetic Sciences,* 332 – 335.

2. Bohn, K., Knaus, J., Wiese, R., Domahs, U. (2013). The influence of rhythmic (ir)regularities on speech processing: evidence from an ERP study on German phrases. *Neuropsychologia, 51*(4), 760 – 771.

3. Henrich, K., Alter, K., Wiese, R., Domahs, U. (2014). The relevance of rhythmical alternation in language processing: An ERP study on English compounds. *Brain and Language, 136*, 19 – 30.

4. Henrich, K., Wiese, R., Domahs U. (2015). How information structure influences the processing of rhythmic irregularities: ERP evidence from German phrases. *Neuropsychologia, 75*, 431 – 440.

THE STATUS OF THE RHYTHM RULE WITHIN AND ACROSS WORD BOUNDARIES IN GERMAN

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ABSTRACT

German as well as other languages show a preference for rhythmical alternation, a phenomenon mostly discussed as the Rhythm Rule. This rule has mainly been explored on the word level, although it can also occur on a phrasal level. This study shows that it operates regularly on both levels. In contrast to its assumed appearance in English, the RR exists not only on the perceptual level but is also used as an articulatory strategy to avoid rhythmically disharmonic stress clashes. Syllable duration turned out to be the main indicator for the perception and production of stress shifts. The results of this study suggest that the RR plays an important role in German prosodic phonology.

Keywords: Rhythm Rule, stress perception, Metrical Phonology, acoustic correlates of stress shift, German stress clash environments

1. INTRODUCTION

Metrical phonology deals with a phenomenon which is entitled as Rhythm Rule (RR) [5]. This rule expresses that adjacent stressed syllables have to be separated from each other in order to avoid a so-called stress clash. Therefore, the RR can operate in two different ways: Either by shifting the weaker of the involved stresses onto another stressable syllable (Reversal Analysis: RA) or by destressing of the weaker syllable (Deletion Analysis: DA) [8]. Both options obtain a rhythmically alternating sequence of stressed and unstressed syllables. Thus, the pursuit of rhythmically well-formedness seems to motivate the application of the RR in different languages, concededly in varying degrees. According to the theory, the RR operates mainly in German compounds, but can also trigger stress shifts on a phrasal level [4, 10] (see Figure 1).

Since the RR is described as an optional process, the aim of this paper is to explore possible differences in its application on word and phrasal level. It is further investigated whether its occurrence is a purely perceptual phenomenon or reflected by phonetic alternations in German speech production. These questions seem to be of major importance since previous studies [6, 9] do not provide a definitive answer.

Figure 1: Application of the RR in German compounds (a) and phrases (b).

	1 2	RR	1 3 2	
a)	**Bahnhof**	→	**Hauptbahnhof**	
	1 2	RR	1 3 2	
b)	**absagen**	→	**Termin absagen**	

2. BACKGROUND AND PREVIOUS STUDIES

The phenomenon of the RR was mostly investigated on English data. These studies showed that the dominant form of the RR seems to be the DA, i.e. although a proper stress shift can be perceived by listeners, there is no acoustic evidence which speaks for a real shift of prominence within a potential stress shift item [2, 8]. Thus, the clash context rather leads to a stress reduction, i.e. a shortening of the duration and a lowering of F0 of the affected syllable [8]. Although previous studies do not fully agree on matters of the realization of the RR and its acoustic correlates, they all show that stress shifts are regularly perceived by English listeners. Hence, the RR plays an important role in English phonology. For German on the contrary, the occurrence and importance of the RR is not conclusive so far. While [6] classifies the RR as a regular albeit purely perceptual phenomenon, the study of [9] showed that stress shifts are not only perceived but also produced in German compounds. However, they conclude that its application is rather the exception than the rule and therefore not as important as in English [9]. The cited studies investigated exclusively compounds. However, the RR's appearance is also described beyond external word boundaries, i.e. on a phrasal level [4, 7, 10] (cf. Figure 1b). The present study extends the investigation of the importance of the RR and its nature to this phrasal level and tries to find experimental support for the hypothesis that the phenomenon of a rhythmically motivated stress shift operates within and beyond word boundaries not only on a perceptual but also on a production level.

3. STUDY 1: PERCEIVED STRESS DISTRIBUTION IN STRESS CLASH ITEMS

A production and perception study was performed in which listeners were asked to evaluate the position of primary, secondary and tertiary stress in different contexts of potential stress clash environments. The crucial question was whether the presence of clashing adjacent syllables across word boundaries affects the distribution of primary and secondary stress in the same way as within words.

3.1. Method

As stimuli, we chose phonological phrases consisting of a disyllabic noun followed by a three-syllable phrasal verb which is initially stressed when uttered in isolation (e.g. *ábsagen* 'to cancel'; ≙potential shift target). The noun preceding the target is either stressed on its first (e.g. *Féier* 'party'; ≙non-clash context) or on its final syllable (e.g. *Termín* 'appointment'; ≙clash context). Thus, the clash-context noun triggers a stress shift in the following phrasal verb. In total, four phrases were tested per condition. Additionally, 11 A(BC)-compounds of the stimuli investigated in [9] were chosen. All A- and B-constituents of these compounds are monosyllabic, whereas the C-constituent of seven compounds consists of two syllables. In these cases, the final syllable contains an unstressable schwa-vowel (e.g. *Stadt-spar-kasse:* /ʃtat.ʃpaː r.ka.sə/). In all stimuli containing a clash context, the secondary stress should shift rightwards onto the next possible syllable, i.e. secondary and tertiary stress should undergo a rhythmic reversal (cf. Figure 2).

Figure 2: Stress clash and expected stress shift in the used stimuli.[1]

a) phrasal level

```
     x                      x
   *x *x                    x     x
  x  x  x x x            x  x   x x x
 Termin absagen  →   Termin absagen
  w  s   s w              w  s   w s
```

b) word level

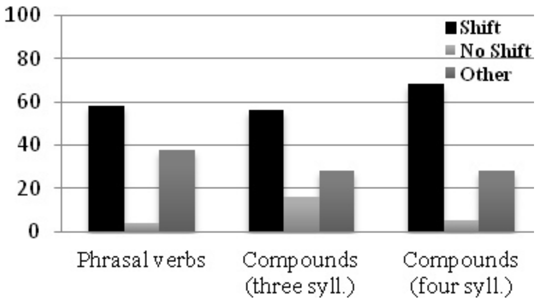
```
  x                          x
 *x     *x                   x        x
  x      x      x            x    x   x
 Haupt_A-bahn_B-hof_C  →  Haupt_A-bahn_B-hof_C
  s      s      w            s    w   s
```

All stimuli were embedded into different carrier sentences. For the compounds, their original newspaper context was chosen. The form of the carrier sentences ensured that each critical stimulus was neither especially highlighted nor at the end of a prosodic phrase in order to avoid the influence of sentence final boundary tones (same design as in [9]). All sentences were read by 13 non-professional speakers. For the stress perception task, all critical stimuli were extracted from their carrier sentence. The stress distribution in the critical compounds and phonological phrases produced by each speaker was evaluated by four linguistically trained listeners each. Neither the speakers nor the listeners were informed about the underlying purpose of this task.

3.2. Results

While all phonological phrases were taken into account, 35 compounds had to be excluded from analysis because these forms were realized with primary stress on the B-constituent or pronounced erroneously. Overall, the evaluation of 52 phonological phrases per condition (clash vs. non-clash context), 43 compounds consisting of three syllables, and 65 quadrisyllabic compounds was analyzed. In the phonological phrases with stress clash context, almost 60% of the phrasal verbs were perceived as stressed on the second syllable, i.e. with a stress shift. According to the listeners, only two of the analyzed 52 phonological phrases contained a real stress clash (<4%). In the remaining cases, the judgment of the four listeners was not definite or the phrasal verb was perceived as bearing phrasal stress. These results show that the RR operates regularly beyond word boundaries in German. The inspection of the two compound types suggests that the number of syllables does not seem to be a factor for the application of stress shift: Over 56% of the trisyllabic compounds and even 68% of the quadrisyllabic compounds were judged as stress-shifted, with a stressed C-constituent. However, the number of perceived stress clashes is somewhat higher for three-syllable compounds compared to quadrisyllabic compounds (16% vs. 5%). Overall, the results of this perception study illustrate the importance of the RR in German within and across word boundaries and make clear that it is a regularly used strategy to avoid stress clashes (cf. Figure 3).

Figure 3: Prominence perception results for study 1 (%).



4. STUDY 2: THE ROLE OF CONTEXTUAL INFLUENCE

The results of various studies with regard to the shift triggering context suggest that its impact varies for German and English. While the perception of potential stress shifts decreases in English when heard without their triggering context [2], German listeners are still able to evaluate stress shifts accurately even when the context is removed [9]. To verify this result for German, the compounds which were identified as shifted in the first study were also presented without the shift-triggering A-constituent.

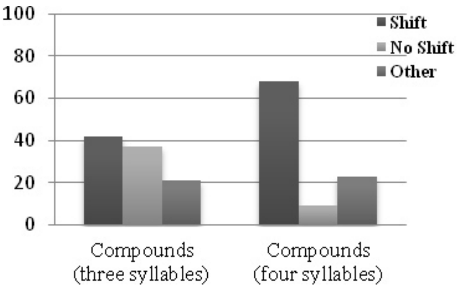
4.1. Method

The syllable of the A-constituent was deleted from the affected items (24 trisyllabic and 44 quadrisyllabic compounds) and the listeners (same subjects as in study 1) had to evaluate the prominence distribution in the remaining (BC)-compound without knowing that this compound originally contained a preceding constituent.

4.2. Results

The validation of stress perception in this study reveals a slightly changed picture regarding the importance of the number of syllables. Without the triggering context, judging the stressed syllable seems to become more complicated in compounds originally consisting of three syllables. In only 42% of the cases, listeners still perceived the C-constituent as the more prominent one, whereas 37% now observe primary stress on the B-constituent. In contrast, the results for the originally quadrisyllabic compounds show that the first syllable of the C-constituent can still clearly be identified as the most prominent one within the (BC)-compound, namely in over 68% of the cases. Only 9% are perceived as being realized with a more prominent B-constituent (cf. Figure 4).

Figure 4: Prominence perception results for study 2 (%).



Hence, the realization of a stress shift articulates itself so clearly in quadrisyllabic compounds that it can still be perceived when heard without its shift triggering context. These findings confirm the results found in [9].

5. RELATION OF PERCEPTION AND PRODUCTION

In order to find out whether the prevailing perception of stress shift is purely motivated by rhythmic expectancies, we investigated whether there is acoustic evidence which attests the application of the RR in these stimuli.

5.1. Method

An acoustic analysis was carried out for all phrasal verbs which were identified as shifted in the clash context condition and their corresponding control verbs. For each of the three syllables, its duration (ms), intensity (dB), and fundamental frequency F0 (Hz) were measured (measured from the whole syllable). A Wilcoxon signed rank test for paired samples was conducted to inspect possible differences between the syllables of the shifted items and the syllables of the identical unshifted control verbs. Therefore, the identical syllable positions of each verb from both conditions were compared with each other.

5.2. Results

The comparison of the two conditions shows that there is a significant difference only between the duration measures of the initial syllables ($Z=-2.045$, $p=0.040$) while no significant differences between the second and final syllables exist. Each syllable pair does neither differ in F0 nor intensity. The significant duration difference for the initial syllables alone suggests that there is no real prominence reversal but an adjustment of the syllables in phrasal verbs affected by a potential stress clash. Since the second syllables do not differ from each

other, this result rather implicates a stress reduction (DA) than a complete stress shift (RA) as the dominant form of the RR on a phrasal level. In order to confirm this assumption, an acoustic analysis of the initial and second syllables within a phrasal verb in both context conditions is necessary but could not be performed here due to the small stimuli number by each speaker.
Comparing the acoustic parameters of the two perceived stress clash phrases from study 1 with the two shifted phrases produced by the same speaker, one can see that these data speak for a RA in the two shifted verbs. The initial syllables in the shifted items are not only shorter than the other two syllables of the verb but also shorter than the initial syllables of the two verbs perceived as unshifted. In the clash items, the initial syllables are clearly longer than the two other syllables (see Table 1).

Table 1: Syllable durations (in ms) for each syllable of the phrasal verbs (underlined) given in the table.

Syllables	S1	S2	S3
Shift:			
1. Termín ab-sa-gen	144	244	194
2. Román vor-le-sen	164	223	186
CLASH:			
1. Vertrág ab-ge-ben	245	153	146
2. Kaplán ein-la-den	244	217	168

Overall, the results suggest that syllable duration is significantly involved in the perception and realization of the RR in German on the phrasal level. Moreover, the phonetic realization of the RR can take various shapes. The findings about the importance of syllable duration are in line with previous studies that highlight the importance of duration for a syllable’s prominence status [1, 3, 6]. Whether DA is also the dominant form of the RR in compounds has to be awaited, since an acoustic investigation was not possible in this study due to the small number of stimuli.

6. GENERAL DISCUSSION

The results of this study reveal that stress shifts are regularly perceived in German compounds as well as in phrasal verbs. The RR seems to operate on a regular basis in order to prevent stress clashes and hence rhythmically irregular structures. This result is in contrast to the findings of [9] which suggest that stress shifts are rather rare in German compounds. Their observation that the appearance of the RR depends on the number of syllables is supported by our findings since especially quadrisyllabic compounds can still be perceived as shifted even when the triggering context is removed. For trisyllabic compounds on the other hand, the accurate evaluation becomes more complicated when heard without the triggering context. The received acoustic data show that, on the phrasal level, a clash is mainly avoided via stress reduction by means of syllable shortening. This probably leads to the perception of a real reversal of prominence. Thus, these data provide important information about the identity of the main acoustic correlate of the RR in German. Moreover, they support the proposition of [9] that stress shifts in German are not only a perceptual phenomenon based on rhythmic expectancies by the listener but also a production strategy to avoid stress clashes.

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[1] The displayed grid notation is reduced to the crucial levels for the illustration of a stress clash in these examples.

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The influence of rhythmic (ir)regularities on speech processing: Evidence from an ERP study on German phrases

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ABSTRACT

The present study investigates the status of rhythmic irregularities occurring in natural speech and the importance of rhythmic alternations in cognitive processing. Previous studies showed the relevance of rhythm for language processing, but there has been only little research using the method of event-related potentials to investigate this phenomenon in a natural metrical context. To this end, an experiment was conducted in which the so-called Rhythm Rule (alternation of stressed and unstressed syllables) was either met or violated by stress clashes or stress lapses which are known to occur in German. The comparison of rhythmic well-formed conditions with the conditions including rhythmic irregularities revealed biphasic EEG-patterns for rhythmically marked structures, i.e., stress clashes and lapses.

The present results show that irregular but possible rhythmic variants are costly in language processing, reflected by an early negativity and an N400 in contrast to the well-formed control conditions. Supposedly, the early negativity reflects error detection in rhythmical structure and supports the view that the brain is sensitive to subtle violations of rhythmical structure. A late positive component reflects the evaluation process related to the task requirements.

The study shows that subtle rhythmical deviations from the Rhythm Rule are perceived and treated differently from well-formed structures during processing, even if the deviation in question is permitted and can therefore occur in language production.

1. Introduction

The processing of spoken language not only relies on the information from lexical accent but also on a harmonic rhythmical structure, i.e., an alternating sequence of stressed and unstressed syllables, the metric accent. It has been shown that a regular pattern of stressed and unstressed syllables is advantageous for speech perception not only for adults (e.g., Cutler & Foss, 1977) but also for infants in early language acquisition (Jusczyk, 1999; Nazzi & Ramus, 2003). Moreover, it is helpful for the speech segmentation process as it leads attention to stressed syllables in speech processing (Cutler & Norris, 1988; Pitt & Samuel, 1990). Various studies revealed that the brain not only reacts to clear metrical violations (e.g., Steinhauer, Alter, & Friederici, 1999; Knaus, Wiese, & Janßen, 2007; Magne et al., 2007; Domahs, Wiese, Bornkessel-Schlesewsky, & Schlesewsky, 2008), but also to even small deviations in language (Schmidt-Kassow & Kotz, 2009b; Rothermich, Schmidt-Kassow, Schwartze, & Kotz, 2010; Rothermich, Schmidt-Kassow, & Kotz; 2012) as well as in musical structures (Koelsch, Gunter, Friederici, & Schröger, 2000; Koelsch & Sammler, 2008; Geiser, Ziegler, Jancke, & Meyer, 2009). An important link between the structures of language and music is the notion of rhythm. A well-formed rhythmic structure is defined as a sequence of alternating strong and weak units. This holds true not only for music but also for prosodic structures in language. Therefore, the rhythmical organization of language seems to be comparable to rhythmical ideals of music which are determined by the Principle of Rhythmic Alternation (PRA) (Sweet, 1875/1876; Jespersen, 1933; Cooper & Meyer, 1960; Abercrombie, 1967; Selkirk, 1984). Put differently, linguistic rhythm results from a harmonious alternating string of stressed and unstressed syllables. Certainly, this principle reflects an ideal state of rhythm which cannot be reached constantly in natural language. A well-known contravention against the PRA is a so-called stress clash of two adjacent stressed syllables which would have to be separated by an unstressed syllable in order to fulfill the PRA. Furthermore, also a juxtaposition of unstressed syllables, a so-called stress lapse, infringes upon this principle (Selkirk, 1984). According strictly to the definition of the PRA and to metrical theories, even two adjacent unstressed syllables build a lapse structure. However, there is some dispute whether two adjacent unstressed syllables can be interpreted as a

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real lapse (cf. Selkirk, 1984; Giegerich, 1985; Nespor & Vogel, 1989; Plag, 1999). In general, there is some consensus that rhythmic deviations in form of stress clashes are less acceptable than stress lapses (Nespor & Vogel, 1989; Kager, 1995).

1.1. Avoidance of rhythmic irregularities

In order to avoid stress clashes, a process called stress shift can be applied. That is, in a sequence of two adjacent stressed syllables, lower level stress can be moved away from primary stress in order to obtain a harmonic structure (e.g., English *thirtéen*→*thìrteen mén*; German *ánziehen*→*Róck anzìehen*). To this end, there are two options available: to shift the weaker of the involved stresses onto another stressable syllable (Reversal Analysis: RA) or to destress the weaker syllable (Deletion Analysis: DA) (Vogel, Bunnell, & Hoskins, 1995). Both options obtain a rhythmically alternating sequence of stressed and unstressed syllables. Since the motivation for these processes is rhythmic in nature, they can be subsumed and are thus also known as the Rhythm Rule (RR, Liberman & Prince, 1977). Hence, the Rhythm Rule represents a linguistic repair strategy which implements the demands of the general PRA. The avoidance of stress clashes is most often necessary in phrases since clashes most commonly appear when particular words are combined. A special difficulty lies in the fact that lexical word stress positions of combined words, i.e., the relative prominence patterns of the included words, are normally preserved under embedding. Thus, syllables which receive stress in a phrase are usually the same syllables that bear lexical stress on the word level (Liberman & Prince, 1977; Giegerich, 1985; Truckenbrodt, 2006). Despite this fact and although the application of stress shifts is optional, such shifts seem to operate highly systematically in languages like English and German (albeit to varying degrees; see Section 1.3). Therefore, there seem to be factors which override this stress preservation rule in the occurrence of a potential stress clash (Selkirk, 1995).

1.2. The importance of rhythmic regularity

The importance of an alternation of stressed and unstressed syllables in languages like German and English might also be motivated by the fact that both languages are stress-timed languages. In this speech rhythm type, the distance between stressed syllables has to be kept isochronous as opposed to syllable-timed languages in which stressed and unstressed syllables are isochronous (Pike, 1945; Abercrombie, 1965, 1967). This classification has turned out to be phonetically and physically untenable since no real temporal periodicity could be measured in various studies (e.g., Bolinger, 1965; Pointon, 1980; Roach, 1982; Dauer, 1983; Beckman, 1992). Still, some studies were able to show evidence for differences between the traditional rhythmic classes, even though it must be acknowledged that this classification cannot be categorical (Roach, 1982; Ramus, Nespor, & Mehler, 1999; Low, Grabe, & Nolan, 2000; Grabe & Low, 2002). Thus, the classification types have been maintained (Kleinhenz, 1996) as two extremes of a continuum (e.g., Roach, 1982; Auer & Uhmann, 1988). Irrespective of physical or psychological isochrony, the concept of rhythmic alternation plays an important role in stress-timed languages (cf. Liberman & Prince, 1977; Selkirk, 1984; Hayes, 1984; Couper-Kuhlen, 1986). Besides, German – as well as English – holds a trochaic standard pattern, i.e., metrical feet in which a stressed syllable precedes an unstressed syllable (Jessen, 1999; Domahs et al., 2008).

Despite the manifold variations that appear in spoken language and the fact that real articulatory homogeneous intervals of stressed syllables do not exist, many studies (Cutler & Foss, 1977; Cutler & Norris, 1988; Pitt & Samuel, 1990) were able to show that regular rhythmic alternations constitute an important and valuable factor in language processing. This is due to the fact that an alternating pattern helps in building up an expectation when the next stressed syllable might appear. Thereby, the predictability of rhythmic entities helps to segment speech (Cutler & Foss, 1977; Cutler & Norris, 1988). Moreover, attention is led to stressed syllables in speech processing ("attentional bounce hypothesis": Pitt & Samuel, 1990). Hence, the stressed syllable seems to be the reference point for segmenting the speech signal into smaller units. Further support for this assumption comes from an ERP study by Domahs et al. (2008) which showed that the position of the first perceived stressed syllable – rather than the destressed, originally stressed syllable – is crucial for the evaluation of words containing a stress violation. This is in line with the Metrical Segmentation Theory which states that stressed syllables guide word recognition (Cutler & Norris, 1988). Moreover, the aforementioned study by Pitt and Samuel (1990) not only showed the advantage of rhythmic regularity but also coincidentally delivered interesting insights into the processing of stress clashes by using a strict trochaic pattern as test stimulus. Violations against this pattern emerged by inserting an iambic structure (e.g., DIAper, *SUBway*, *REAson*, *deLUXE*, *PERmit*). Thus, this structure inherits also a proper stress clash (*deLUXE PERmit*). Therefore, its results not only speak for an advantage of rhythmically regular patterns but lead also to the assumption that rhythmic irregularities like stress clashes cause a decelerated reaction and thus an obstacle in language processing.

1.3. Production and perception studies

So far, the importance of the PRA and stress shifts have been mainly explored via perception and production studies regarding rhythmically motivated stress shifts.

Rhythmic regularity and hence the phenomenon of stress shifts was mainly investigated in English. Different studies revealed that for English speakers destressing seems to be the dominant strategy in order to avoid stress clash, i.e., although a proper stress shift can be perceived by listeners, there is no acoustic evidence for a real shift of prominence within a potential stress shift item (Grabe & Warren, 1995; Vogel et al., 1995).

Although previous studies do not fully agree on matters of the realization of the RR and its acoustic correlates, they all concur on the view that the RR and hence rhythmic alternation plays an important role in English.

Regarding the implementation of the RR in German, the occurrence and importance of stress shifts is not conclusive: While Mengel (2000) classifies the RR as a regular albeit purely perceptual phenomenon, other studies showed that stress shifts are not only perceived but also produced by German speakers (Wagner & Fischenbeck, 2002; Bohn, Knaus, Wiese, & Domahs, 2011). However, while Wagner and Fischenbeck (2002) conclude that its application is rather the exception than the rule, the results of Bohn et al. (2011) speak in favor of a highly regular usage of stress shifts in order to obtain a regular, alternating stress pattern. So far, only these few studies investigated the role of the RR and rhythmically motivated stress shifts in German. All studies agree that its application is optional. However, it seems to be the case that shifts can generally be perceived in German. Still, which repair strategy is predominantly used in production to avoid rhythmical deviations is not fully elucidated yet. This might also be due to the highly variable use in speakers and thus needs to be further studied and tested in future studies.

With regard to the on-line processing of this rhythmic phenomenon, which might shed light on this question more deeply, little is known yet. Assuming that the application of stress shifts is optional, stress clashes might be perceived as well-formed in German and therefore might not evoke different brain responses

Table 1
Experimental conditions and filler items.

Condition	Example
Correct SHIFT	Sie soll den **Terˈmin abˈsagen**, wie besprochen She is supposed to cancel the appointment, as discussed
Correct NO SHIFT	Sie soll die ˈ**Feierˈabsagen**, wie besprochen She is supposed to cancel the party, as discussed
CLASH	Sie soll den **Terˈminˈabsagen**, wie besprochen She is supposed to cancel the appointment, as discussed
LAPSE	Sie soll die ˈ**Feier abˈsagen**, wie besprochen She is supposed to cancel the party, as discussed
Filler correct	Sie soll die ˈ**Preise reduˈzieren**, wie immer She is supposed to reduce the prices, as usual
Filler incorrect	Sie soll die ˈ**Preise reˈduzieren**, wie immer She is supposed to reduce the prices, as usual

to either rhythmic deviations or shifted forms although the latter are forms that do not occur in isolation but only in phrases to resolve stress clashes (see Table 1). To investigate the role of shifted and non-shifted stresses in the processing of rhythmic structures, a study utilizing event-related potentials (ERPs) was conducted.

1.4. Previous ERP studies on rhythmic processing

Until recently, only a few psycholinguistic and especially neurolinguistic studies have been conducted on the role of rhythm and prosody, since for a long time the focus of linguistic research was put especially on syntactic or lexical processing. However, ERP studies of the last few years showed that prosodic information influence auditory processing on a lexical as well as on a structural stage (e.g., Steinhauer et al., 1999; Friedrich, Kotz, Friederici, & Alter, 2004; Knaus et al., 2007; Domahs et al., 2008). Moreover, the importance of rhythm and metrics has been revealed by various studies (Magne et al., 2007; Schmidt-Kassow & Kotz, 2009a,b; Rothermich et al., 2010, 2012; Marie, Magne, & Besson, 2011). These studies showed that the brain clearly reacts to rhythmic deviations and violations if an expected rhythmic structure is not met. In most studies using ERPs, this was reflected by a negativity followed by a positive component. However, the interpretation of the reported components varies. Knaus et al. (2007), Magne et al. (2007), and Marie et al. (2011) report an N400 effect for incorrect stress patterns which reflects higher costs in lexical retrieval. A similar negativity effect was found by Schmidt-Kassow and Kotz (2009a). They also consider increased costs in lexical retrieval as a possible source of this effect, but also suggest the possibility that this effect might be a subcomponent of an LAN (left anterior negativity). Accordingly, the higher efforts evoked by metrical violations may reflect a general rule-based error-detection, as postulated by Hoen and Dominey (2000). Therefore, the negativity found may be an instance of an LAN. Marie et al. (2011) conclude this interpretation for their negative component as well. Support for this interpretation comes from further studies which explain the reported negativity as a response to the detection of metrical errors in auditory processing (Brochard, Abecasis, Potter, Ragot, & Drake, 2003; Abecasis, Brochard, Granot, & Drake, 2005; Rothermich et al., 2010, 2012).

The second component, a subsequent positivity, only occurs if the participants' attention is directed towards the metrical structure by the given task (Domahs et al., 2008; Knaus et al., 2007; Magne et al., 2007; Marie et al., 2011; Schmidt-Kassow & Kotz, 2009b; Rothermich et al., 2012). A late positive component hence represents a task-sensitive evaluation and reanalysis mechanism, which is regarded as a general restructuring process by Domahs et al. (2008) and Schmidt-Kassow and Kotz (2009a). However, this component is labeled differently in the studies mentioned. While some researchers (Knaus et al., 2007; Magne et al., 2007; Domahs et al., 2008) assume their positivity effects to be members of the P300 family, Schmidt-Kassow and Kotz (2009a,b), Marie et al. (2011), and Rothermich et al. (2012) describe it as a P600. This is probably due to the fact that the 'classic' P600 is interpreted as a correlate of syntactic reanalysis processes (see e.g., Steinhauer et al., 1999).

1.5. The present study

As can be seen from the results presented above, the presence or absence of rhythmically motivated stress shifts remain to be tested with the help of the ERP technique. Therefore, the present study concentrated on the cognitive processing of rhythmical alternations to explore possible differences in the processing of rhythmically well-formed and rhythmically marked structures.

Since the reported off-line studies draw different conclusions on this topic, an ERP study should deliver a finer-grained picture of the acceptability of rhythmically ill-formed structures in language processing. As rhythmically induced stress shifts seem to be, according to Wagner and Fischenbeck (2002), an optional and rare phenomenon in German, the question is whether detectable general differences between well-formed structures and rhythmic deviations appear at all. In contrast, other studies state that stress shifts are predominantly perceived (Mengel, 2000; Bohn et al., 2011) and applied (Bohn et al., 2011) in German. The detection of processing differences between rhythmic deviations and their well-formed counterparts might therefore shed more light onto this topic. Furthermore, it is interesting to investigate how stress clashes are perceived and evaluated by listeners and how this evaluation might possibly differ from the brain's reaction. Moreover, since not only stress clashes but also stress lapses represent a rhythmic deviation, another question was whether differences between these two deviation types would appear. As mentioned earlier, stress lapses seem to be less problematic than clashes, therefore one might expect stronger reactions for stress clashes.

With regard to the results of previous related ERP studies, a further objective was to clarify the nature of the negativity effect by combining lexical and rhythmic deviations. Moreover, it was tested whether compliance with rhythmic ideals is advantageous for language processing and whether rhythmically induced stress shifts are an obligatory technique to fulfill these ideals.

2. Methods

2.1. Participants

Twenty-six (16 women) right-handed monolingual native speakers of German participated in the experiment. Their mean age was 24 years (age range 20–30 years). All participants had normal or corrected-to-normal vision and none of them had hearing deficits. Each subject was paid for participation on the study. Informed consent was obtained from all participants and privacy rights were always observed.

2.2. Stimuli

To investigate electrophysiological effects correlated with rhythmically motivated stress shifts and clashes, phonological phrases were chosen as stimuli which consisted of a noun and a phrasal verb. A characteristic feature of the selected German phrasal verbs is that they are initially stressed by default and that they allow for stress variation: According to Kiparsky (1966), their stress can and should be shifted to the next stressable syllable if it otherwise clashed with primary stress of a preceding noun. Thus, in a noun–verb phrase such as *Termín àbsagen* 'cancel appointment', initial stress of the complex verb shifts from the particle to the second syllable: *Termín absàgen*. If there is no adjacent syllable bearing primary stress, main stress remains on the initial syllable of the phrasal verb, as in *Féier àbsagen*. Since this stress shift is an optional process (as mentioned in the Introduction), stress clashes can potentially occur. To detect how the brain reacts to these different options, 30 phonological phrases consisting of a disyllabic noun and a trisyllabic phrasal verb (stress shift target) were created. To receive a condition with a (theoretically) necessary stress shift and one without, two noun groups with different stress patterns were chosen for the disyllabic nouns. Since the phrasal verbs, i.e., the stress shift targets, are stressed on the initial syllable in isolation (e.g., *ábsagen* 'cancel'), the group of disyllabic nouns with initial stress (e.g., *Féi.er* 'party') was chosen for the condition NO SHIFT. If the verbs are on the contrary preceded by a finally stressed noun, stress clash is avoided by stress shift on the phrasal verb. Hence, nouns with final stress were used for the condition SHIFT (e.g., *Ter.mín* 'appointment').

These two kinds of nouns were combined with one adequate phrasal verb to evoke both possible stress patterns in the phrasal verb (Féi.er àbsagen vs. Ter.mín absàgen). Thus, all shifted and unshifted forms of phrasal verbs were produced naturally by the preceding trigger noun without artificially manipulating phonetic parameters. Each noun pair was controlled and matched for frequency, according to the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) in order to minimize lexical frequency effects on the processing of the different conditions. The thirty phonological phrases of each condition were embedded into an invariant carrier sentence to ensure that the target phrases were located at identical prosodic phrase positions and not influenced differently by intonational properties. A further crucial criterion was that the critical phrases did not occur at the end of the sentence. In such positions, downstep phenomena usually occur which lower the pitch of the final word or syllable. For illustration of the stimuli constructed and their embedding, see Table 1.

Stimuli were spoken by a linguistically trained female speaker of German at a normal speech rate and were digitally recorded with a sampling rate of 44.1 kHz and a 16 bit (mono) sample size, using the sound recording and analysis software Amadeus Pro (version 1.5.3, HairerSoft) and an electret microphone (Beyerdynamic MC 930C) in an anechoic room.

In order to obtain the critical conditions CLASH and LAPSE without manipulating phonetic parameters, the sentences of the two naturally spoken and recorded conditions SHIFT and NO SHIFT were cut between noun and the verb's onset. The final part of each sentence of one condition was spliced with the first part of the same sentence of the other condition and vice versa to obtain 30 sentences with ill-formed rhythmical structures, i.e., stress clashes and stress lapses. Hence, the finally stressed nouns of the condition SHIFT (e.g., *Ter.mín*) were combined with the initially stressed phrasal verbs of the condition NO SHIFT (e.g., *àbsagen*) in order to create the stimuli for the deviation condition CLASH. For the condition LAPSE, the nouns bearing initial stress (e.g., *Féi.er*) of the condition NO SHIFT were combined with the shifted forms of phrasal verbs (e.g., *absàgen*) of the condition SHIFT in order to obtain two adjacent unstressed syllables, see Table 2. The sentences of the well-formed conditions SHIFT and NO SHIFT were also spliced between noun and verb in order to avoid a splicing effect in the critical conditions. For these conditions, each sentence of the two control conditions was recorded twice and the first sentence part of recording 1 was spliced with the final sentence part of recording 2. The same procedure was applied to the filler sentences. All stimuli were controlled for and normalized in loudness, i.e., the volume of all sentences was adjusted to a uniform level of volume throughout all used stimuli. This loudness adjustment was carried out via auditory inspection by the first author using the sound recording and analysis software Amadeus Pro (version 1.5.3, HairerSoft).

A phonetic analysis of the phrasal verbs of the two distinct conditions showed that the speaker had produced real stress shifts in the condition SHIFT and no shifts in the condition NO SHIFT. The analysis revealed syllable duration to be the decisive factor for stress shifts: In order to obtain a perceptible shift, the initial syllable of the phrasal verb was significantly shortened, whereas the second syllable, i.e., the first syllable within the verb stem, was lengthened. Hence, the speaker produced real prominence reversals within the phrasal verbs. The cross-splicing of both conditions thus ensured that the participants heard clear stress clashes of two adjacent stressed syllables in the sentences of the CLASH condition and two adjacent unstressed syllables in the LAPSE condition. Additionally, 60 filler sentences, 30 with correct and 30 with incorrect stress patterns of an included quadrisyllabic verb were recorded. The filler items were embedded in similar sentences and spliced as well.

2.3. Procedure

180 stimuli (30 per condition and 60 fillers) were distributed over four blocks of 45 sentences, each taking approximately five minutes. Experimental and filler sentences were presented in a pseudo-randomized order, and each phrasal verb appeared only once per condition within each block. In order to avoid sequence effects, the blocks' order varied between the participants as well. Participants were seated in front of a computer screen in a dimly lit, sound-attenuating room during the experiment. After a short practice phase, the first experimental block started with the request to click any key to begin the experiment. This ensured the participant's attention when an experimental block started. Each trial was introduced by a fixation cross that appeared for 500 ms. It was followed by the auditory presentation of a stimulus embedded in a carrier sentence. The sentences were presented auditorily via two loudspeakers. After the offset of the heard stimulus, the fixation cross disappeared from the screen and a question mark came up which gave the signal for the participants to perform the respective evaluation within 2000 ms and to blink. The participants' task was to decide whether the heard sentences sounded prosodically natural or not as accurately and as fast as possible by pressing one of four buttons. The assignment of buttons to four possible answers (natural, rather natural, rather unnatural, unnatural) was counterbalanced across participants. This task directed the participants' attention consciously to the rhythmic and metrical features of each sentence. This was important, given that rather small irregularities in rhythm are only detectable and assessable if the focus is on the metrical structure (e.g., Knaus et al., 2007; Schmidt-Kassow & Kotz, 2009b). Moreover, this ensured a certain amount of comparability between the conscious behavioral data and the unconscious ERP data. The next trial started after 2000 ms with a new fixation cross. Between separate blocks, participants were offered a short break of approximately one minute to rest their eyes. All procedures were performed in compliance with relevant laws and institutional guidelines.

2.4. ERP recordings

An electroencephalogram (EEG) was recorded from overall 23 Ag/AgCl electrodes with a BrainVision (Brain Products GmbH) amplifier. Four electrodes measured the electrooculogram, i.e., horizontal and vertical eye movements. Two auricle electrodes served as references and were placed at the left and right mastoids. The C2 electrode served as ground. EEG and EOG were recorded with a sampling rate of 500 Hz and filtered offline with a 0.3 to 20 Hz bandpass filter. All electrode impedances were kept below 5 kΩ. Prior to data analysis, all individual EEG recordings were automatically and manually scanned for artifacts from eye or body movements and muscle artifacts. Artifacts with an amplitude above 40 μV were excluded automatically, a subsequent visual screening excluded any further artifacts. In total, 2.9% of the critical stimuli and 2.6% of the filler items had to be excluded from analysis.

2.5. Data analyses

For the behavioral data analysis, the arithmetical mean of all responses for each condition was used. Therefore, each of the four possible response levels was allocated to a numerical value: 1 ≙ natural, 2 ≙ rather natural, 3 ≙ rather unnatural, and 4 ≙ unnatural. The arithmetical means were analyzed with an ANOVA with the factors rhythm condition and well-formedness. As mentioned before, this evaluation response was given with a delay after the offset of the sentence, due to the prevention of movement artifacts. Based on this temporal distance between the perception of each critical item and the response, the measured reaction times were not meaningful. Therefore, an independent reaction time study was undertaken with the identical set of stimuli. Its results will be reported in the next section.

For the EEG data, the following regions of interest (ROIs) were statistically analyzed with a multifactorial repeated-measures ANOVA: frontal (F3, FZ, F4), central (C3, CZ, C4), parietal (P3, PZ, P4) as well as left anterior (F3, F7, FC5), right anterior (F4, F8, FC6), left posterior (P3, P7, PC5), and right posterior (P4, P8, CP6). Averages were calculated from the particle verb's onset up to 1500 ms thereafter with a baseline of 200 ms preceding the onset. Time windows for each paired comparison were chosen based on hypotheses taken from the literature on rhythmical processing (Magne et al., 2007; Knaus et al., 2007; Domahs et al., 2008; Domahs, Kehrein, Knaus, Wiese, & Schlesewsky, 2009; Schmidt-Kassow & Kotz, 2009a; Rothermich et al., 2010) and were adjusted on the basis of visual inspection of the grand average curves. Reported results will refer mainly to the quadrant ROIs. For effects with more than one degree of freedom, Huynh-Feldt (1976) corrections were applied to the *p*-values.

3. Results

3.1. Behavioral data

The ANOVA for judgment data revealed main effects for the factors rhythm condition and well-formedness (words stressed correctly in SHIFT and NO SHIFT or incorrectly in LAPSE and CLASH) [rhythm condition: $F(1,25)=89.56$, $p=.000$; well-formedness: $F(1,25)=44.78$, $p=.000$], as well as an interaction of the two factors [$F(1,25)=66.11$, $p=.000$]. A further analysis of the two pairs CLASH and SHIFT and LAPSE and NO SHIFT showed that the experimental violation conditions CLASH and LAPSE were evaluated as less natural than the control conditions (on a scale from 1=natural to 4=unnatural). The stimuli of LAPSE were classified as significantly less natural than the stimuli of the control condition NO SHIFT [mean 2.23 (SD.34) vs. mean 1.89 (SD.28); $F(1,25)=74.95$, $p=.000$], the difference between CLASH and SHIFT narrowly failed to demonstrate statistical significance [mean 1.74 (SD.26) vs. mean 1.68 (SD.24); $F(1,25)=3.36$, $p=.079$] but here also the rhythmically well-formed structure was evaluated as more natural than the stimuli including a stress clash. The behavioral data from the additional reaction time study support these results. In this study, the response possibilities were limited to only two: natural (≙ 2) vs. unnatural (≙ 1). Here, the difference between CLASH and SHIFT did not become significant neither [$T(19)=-0.54$, $p>.05$] but there was a clear difference between LAPSE and NO SHIFT [$T(19)=4.71$, $p=.000$]. Thus, in both experiments LAPSE was evaluated as less natural than all other conditions, even CLASH. The *t*-tests conducted for reaction times reveal an additional important difference between the two ill-formed rhythmical structures. While no differences were found for the responses for LAPSE and its control condition NO SHIFT [$T(19)=-0.91$, $p>.05$], participants needed significantly more time to evaluate structures containing stress clashes than stress shifts [$T(19)=-3.35$, $p=.003$] (see Fig. 1). Note here that due to lexical differences, caused by the different preceding noun types (Féier vs. Termín), only these stated pairs (CLASH and SHIFT, LAPSE and NO SHIFT) can be tested and statistically compared with each other, as they share the same preceding noun group.

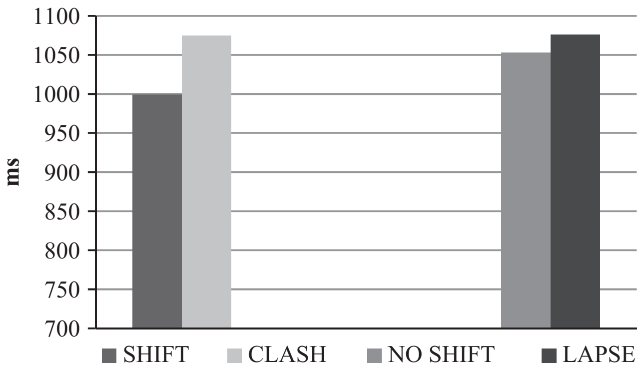

Fig. 1. Reaction times for each condition in ms.

3.2. ERP data

As can be seen in Figs. 2–5, biphasic patterns were found for both rhythmically marked structures CLASH and LAPSE in comparison to each control condition. The first two comparisons are between CLASH & SHIFT and LAPSE & NO SHIFT, respectively. In

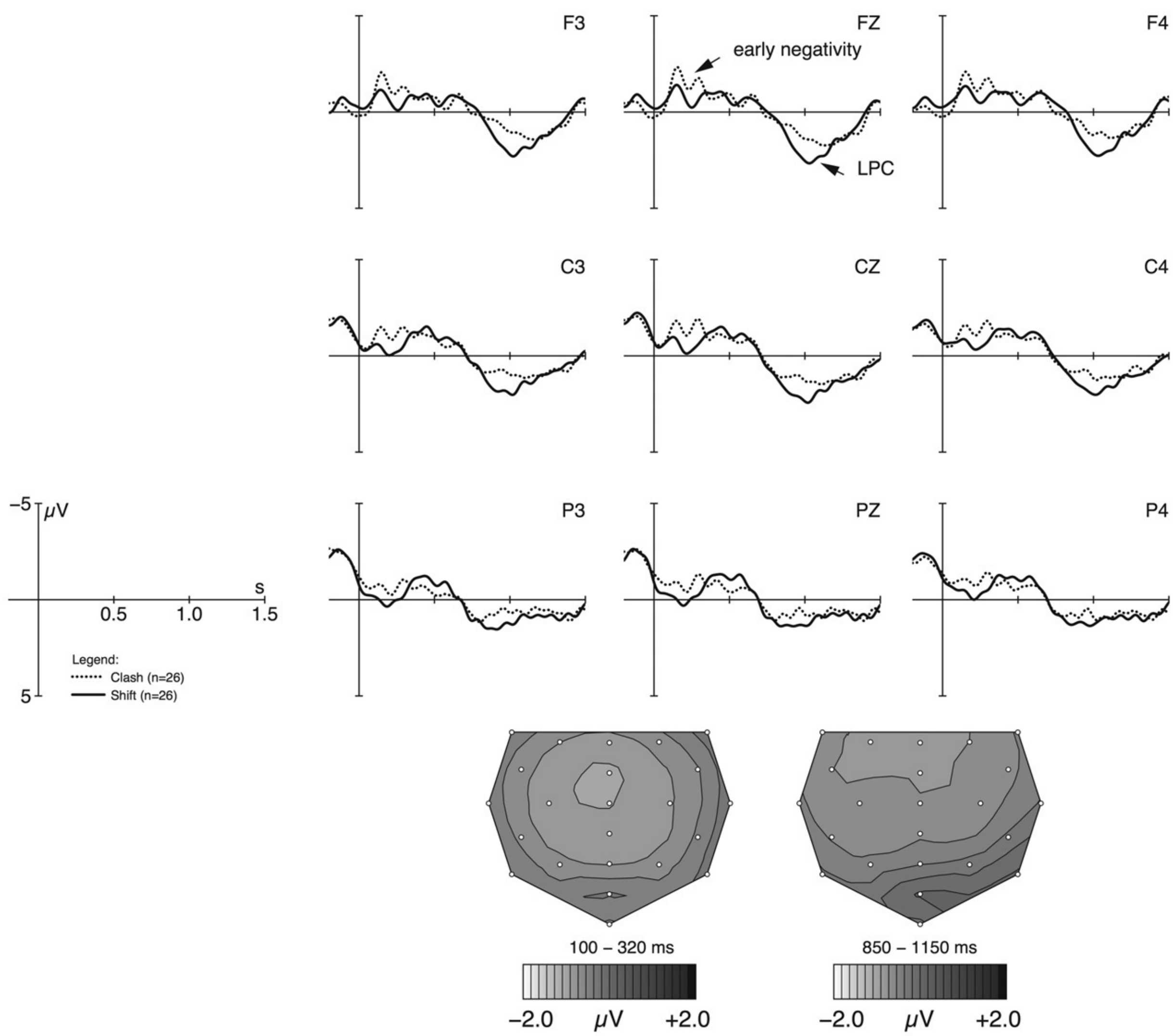

Fig. 2. Grand averages of event-related potentials obtained for the conditions CLASH and control condition SHIFT measured from 200 ms prior the verb onset up to 1500 ms. Topographic difference maps across 23 electrodes show differences between the conditions CLASH and SHIFT in the two critical time windows 100–320 ms and 850–1150 ms.

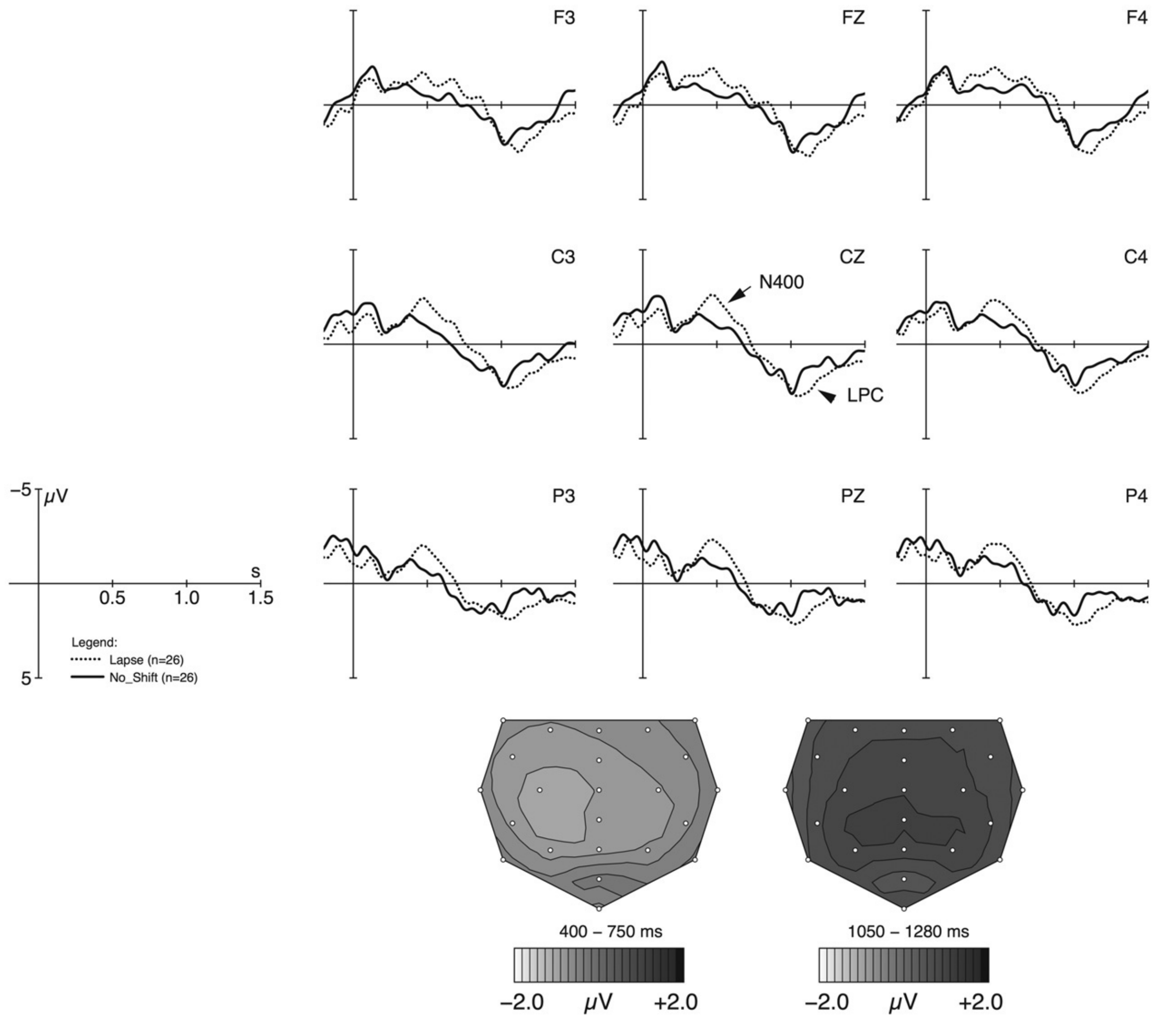

Fig. 3. Grand averages of event-related potentials obtained for the conditions LAPSE and control condition NO SHIFT measured from 200 ms prior the verb onset up to 1500 ms. Topographic difference maps show differences between the conditions LAPSE and NO SHIFT in the two critical time windows 400–750 ms and 1050–1280 ms.

these comparisons, the preceding trigger noun is identical whereas the following phrasal verb either fulfills the rhythmic demands of this noun (control conditions SHIFT and NO SHIFT) or deviates this demand (CLASH and LAPSE). The further two comparisons (CLASH and NO SHIFT, LAPSE and SHIFT) should reveal whether any difference between the first two main comparisons are merely due to the different stress positions in the phrasal verbs that were compared with each other, or whether possible effects are in fact evoked by the rhythmic deviations. Moreover, in order to compare potential differences between the effects elicited by the critical conditions CLASH and LAPSE, difference waves of the two main comparisons were computed by subtracting control conditions from deviant conditions (see Fig. 6). Additionally, difference brain maps across the 23 measured electrodes for all statistically significant time windows were created. Detailed results will be discussed separately for the two rhythmically ill-formed structures and their control conditions.

The comparison of the filler conditions revealed a similar biphasic effect pattern consisting of a negativity (250 to 470 ms) [$F(1,25)=21.10$, $p=.000$] and a following positivity between 600 and 1200 ms [$F(1,25)=191.93$, $p<.000$]. The negativity effect found is interpreted as an instance of an N400 effect which reflects the increased costs in lexical retrieval due to the stress violation in the verbs included in these sentences. Thus, these findings show that all participants were able to detect clear deviations of word stress.

3.2.1. *Comparison between CLASH and SHIFT*

The comparison of the conditions CLASH and SHIFT elicited an early negativity in an early time window (100–320 ms) followed by a late positive component (850–1150 ms). The calculation of a repeated measures ANOVA showed a main effect for rhythm condition [$F(1,25)=10.67$, $p=.003$] but no interaction between region and rhythm condition. However, an analysis of the separate regions was calculated in order to clarify the nature of this negativity effect and was guided by the hypothesis that this negativity is a subcomponent of the LAN, as found in previous related studies. In line with our hypothesis, this analysis revealed indeed a more pronounced effect in the left hemisphere [$F(1,25)=15.40$, $p<.001$]. Statistical analyses of the second time window showed that stress clashes lead to a reduced positivity effect [$F(1,25)=14.10$, $p<.001$]. Moreover, it revealed a significant interaction between the factors region and rhythm condition [$F(3,75)=3.73$, $p=.027$]. The post-hoc analyses of this interaction by region displayed a stronger occurrence of this effect in the left

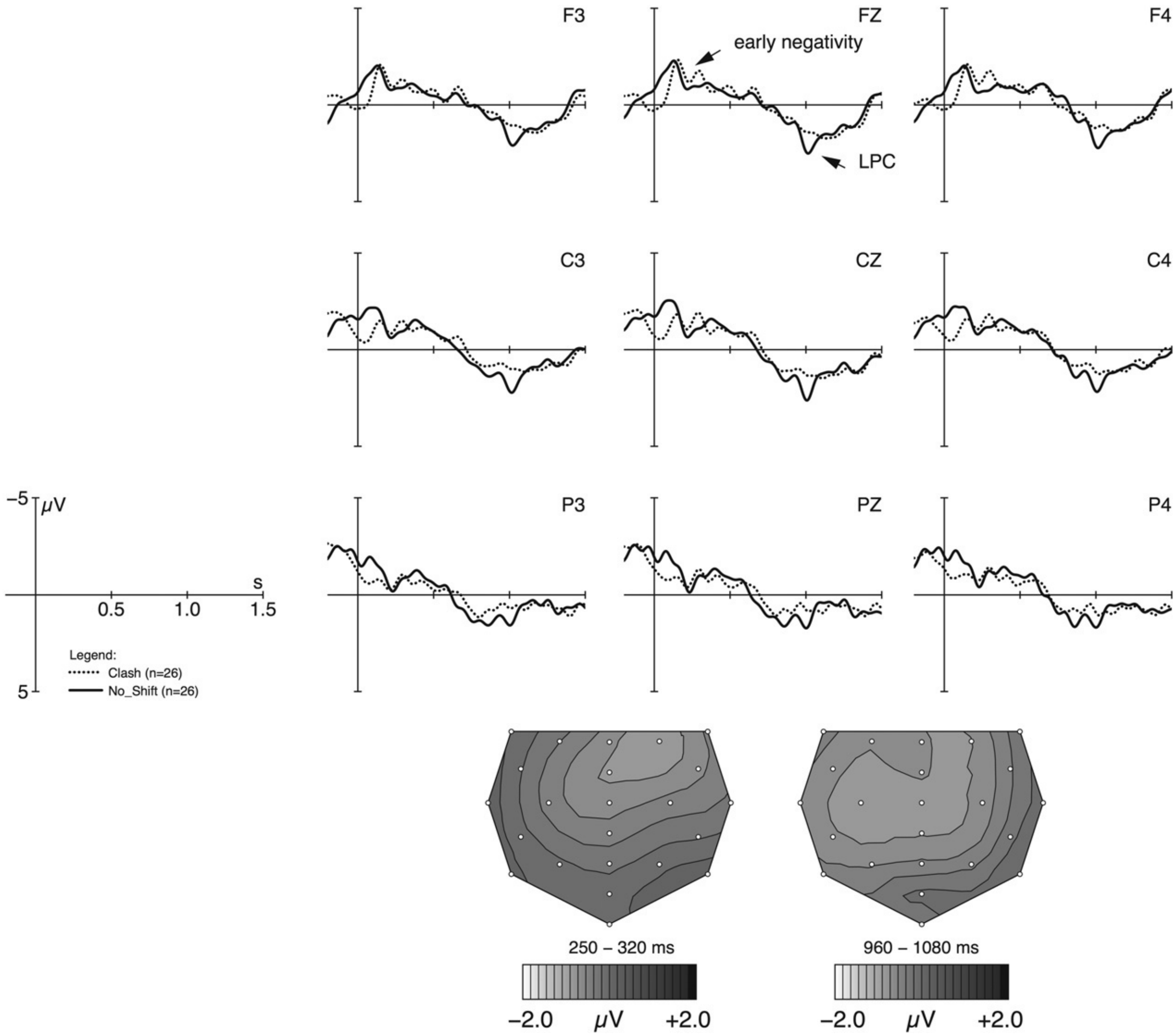

Fig. 4. Grand averages of event-related potentials obtained for the conditions CLASH and control condition NO SHIFT measured from 200 ms prior the verb onset up to 1500 ms. Topographic difference maps show differences between the conditions CLASH and NO SHIFT in the two critical time windows 250–320 ms and 960–1080 ms.

anterior region [$F(1,25)=17.14$, $p<.001$], although all separate regions – aside from right posterior – manifest a significant difference as well.

3.2.2. Comparison between LAPSE and NO SHIFT

For the comparison of LAPSE and NO SHIFT, effects occurred later than in the first comparison. Therefore a later time window was investigated. Note that the position of the stressed syllable in the critical condition LAPSE is the second syllable and not the first as in CLASH. Since a rhythmical deviation can only be detected from this point onwards (Cutler & Norris, 1988: Metrical Segmentation Strategy), the dependent effects occur with the beginning of the stressed syllable and not with the verb's onset. Therefore, the following time windows were chosen: from 400 to 750 ms and from 1050 to 1280 ms. Comparing the condition LAPSE and its control condition NO SHIFT showed a strongly significant negativity effect for the condition LAPSE but no interaction between the factors region and rhythm condition [$F(1,25)=25.12$, $p<.000$]. However, the effect seems to be stronger in the centro-parietal region. This negativity effect is followed by a late positive component, which is more pronounced for LAPSE than for NO SHIFT. Here, this positive component is not reduced in its amplitude like for stress clashes but is very pronounced in its shape, especially in the posterior region. There was only a main effect for the factor rhythm condition but no significant interaction between this factor and region [$F(1,25)=10.96$, $p=.003$].

3.2.3. Comparison between CLASH and NO SHIFT

In order to test whether the effects were evoked by manipulations of lexical stress, two further comparisons were calculated. In the comparison of CLASH and NO SHIFT both conditions maintain the default stress pattern on the first syllable of the included phrasal verb. Hence, this comparison should show whether the rhythmic deviation in CLASH is exclusively responsible for the negativity obtained in the comparison of CLASH and SHIFT as reported in Section 3.2.1. If this is the case, this comparison should reveal a negative component for CLASH, too. As can be seen in Fig. 4, we obtained a biphasic pattern also in the comparison of conditions with identical stress position. The first time window (250–320 ms) shows a stronger negativity for CLASH than for NO SHIFT. However, this effect did not reach a significant status but a significant interaction between the factors region and rhythm condition [$F(3,75)=3.23$, $p=.036$]. Resolving this interaction, a significant right anterior negativity was revealed [$F(1,25)=5.36$, $p=.030$]. In the second time window (960–1080 ms),

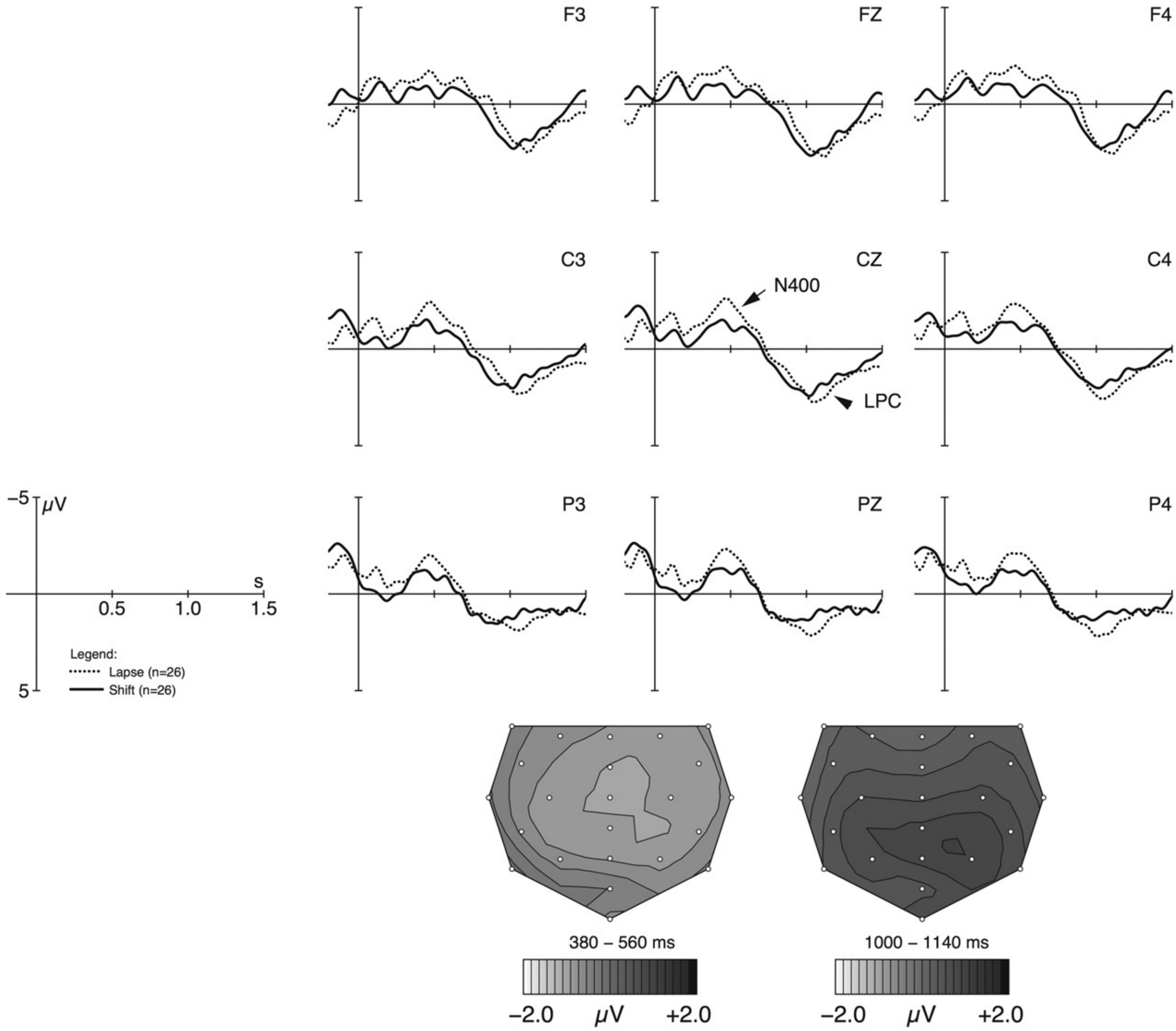

Fig. 5. Grand averages of event-related potentials obtained for the conditions LAPSE and control condition SHIFT measured from 200 ms prior the verb onset up to 1500 ms. Topographic difference maps show differences between the conditions LAPSE and SHIFT in the two critical time windows 380–560 ms and 1000–1140 ms.

a reduced positivity effect is obtained for stress clashes [$F(1,25)=4.34$, $p=.048$]. These results support our hypothesis that the rhythmic deviation in CLASH is mainly responsible for the effects in the first reported comparison of CLASH and SHIFT and not the differences in stress position between CLASH and SHIFT.

3.2.4. Comparison between LAPSE and SHIFT

The two conditions which both include a violation against the default lexical stress pattern were also compared with each other (Table 3). While this lexical deviation is rhythmically motivated in SHIFT, this is not the case in LAPSE. If the lexical deviation of the condition LAPSE is exclusively responsible for the effects obtained in the comparison of LAPSE and NO SHIFT, the comparison between LAPSE and SHIFT should not show any differences, as the phrasal verbs in SHIFT and LAPSE bear the identical stress pattern. The analysis of two time windows showed that LAPSE leads to a strong negativity effect in comparison to SHIFT [$F(1,25)=11.27$, $p=.002$] in the first time window (380–560 ms). In the second time window from 1000 to 1140 ms, LAPSE evoked a moderate positive component [$F(1,25)=3.65$, $p=.067$]. Moreover, a significant interaction between the factors region and rhythm condition [$F(2,50)=4.89$, $p=.030$] was revealed. Post-hoc analyses of this interaction by region displayed that this positivity is most pronounced in the parietal region [$F(1,25)=6.60$, $p=.016$]. These effects are in line with our hypothesis that the interplay of lexical and rhythmical deviations in LAPSE evoked the effects for LAPSE in the comparison of LAPSE and NO SHIFT.

Finally, the two control conditions were tested against each other in order to control for effects purely elicited by lexical deviations. This comparison showed no significant differences in the grand averages. The impression of a negative component at the onset is most likely conditioned by the processing of preliminary lexically and rhythmically different noun groups.

4. Discussion

The present paper explored the importance and influence of rhythmic regularities in speech processing by using the method of ERPs. The aim of the study was to show that metrical deviations can even be detected in a natural, not strictly rhythmically regular environment, in contrast to the material used in the studies of Schmidt-Kassow and Kotz (2009a) and Rothermich et al. (2010, 2012). Furthermore, we tried to clarify whether rhythmic deviations evoke a similar biphasic pattern as in the studies mentioned earlier and how these effects can be explained in terms of cognitive processing.

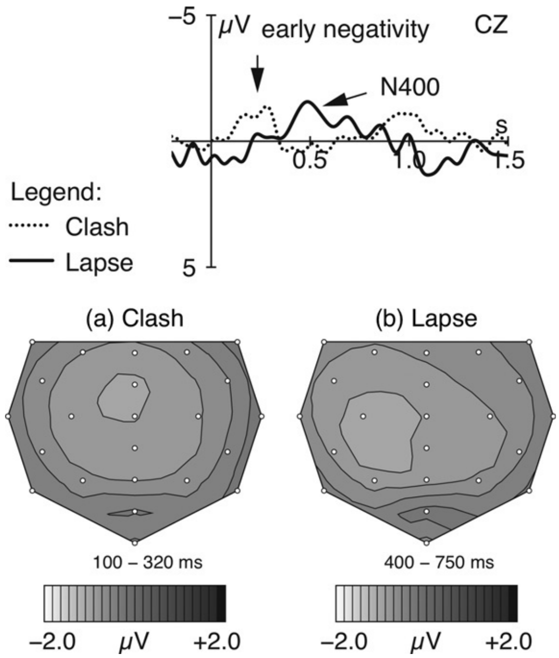

Fig. 6. ERP difference waves contrast the different negativity effects found for CLASH and control condition SHIFT (dotted) and LAPSE and control condition NO SHIFT (solid). Topographic difference maps for the time windows including the negativity effect: (a) CLASH–SHIFT (100–320 ms) and (b) LAPSE–NO SHIFT (400–750 ms).

Our results reveal a biphasic pattern for all tested comparisons. In the following, possible explanations for negativities and positivities found will be discussed in turn together with the behavioral data.

4.1. Negativity effects

The negativity found for CLASH in comparison to (i) SHIFT and (ii) NO SHIFT most likely reflects the error detection in the rhythmical structure of these sentences, i.e., the violation of the Principle of Rhythmic Alternation (see Section 1). The preservation of the lexical stress pattern in the CLASH condition and the early occurrence between 100 and 320 ms cast some doubt on an explanation as a lexical retrieval effect. Hence, we rather interpret this early negativity effect as an instance of a general rule-governed error detection mechanism activated by a rhythmic irregularity. This interpretation is supported by similar results of previous studies focusing on rhythmic deviations (e.g., Schmidt-Kassow & Kotz, 2009a; Rothermich et al., 2010, 2012). Similar to results reported by Rothermich et al. (2010, 2012) for metric deviations, we also found a fronto-central early negativity which might be a subcomponent of an LAN (cf. Hoen & Dominey, 2000). Interestingly, besides other negativity effects found, Rothermich et al. (2012) reported an early negativity elicited by metrically unexpected words. It appears when such words were presented in a metrically controlled, regular context, with task-required focus on the metric structure. In the present study, the context sentence is only controlled for the trigger noun but otherwise not metrically regular. Still, a similar negativity is elicited by the rhythmic deviation of CLASH. Note that a similar component does not only occur in the context of language processing but was also observed in different areas outside of linguistic processes, e.g., in deviations in tone sequences (Brochard et al., 2003; Abecasis et al., 2005; Geiser et al., 2009) and in musical sequences (Patel, Gibson, Ratner, Besson, & Holcomb, 1998; Koelsch et al., 2000), as well as in violations of arithmetic rules (Jost, Beinhoff, Henninghausen, & Rösler, 2004; Núñez-Peña & Honrubia-Serrano, 2004). Functionally, this negativity may be interpreted – comparable to the LAN – as the reflection of recognizing deviations and violations in regular structures. The topography of this negativity also supports this interpretation, since the elicited early negativity has a mainly frontal distribution (see difference brain maps in Figs. 2 and 6). A similar component has also been found in related studies reported earlier (Koelsch et al., 2000; Schmidt-Kassow & Kotz, 2009a; Rothermich et al., 2010, 2012).

Moreover, as the early negativity seems to reflect rather a general than language-specific error detection mechanism, related studies were able to show that this negativity is elicited for rhythmic irregularities irrespective of a matching rhythmic task, i.e., independent of attentional focus towards the rhythmic structure (Schmidt-Kassow & Kotz, 2009a; Rothermich et al., 2010). These findings confirm the independent processing of metrical and rhythmic structures during speech processing and suggest that the negativity found in the present study for CLASH sentences would also be elicited if attentional focus was not on the metrical structure of the sentences heard. This hypothesis is supported by the fact that the present task did not explicitly lead the participants' attention towards the critical structures, but rather in a more general direction of rhythm and meter. We therefore postulate that the early negativity reflects the detection of rhythmic deviations irrespective of task requirements. Since the task was to evaluate the sentences' naturalness rather than to judge rhythmic conditions as correct or incorrect, this task setting was not as explicit as in related studies with clearly explicit and implicit task settings.

The negative component found for LAPSE in comparison to (i) NO SHIFT and (ii) SHIFT might also be explained by the violation of the PRA. The rhythm type of the preceding disyllabic noun (*Féi.er*) allows for a following strong syllable. Hence, stress shift in the following phrasal verb is not only rhythmically unmotivated but also leads to a violation of the PRA and thus an unfulfilled expectation. Furthermore, due to the shifted stress, LAPSE exhibits deviations from the lexical stress pattern, opposed to the verbs in the condition NO SHIFT. Therefore, another interpretation for the negativity found for LAPSE is conceivable, namely that it is an instance of the N400. Previous experiments showed that the deviation from lexical stress patterns increases costs in lexical retrieval, independent from explicit or implicit task settings (Friedrich et al., 2004; van Donselaar, Koster, & Cutler, 2005; Knaus et al., 2007; Magne et al., 2007). This interpretation is supported by the latency of the negativity found for LAPSE in comparison to NO SHIFT at 400 ms post onset and its rather centro-parietal distribution (see Figs. 3 and 6).

Comparing LAPSE with SHIFT, it is important to keep in mind that SHIFT deviates from the lexical stress pattern in the same way as LAPSE does. Nonetheless, the comparison revealed a more pronounced negativity for LAPSE. The lack of a similar negativity effect for the condition SHIFT suggests that the rhythmic irregularity in LAPSE leads to the detection of the lexical deviation in LAPSE and thus that the lexical deviations in SHIFT are rhythmically licensed. Due to the preceding finally stressed noun in SHIFT, a stress shift within the following verb is rhythmically preferred. Further support for this interpretation comes from a study by Rothermich et al. (2012) who showed that the amplitude of an N400 effect evoked by semantically unlicensed words decreases if their stress pattern is in accordance with the surrounding metrically regular pattern in opposition to semantically and metrically deviant forms. This finding is in line with our hypothesis that rhythmic regularity strongly influences the processing of speech. Violations of lexical stress seem hence to be licensed by rhythmic demands. Since stress shift is not rhythmically licensed in LAPSE sentences, it is very likely that the negativity effect induced by LAPSE belongs to the N400 family. This is reinforced by the fact that this effect evolves around 400 ms post onset in both

Table 2
Cross splicing procedure for the critical conditions CLASH and LAPSE.

Condition	Sentence part 1	Sentence part 2
Correct SHIFT	[Sie soll den **Ter'min**]$_{\text{SHIFT}}$	[**ab'sagen**, wie besprochen.]$_{\text{SHIFT}}$
Correct NO SHIFT	[Sie soll die **'Feier**]$_{\text{NO SHIFT}}$	[**'absagen**, wie besprochen.]$_{\text{NO SHIFT}}$
CLASH	[Sie soll den **Ter'min**]$_{\text{SHIFT}}$	[**'absagen**, wie besprochen.]$_{\text{NO SHIFT}}$
Correct NO SHIFT	[Sie soll die **'Feier**]$_{\text{NO SHIFT}}$	[**'absagen**, wie besprochen.]$_{\text{NO SHIFT}}$
Correct SHIFT	[Sie soll den **Ter'min**]$_{\text{SHIFT}}$	[**ab'sagen**, wie besprochen.]$_{\text{SHIFT}}$
LAPSE	[Sie soll die **'Feier**]$_{\text{NO SHIFT}}$	[**ab'sagen**, wie besprochen.]$_{\text{SHIFT}}$

Table 3
Different types of ERP effects in different time windows for all comparisons.

Comparison	Negativity	Positivity	Critical phrases
CLASH and SHIFT	100–320 ms **	850–1150 ms ***	Termín *àbsagen* vs. Termín *absàgen*
LAPSE and NO SHIFT	400–750 ms ***	1050–1280 ms **	Féier *absàgen* vs. Féier *àbsagen*
CLASH and NO SHIFT	250–320 ms * (right anterior)	960–1080 ms *	Termín *àbsagen* vs. Féier *àbsagen*
LAPSE and SHIFT	380–560 ms **	1000–1140 ms * (parietal)	Féier *absàgen* vs. Termín *absàgen*

Statistical significance is indicated by * ($p<.05$); ** ($p<.01$); *** ($p<.001$). Underlined words (*àbsagen*) indicate the critical word's onset for average calculation.

comparisons of LAPSE with NO SHIFT and SHIFT. Hence, the accumulation of lexical and rhythmical violations seems to be responsible for the strong effect for LAPSE, i.e., the hindered lexical retrieval combined with the rhythmic deviation results in a larger N400 effect. This possibility is further supported by the results of the behavioral data and the additional reaction time study, in which the condition LAPSE was evaluated as least natural, even in comparison to CLASH.

The results demonstrate that the brain is sensitive to rhythmic deviations, although some results of previous production and perception studies describe them as possible and unproblematic structures in the use of German (Wagner & Fischenbeck, 2002). What is even more important is the fact that the rhythmic error detection mechanism is also detectable in a rhythmically natural context which does not consist of a repeating trochaic structure, as in the studies by Schmidt-Kassow and Kotz (2009a,b) and Rothermich et al. (2010, 2012). This shows that the brain builds up certain rhythmic expectations along the PRA and is thus able to detect deviations like clash and lapse even in contexts that do not contain strong cues about the rhythmic structure of the incoming speech signal.

4.2. Positivity effects

In most comparisons we observed not only negativities but biphasic ERP patterns. Concerning positivity effects, we observed differences between the two deviation types, as the amplitude of the positivity is very pronounced for LAPSE but reduced for CLASH. Related studies (cf. Knaus et al., 2007; Domahs et al., 2008) assume that a late positive component is a member of the P300 family reflecting the detection and evaluation of the metrical violations in comparison with the correct control conditions. Hence, the component found here is interpreted to reflect the evaluation process which is related to the task requirements. Recall that the participants were asked to evaluate the naturalness of the sentences heard. As stated earlier, this task setting which directed the participants' attention consciously to the rhythmic and metrical features of the sentences heard was responsible for the occurrence of late positive components. This is important, given that related previous studies showed that the reflection of irregularities in rhythm and meter in form of late positive components are only detectable and assessable if the focus lies on the metrical structure (e.g., Knaus et al., 2007; Magne et al., 2007; Schmidt-Kassow & Kotz, 2009b; Rothermich et al., 2010, 2012; Marie et al., 2011). Thus, the positivities elicited here by using a rather explicit task would probably not occur with an implicit task as the late positive components reflect processes related with the evaluation of stimuli. Support for the task-relatedness of this component comes from various studies which interpret the late positive component as a reflection of task-specificity and task-sensitivity (cf. Picton, 1992; Coulson, King, & Kutas, 1998; Knaus et al., 2007; Magne et al., 2007; Domahs et al., 2008, 2009; Domahs, Genc, Knaus, Wiese, & Kabak, 2012; Schmidt-Kassow & Kotz, 2009a,b; Marie et al., 2011). However, although the component seems to be related to the explicit evaluation task, the asymmetrical amplitude patterns of the two critical conditions suggest that the effect found here does not, as in the studies reported earlier, show the comparison of the incorrect stimulus with the built-up expectation. If the positivity purely reflected the detection of a mismatch, both deviant conditions should show more pronounced amplitudes. Therefore, this interpretation cannot explain the present results. The effect rather reflects the degree of complexity and difficulty, i.e., the resolvability of the given task: The easier the evaluation, the stronger the positivity effect. Since LAPSE includes rhythmical and lexical violations, its structure deviates even stronger from expectancy than CLASH, which includes solely a rhythmic deviation. Hence, the sentences including two violations seem to be easier to evaluate as unnatural while the rhythmic deviation in the CLASH sentences seems to be harder to detect and thus to categorize. In comparison with stress clash structures, rhythmically regular structures are therefore easier to evaluate as correct. The particular difficulty of stress clash structures might arise from the fact that the verbs contain a correct lexical stress pattern, but violate the demands of a regular rhythmic structure. Therefore, it may be the case that sentences containing stress clashes are not directly and consciously recognized as deviations. The difficulty to judge sentences including CLASH may lead to higher processing costs, i.e., sentences are retained longer in the auditory working memory for inspection and evaluation as natural or unnatural. Such an explanation is supported by the component's position in the fronto-central area, where auditory working memory is supposed to be located (e.g., Kaiser & Lutzenberger, 2004; Eulitz & Obleser, 2007). However, the connection between a pronounced effect in the fronto-central area measured by an EEG and working memory regions is very speculative, since the spatial resolution of ERPs is poor. Therefore, this locality hypothesis needs to be further tested with a method that offers higher spatial resolution, for example fMRI.

The results of the reaction time study complement the interpretation of decelerated evaluation: The comparison of CLASH and SHIFT showed that significantly more time was needed for the evaluation of sentences including a stress clash, whereas no significant reaction time difference was found for LAPSE and its control condition NO SHIFT. Moreover, the behavioral data revealed that only LAPSE was judged as unnatural. The behavioral data support the idea that the deviations in CLASH are perceived more unconsciously and are therefore harder to detect. Additional support for our interpretation of the reduced positivity found for CLASH comes from a study by Domahs et al. (2009). In this study, the comparison of existing words with well-formed pseudo-words and phonotactically deviant non-words showed clearly that correct evaluation of existing as well as non-words is easier and hence faster than the evaluation of well-formed pseudo-words, as these pseudo-words can neither be rejected as easily as non-words, nor be accepted as correct like existing words. The amplitude of the positive component for this word type was also less pronounced in comparison to the amplitudes of the other two word types.

A recent study on the processing of Turkish word stress (Domahs et al., 2012) illustrates the relation between task resolvability and the occurrence of a late positive component, as well: Words with violations of the default pattern elicited strong positivity effects while no pronounced positivity could be found for words incorrectly stressed with the default pattern. Turkish participants had difficulties to judge the default as incorrect. This process is reflected by a largely reduced positive curve progression. Further, in a study by Schwartze, Rothermich, Schmidt-Kassow, and Kotz (2011), smaller P3b effects were elicited for deviations in temporally irregular structures, whereas the embedding of deviant tones in an isochronous structure led to a more pronounced positivity effect. The authors interpreted the stronger amplitude as a reflection of facilitated processing due to facilitation of the given task via temporal regularity. Hence, also these results endorse our interpretation of the late positive component reflecting the degree of task-resolvability. Note that while a pronounced amplitude for this late positive component reflects processing facilitation, the opposite is true for the negativities reported in this study, where larger amplitudes reflect enhanced processing costs. Thus, amplitude strength cannot be interpreted consistently as a reflection of processing costs (cf. Domahs et al., 2009, 2012; Rothermich et al., 2012).

The late positive components reflect the characteristic features of the P3b component found in previous related studies (e.g., Knaus et al., 2007; Magne et al., 2007; Domahs et al., 2008, 2009, 2012; Schwartze et al., 2011). Interestingly, all these effects labeled as a "P300" developed in time windows with an onset at around 500 or 800 ms (Magne et al., 2007), 500–1100 ms (Knaus et al., 2007), and 500–900 ms (Domahs et al., 2008), i.e., these effects show similar latencies as the positive components in the present study. The variability of latency of the P300 across studies can be explained by the nature of the stimuli used: In the processing of auditory stimuli, the effect's latency depends on the acoustic signal and the position of the stressed syllable in the speech signal. For instance, Domahs et al. (2008) observed that the evaluation positivity was time-locked with the occurrence of stressed syllables, i.e., stress shifts from final to initial syllables (e.g., *ˈVitamin instead of Vitaˈmin) elicit an earlier positivity effect than shifts from initial to final syllables (e.g., *Anaˈnas, ˈAnanas) (Domahs et al., 2008). This is line with the latency onsets of the positivity effects in the present study: The reduced late positive component found for CLASH structures has an earlier occurrence than the enhanced positive component found for LAPSE whose onset is 200 ms later.

The amplitude differences of CLASH and LAPSE as well as the behavioral data and the reaction time data show that unlicensed stress shifts are less acceptable than stress clashes, since they not only disrupt rhythmic alternation but also complicate lexical retrieval due to the violated lexical stress pattern. This is reflected by the N400 effect found for LAPSE. This violation enhances the evaluation of lapses as unnatural, shown by a pronounced following positive component. On the contrary, stress clashes require more complex processing due to their structure: They maintain the lexical stress pattern, but the compliance with lexical stress rules violates the demands of a regular rhythmic structure, leading to an early negativity effect and a reduced positivity for CLASH. Finally, the lack of ERP differences between the two control conditions NO SHIFT and SHIFT further supports the assumption that the observed effects are purely induced by metrical irregularities in the critical conditions. These results support the assumption that such effects may also be generalizable to other stress-timed languages such as English, for which even stronger rhythmical adjustments on stress positions can be observed in comparison to German (Liberman & Prince, 1977; Grabe & Warren, 1995; Vogel et al., 1995; see Section 1). Future work has to show how rhythmical regularities generally influence the production and perception of word stress.

5. Conclusion

The present results show that the phenomenon of rhythmically induced stress shifts plays an important role in the processing of German. The data confirm that rhythmic irregularities are perceived and processed differently from well-formed structures, even in natural contexts. This can be seen not only from the results for the explicit judgment of naturalness but also, and more importantly, from the detected ERP and reaction time data which reflect more implicit processes. These findings contradict the proposition that constant rhythmic patterns are a purely perceptual repair phenomenon. Our data suggest that alternating structures are indeed distinguished from rhythmically deviating structures, as our results illustrate the brain's sensitivity to even small rhythmic deviations which can be produced and perceived by Germans.

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The relevance of rhythmical alternation in language processing: An ERP study on English compounds

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ABSTRACT

This study investigates the influence of rhythmic expectancies on language processing. It is assumed that language rhythm involves an alternation of strong and weak beats within a linguistic domain. Hence, in some contexts rhythmically induced stress shifts occur in order to comply with the Rhythm Rule. In English, this rule operates to prevent clashes of stressed adjacent syllables or lapses of adjacent unstressed syllables. While previous studies investigated effects on speech production and perception, this study focuses on brain responses to structures either obeying or deviating from this rule. Event-related potentials show that rhythmic regularity is relevant for language processing: rhythmic deviations evoked different ERP components reflecting the deviance from rhythmic expectancies. An N400 effect found for shifted items reflects higher costs in lexical processing due to stress deviation. The overall results disentangle lexical and rhythmical influences on language processing and complement the findings of previous studies on rhythmical processing.

1. Introduction

The distribution of word stress in English compounds and phrases ("*thirtèen mén*") is a phenomenon frequently discussed especially in the framework of Metrical Phonology (Hayes, 1984; Liberman & Prince, 1977; Nespor & Vogel, 1989; Selkirk, 1984). Under embedding, two stressed syllables may be placed adjacently leading to a so-called stress clash. In order to avoid such clashes, the stress pattern of the first word can be reversed (*thirtéen* → *thìrteen mén*). This phenomenon occurs in various other languages, e.g., German (see Kiparsky, 1966; Wiese, 1996). In German, secondary stress can be moved away from a clashing primary stress especially in compounds (*Háuptbàhnhof* → *Háuptbahnhòf 'main train station'*) but also in phrases containing phrasal verbs (*Termín àbsagen* → *Termín absàgen 'cancel appointment'*).

These rhythmic adjustments appear highly systematically in different languages although word stress is normally preserved under embedding (Liberman & Prince, 1977; Truckenbrodt, 2006). As these types of stress shifts clearly violate this requirement, there have to be factors overriding this stress preservation rule in the case of potential stress clashes (Selkirk, 1995). Several approaches tried to give an explanation for this exception (Hayes, 1984; Liberman & Prince, 1977; Ries, 1907; Selkirk, 1984; Speyer, 2010; Sweet, 1875). Irrespective of more or less fine-grained differences, all approaches share the assumption that stress shifts produce an even, alternating sequence of stressed and unstressed syllables. Therefore, stress shifts seem to be applied in order to achieve an ideal rhythm of alternating strong and weak units. The trigger for this process is hence of rhythmic origin, an instantiation of the Rhythm Rule (RR), a repair strategy to avoid sequences of stressed or unstressed syllables (Liberman & Prince, 1977). The output of the RR resembles alternating beat sequences in musical structures. Both music and language try to obey the so-called Principle of Rhythmic Alternation (PRA) which demands a harmonious alternating string of stressed and unstressed syllables or beats. Hence, stressed and unstressed units are preferred to alternate in a rhythmically ideal pattern (Abercrombie, 1967; Cooper & Meyer, 1960; Selkirk, 1984; Sweet, 1875/76). However, this principle can only be obeyed to varying degrees, as strict regularity/periodicity is and cannot be given in natural language.

This principle of alternating units can not only be violated by stress clashes but also by sequences of unstressed syllables, so-called stress lapses (Selkirk, 1984). There is some dispute how many adjacent unstressed syllables can be interpreted as a real lapse (cf. Nespor & Vogel, 1989; Plag, 1999; Selkirk, 1984), but

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according to the strict definition of the PRA and to metrical theories, even two adjacent unstressed syllables can be considered as a lapse structure. However, there is some consensus that stress clashes are generally less acceptable than lapses (Nespor & Vogel, 1989).

As mentioned above, an alternation of stressed and unstressed syllables without exception is not achievable in natural language. However, the English language seems to obey the PRA to a large extent, as the attempt to achieve an alternating pattern of syllables has influenced the development of English grammar and especially its prosodic structure (Schlüter, 2005). Many studies reveal that especially lexical phonology is heavily influenced by rhythmic preferences. For example, it is argued that stress patterns of nouns and verbs were shaped by following rhythmic preferences (Kelly, 1988; Kelly & Bock, 1988).

This strong influence of rhythm is also motivated by the circumstance that English belongs to the group of stress-timed languages. Following Pike (1945) and Abercrombie (1965), Abercrombie (1967), languages can be divided into stress-timed (i.e., stressed syllables are isochronous) and syllable-timed languages (i.e., all syllables are distributed isochronously). Although the theory of isochrony has turned out to be phonetically and physically untenable (e.g., Beckman, 1992; Bolinger, 1965; Roach, 1982), the classification types have been maintained (Kleinhenz, 1996) as two extremes of a continuum (e.g., Auer & Uhmann, 1988; Roach, 1982). On this continuum, English represents important characteristic features of the stress-timed languages, and as such is particularly influenced by the concept of rhythmic alternation, irrespective of physical or psychological isochrony (cf. Couper-Kuhlen, 1986; Hayes, 1984; Liberman & Prince, 1977; Selkirk, 1984). Moreover, the trochee, a foot consisting of a strong syllable followed by a weak one, is not only a common rhythmic pattern in English but is also considered as its preferred structure (Dresher & Lahiri, 1991; Selkirk, 1984; Shapiro & Beum, 1965). Thus, a strategy like the RR turning potential stress clash structures into a regular trochaic structure (*champàgne cócktails* → *chàmpagne cócktails*) is a highly attractive option.

1.1. Advantages of rhythmic regularity

Rhythmic alternations are not only advantageous in relation to language structure but also for speech perception (Cutler & Foss, 1977) and in early language acquisition (Jusczyk, 1999; Nazzi & Ramus, 2003). Various studies revealed the supportive function of alternating rhythmic structures for the speech segmentation process and language processing (Cutler & Foss, 1977; Cutler & Norris, 1988; Grosjean & Gee, 1987; Mattys, 2000; Rothermich & Kotz, 2013): rhythmic regularity helps building up expectations when the next stressed syllable might appear.

Moreover, even sequences of stressed and unstressed units seem to be easier to memorise and thus more efficient in terms of processing (Auer & Uhmann, 1988; Bolinger, 1981). Indeed, deviations from rhythmic regularity slow down speech production and increase the speech error probability (Tilsen, 2011). Stress clashes in a sequence of disyllabic words (e.g., *SUBway*, *REAson*, ***deLUXE***, ***PERmit***) cause a decelerated reaction in speech perception (Pitt & Samuel, 1990) and are thus an obstacle in language processing. A reaction time study (Bohn, Knaus, Wiese, & Domahs, 2013) on rhythmic irregularities in German phrases showed that stress clash structures need more time to be evaluated and processed compared to rhythmically regular structures. Regarding the English language, aiming at an even rhythm seems to be an underlying, unconscious constraint in speech production: a study by Kelly and Bock (1988) revealed the tendency of English speakers to assign stress to non-words in a way that their stress patterns blend harmoniously into a regular sentence rhythm pattern.

1.2. Realisation of the Rhythm Rule: perception and production studies

The influence of the RR and its implementation in language production and perception has been studied thoroughly. However, the existing results to date are not fully conclusive. Different studies claimed that there is no acoustic evidence for a real shift of prominence within potential stress shift items (e.g., Cooper & Eady, 1986; Grabe & Warren, 1995; Vogel, Bunnell, & Hoskins, 1995). However, listeners declare to perceive proper stress shifts regularly, albeit only when presented in a shift-triggering context (e.g., *-TV* in *TV soaps* but *T̂V* when presented in isolation; Grabe & Warren, 1995). These findings support the conclusion that stress shifts are rather a purely perceptual phenomenon than an option in language production: several studies found evidence for rhythmic biases in perception, i.e., to hear rhythmically alternating patterns even when they are non-existent (Allen, 1975; Auer & Uhmann, 1988; Lehiste, 1977). Moreover, some authors argue that the perception of stress shifts is due to the tendency to place pitch accents at the left edge of constituents (Bolinger, 1958, 1965; Shattuck-Hufnagel, 1995). Grabe and Warren (1995) suggest that potential stress shift items like premodifiers (e.g., *insane*, *sixteen*, *unfair*) might not possess fixed default stress in their lexical prosodic form, but that their stress assignment is context-dependent in order to prevent potential clash situations, i.e., stress falls on the initial syllable in prenuclear positions when the following word is in nuclear position, otherwise it might be stressed on the final syllable.

However, the RR cannot only be realised by producing real stress shifts (Reversal Analysis) but also by destressing or reducing the prominence of a clashing syllable (Deletion Analysis, Selkirk, 1984; Vogel et al., 1995). Indeed, destressing seems to be the dominant production strategy in English (Horne, 1990; Vogel et al., 1995). Vogel et al. (1995) showed that the final syllable of a word like *thirteen* is significantly reduced in its duration and fundamental frequency (F_0) in clash contexts (e.g., *thirteen mén*) compared to non-clash contexts (e.g., *thirteen cadéts*). Hence, instead of stress reversal, the prominence of the clashing syllable is reduced. Listeners are nonetheless able to hear stress shifts which is due to the weakening of the final syllable making the initial syllable perceptually stronger. Closer examination of the data by Grabe and Warren (1995) reveals similar results: the two syllables of stress shift items are equalised in their duration and F_0 in clash situations compared to non-clash contexts.

The results obtained from studies with aphasic patients (Gandour & Baum, 2001; Grela & Gandour, 1999) also support the RR being a systematically used phonological rule in English. Although left-hemisphere damaged patients – in contrast to non-neurological control participants – did not show significant phonetic evidence for producing stress reductions, they also tried to produce requested stress shifts. Phonetic analysis showed that the lack of ability to destress the affected syllable is due to a deficit in producing adequate syllable durations in general. Apparently, all speakers try to adapt stress patterns to the rhythmic context.

Most of the studies cited state that the two avoidance strategies are not only optional and speaker-dependent but also highly variable in general. Since the RR is not an obligatory rule, phrases including stress clashes can generally be realised. However, in these cases another strategy is used which diminishes the rhythmic disharmony: the affected syllable can be lengthened instead and is additionally followed by a pause, inserted before the following word (Hayes, 1984; Liberman & Prince, 1977; Nespor & Vogel, 1989). This shows the apparent difficulty for speakers to produce real stress clashes within a phonological phrase. By syllable lengthening and pause insertion, one phrase is split up in two. Hence, the clashing elements are not any longer in the same phonological phrase, which seems to be the domain for RR application (Nespor & Vogel, 1986).

Although previous studies do not fully agree on matters of the realisation of the RR, they all concur on the view that it is existent not only on a perceptual but also an articulatory level and thus plays an important role in English.

1.3. ERP studies on rhythmic regularity and rhythmic processing

To date, there have been numerous production and perception studies on the influence of rhythmic regularity. In contrast, only a few psycholinguistic and especially neurolinguistic studies have been conducted on the role of rhythm and prosody.

ERP studies of the last few years showed that prosodic information is important and influences auditory processing on a lexical as well as on a structural level (e.g., Domahs, Wiese, Bornkessel-Schlesewsky, & Schlesewsky, 2008; Friedrich, Kotz, Friederici, & Alter, 2004; Steinhauer, Alter, & Friederici, 1999). It has also been shown that supra-segmental information plays an important role in language processing. For instance, deviations of basic phonetic cues such as pitch, duration, and intensity in speech and music sounds evoke biphasic ERP patterns consisting of an early negativity (N2b), an MMN (mismatch negativity) and a P300 (Tervaniemi et al., 2009). The importance of rhythm and metrics in language (Bohn et al., 2013; Magne et al., 2007; Marie, Magne, & Besson, 2011; Rothermich, Schmidt-Kassow, & Kotz, 2012; Rothermich, Schmidt-Kassow, Schwartze, & Kotz, 2010; Schmidt-Kassow & Kotz, 2009a,b) as well as in musical structures (Geiser, Ziegler, Jancke, & Meyer, 2009; Koelsch, Gunter, Friederici, & Schröger, 2000; Koelsch & Sammler, 2008) has been revealed by various studies, supporting the status of the PRA as an important link between the structures of language and music.

These studies showed that the brain clearly reacts to rhythmic deviations if an expected rhythmic structure is not met. In most studies using ERPs, this was reflected by a biphasic pattern: a negativity followed by a late positive component. However, the reported components have been interpreted differently. While Knaus, Wiese, and Janßen (2007), Magne et al. (2007), and Marie et al. (2011) report an N400 effect for incorrect stress patterns which reflects higher costs in lexical retrieval, Schmidt-Kassow and Kotz (2009a) suggest that the similar negativity effect they had found might rather be a subcomponent of a left anterior negativity (LAN), although they also consider increased costs in lexical retrieval as a possible source of this effect. They argue that the higher efforts evoked by metrical violations may reflect a general rule-based error-detection, as postulated by Hoen and Dominey (2000). Marie et al. (2011) also found a negative component and consider this interpretation as well. Support for the interpretation of this component as an LAN comes from further studies which explain the reported negativity as a response to the detection of metrical errors in auditory processing (Abecasis, Brochard, Granot, & Drake, 2005; Brochard, Abecasis, Potter, Ragot, & Drake, 2003; Rothermich et al., 2010, 2012). In the study by Bohn et al. (2013) on German rhythmic irregularities, both described negativities were found, an N400 effect for lexical deviations in form of incorrect stress patterns as well as an LAN-like component elicited by rhythmical deviations in form of stress clashes.

The following component, a subsequent positivity, only occurs if the participants' attention is directed towards the metrical structure by the given task (Domahs et al., 2008; Knaus et al., 2007; Magne et al., 2007; Marie et al., 2011; Rothermich et al., 2012; Schmidt-Kassow & Kotz, 2009b; Tervaniemi et al., 2009). Hence, a late positive component represents a task-sensitive evaluation and reanalysis mechanism (Domahs et al., 2008; Schmidt-Kassow & Kotz, 2009a). However, labelling of this component also varies in the studies mentioned. Some researchers (Domahs et al., 2008; Knaus et al., 2007; Magne et al., 2007; Tervaniemi et al., 2009) assume their positivity effects to be members of the P300 family, whereas Schmidt-Kassow and Kotz (2009a,b), Marie et al. (2011), and Rothermich et al. (2012) describe it as a P600. This is probably due to the fact that it resembles the 'classic' P600 which is interpreted as a correlate of syntactic reanalysis processes (e.g., Steinhauer et al., 1999).

As can be seen from the studies presented, the on-line processing of rhythmic deviations has been given some attention in psycho- and neurolinguistic research. With regard to the influences of the RR on rhythmic regularity, i.e., the presence or absence of rhythmically induced stress shifts, little is known yet, however. Thus, the importance of the RR in the English language remains to be tested using the ERP technique.

1.4. ERP study on the RR: hypotheses

The present study investigated the question how rhythmical alternations or, rather, deviations from alternating patterns in form of stress clashes and lapses in the English language are processed in the brain. A similar study on well-formed rhythmic structures in comparison to stress clashes and lapses in German (Bohn et al., 2013) showed that rhythmic irregularities are indeed perceived and processed differently from well-formed structures. However, these rhythmic deviations can – at least according to preceding production and perception studies – be perceived and produced by Germans.

For English, the production and perception studies mentioned draw different conclusions on this topic but agree on the point that the RR is a relevant yet optional process. Thus, it is important to see how the brain reacts to similar deviations in this language.

Assuming that the application of the RR is optional, stress clashes might possibly be perceived as well-formed in English. Moreover, some authors regard rhythmically induced stress shifts to be a purely perceptual phenomenon. Hence, rhythmic deviations in form of stress clashes might not evoke different brain responses compared to alternating structures when presented in a shift-triggering context. They might also be perceived as stress shifted. If, however, stress clashes are perceived as a rhythmic irregularity and are processed differently from well-formed stress shifted structures, this should become visible in the ERP waveforms. Moreover, the question arises whether stress lapses, which are regarded as less problematic than clashes, are processed differently as well.

Thus, the main question is whether detectable general differences between well-formed structures and rhythmic deviations appear and whether the two different deviation types (clash and lapse) show processing differences as they did in a study on German rhythmic irregularities (Bohn et al., 2013). Therefore, we expect that a study utilising event-related potentials (ERPs) will deliver a finer-grained picture of the acceptability of rhythmically ill-formed structures in language processing. Furthermore, due to the varying results from previous production and perception studies (see Section 1.2), additional evidence is needed on how stress clashes are perceived and evaluated by listeners, and how this meta-linguistic evaluation (behavioural data) might possibly differ from the brain's reaction (EEG data). In order to gain such behavioural data, the participants' task in the present study was to judge the prosodic naturalness of the sentences presented (see also Section 2.2). With regard to the results of previous related ERP studies, a further objective was to clarify the nature of the negativity effect (N400 vs. LAN) by combining lexical and rhythmic deviations. The present study addresses this issue and will provide further insight into the question how rhythmic predictability and violations of these predictions influence language processing.

Due to the fact that rhythmically induced stress shifts in English occur in the word preceding the shift-triggering word, the legitimacy of a stress shift is not clear when the shifted word is encountered. Therefore, it should be possible to disentangle lexical and rhythmical negativity effects. Lexical deviations in form of shifted word stress should further provide some insight into the accuracy of Grabe & Warren's (1995) proposal that potential stress shift items carry context-dependent instead of default lexical stress. If so, no N400 effect should be detectable for stress shifted items in this study since an N400 effect would reflect a more complex lexical retrieval process. The rhythmic deviations, on the other hand, could evoke an LAN-like component reflecting the detection of rhythmic errors.

2. Methods

2.1. Stimuli

For the investigation of electrophysiological effects correlated with the RR, we selected phrases of the "*thirteen men*" type as experimental stimuli. More precisely, compounds and phrases consisting of two words that build a premodifier + noun combination were chosen. The disyllabic modifier was either an adjective (*idéal*), a numeral (*thirtéen*), or a noun (*champágne*) with lexical stress on the final syllable, followed by a disyllabic noun bearing compound stress (*pártners*, *cadéts*). This fact is crucial since stress clashes are resolved by shifting the weaker one of the two involved stresses away from primary stress (Kiparsky, 1966; Liberman & Prince, 1977) or by reducing its prominence (Selkirk, 1984; Vogel et al., 1995). For instance, in a noun-noun-compound like *champàgne cócktails*, final stress of the modifier can be shifted leftwards to its initial syllable: *chàmpagne cócktails*. If the following disyllabic noun bears stress on its final syllable, a shift is unnecessary. Thus, secondary stress remains on the final syllable of the modifier: *champàgne dessérts*.

To detect how the brain reacts to these different stress combinations, 15 two-word-structures consisting of a disyllabic premodifier (stress shift target) and a following disyllabic noun were created. To derive a balanced set of conditions with and without stress shift, two different stress patterns were chosen for the disyllabic head nouns: the finally stressed modifier (e.g., *champágne*) was (1) followed by a head noun with final stress (e.g., *dessérts*; NO SHIFT condition) and (2) followed by a head noun with initial stress (e.g., *cócktails*; SHIFT condition).

Head nouns used in both conditions were overall checked and matched for frequency using corpus-based monolingual English dictionaries, provided by "Corpora Wortschatz Universität Leipzig" (Projekt Deutscher Wortschatz 1998–2012).

All two-word-structures of each condition were embedded into a carrier sentence which ensured that the target phrases were located at identical sentence positions. Additionally, 184 filler sentences were included, 92 with correctly and 92 with incorrectly stressed disyllabic verbs. The filler items were embedded into different sentence contexts in order to provide a greater variety of sentence constructions. For illustration of the stimuli constructed and their embedding, see Table 1.

Stimuli were recorded with a sampling rate of 44.1 kHz and a 16 bit (mono) sample size in an anechoic room. For recording and stimuli preparation, the sound recording and analysis software Amadeus Pro (version 1.5.4, HairerSoft) and an electret microphone (Beyerdynamic MC 930C) were used.

Table 1
Experimental conditions and filler items.

Condition	Example
Correct SHIFT	The **'champagne** 'cocktails are very pricey
Correct NO SHIFT	The **cham'**pagne de'sserts are very delicious
CLASH	The **cham'**pagne 'cocktails are very pricey
LAPSE	The **'champagne de'**sserts are very delicious
Filler correct	I like to **in'**vite good friends
Filler incorrect	*I like to **'invite** good friends

* Words written in bold illustrate the critical phonological phrase/verb. An asterisk illustrates sentences containing incorrectly stressed words.

All sentences of the conditions SHIFT and NO SHIFT were recorded and spoken naturally by a female native speaker of British English at a normal speech rate. In order to create the two violation conditions CLASH and LAPSE, each sentence was cut between premodifier offset and onset of the head noun. The resulting sentence fragments of SHIFT and NO SHIFT conditions were cross-spliced (see Table 2). Thus, a finally stressed premodifier *champágne* was followed by an initially stressed head noun *cócktails* (CLASH condition), and an initially stressed premodifier *chámpagne* was followed by a finally stressed head noun *dessérts*. By using this cross-splicing technique, we were able to obtain two rhythmically deviant conditions without manipulating phonetic parameters. Besides, this technique ensured that identical realisations of shifted words were used in the conditions SHIFT and LAPSE and of unshifted words in the conditions NO SHIFT and CLASH.

It is crucial to point out that not only the sentences of the conditions CLASH and LAPSE were created via splicing but also the sentences of the well-formed conditions SHIFT and NO SHIFT in order to avoid a splicing effect only for deviant conditions. For this purpose, each sentence of the two control conditions was recorded twice and the first sentence part of recording 1 was spliced with the final sentence part of recording 2. The same procedure was applied to all filler sentences. Finally, all stimuli were controlled for and normalised in loudness, i.e., the volume of all sentences was adjusted to a comparable level of volume throughout all used stimuli. This loudness adjustment was carried out by the corresponding author using the sound recording and analysis software Amadeus Pro (version 1.5.4, HairerSoft).

To guarantee that participants would encounter distinguishable shifted and unshifted words in the control conditions and real rhythmic violations in the critical conditions, a phonetic analysis was conducted. This analysis confirmed that the speaker had produced real stress shifts in the condition SHIFT by reversing the prominence of F_0 over the two syllables. In addition, final syllables (in SHIFT condition) were significantly shortened in comparison to the initial syllables and also in comparison to the final syllables of the NO SHIFT condition. These results suggest that F_0 and duration seem to be decisive factors for the realisation of stress shifts in (British) English. They also speak against the "early accent" account which suggests that the first pitch of a phrase tends to be positioned generally as early as possible at the left edge of the phrase (see Section 1.2). Since only words in the SHIFT condition carry higher pitch on the initial syllable, but not in the NO SHIFT condition, the present stimuli do not support the early accent account. Fig. 1 demonstrates the differences between shifted and unshifted items using the example of the item *ideal* and its realisation in the two phrases *ideal trainees* (NO SHIFT, left) and *ideal partners* (SHIFT, right).

The speaker produced real prominence reversals within the modifying nouns, thus, cross-splicing of both conditions ensured that the participants heard clear stress clashes (two adjacent stressed syllables) in the sentences of the CLASH condition and two adjacent unstressed syllables in the LAPSE condition.

2.2. Procedure

The sentences of the four experimental conditions were presented twice resulting in 30 sentences for each condition for data analysis. In total, 304 stimuli (30 per condition and 184 fillers) were distributed over eight blocks consisting of 38 sentences each, each taking approximately five minutes. In order to avoid sequence effects, the order of blocks varied across participants. Sentences of the critical and filler conditions were presented in a pseudo-randomised order, and each premodifier (stress shift target)

Table 2
Cross-splicing procedure for the critical conditions CLASH and LAPSE.

Condition	*Sentence part 1*	*Sentence part 2*
Correct NO SHIFT	[The **cham'pagne**]$_{\text{NO SHIFT}}$	[**de'sserts** are very delicious.]$_{\text{NO SHIFT}}$
Correct SHIFT	[The **'champagne**]$_{\text{SHIFT}}$	[**'cocktails** are very pricey.]$_{\text{SHIFT}}$
CLASH	[The **cham'pagne**]$_{\text{NO SHIFT}}$	[**'cocktails** are very pricey.]$_{\text{SHIFT}}$
Correct SHIFT	[The **'champagne**]$_{\text{SHIFT}}$	[**'cocktails** are very pricey.]$_{\text{SHIFT}}$
Correct NO SHIFT	[The **cham'pagne**]$_{\text{NO SHIFT}}$	[**de'sserts** are very delicious.]$_{\text{NO SHIFT}}$
LAPSE	[The **'champagne**]$_{\text{SHIFT}}$	[**de'sserts** are very delicious.]$_{\text{NO SHIFT}}$

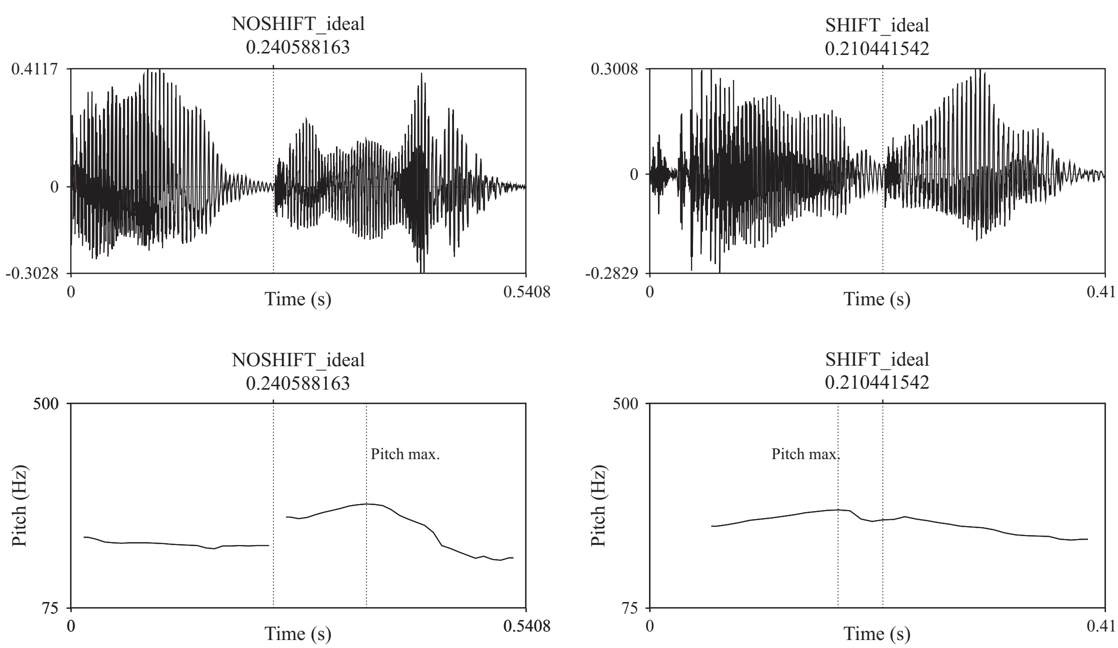

Fig. 1. Waveforms and pitch contours of the word *ideal*. Left column: initially unstressed version from the phrase *ideal trainees* (NO SHIFT). Right column: initially stressed version from the phrase *ideal partners* (SHIFT).

appeared only once within each block. During the experiment, participants were seated in front of a computer screen in a dimly lit, sound-attenuating room. The experiment started after a short practice phase.

Each trial started with the presentation of a fixation cross for 500 ms on the centre of the computer screen. This visual cue was followed by the auditory presentation of the sentences via two loudspeakers. The fixation cross disappeared from the screen after the offset of the sentences and a question mark came up with a time-out of 2000 ms. Participants were instructed to evaluate the sentences by pressing one of four specific buttons as soon as the question mark appeared. Their task was to decide as accurately and as fast as possible whether the presented sentences sounded prosodically natural or unnatural. The assignment of buttons to four possible answers (natural, rather natural, rather unnatural, unnatural) was counterbalanced across participants. Given that rather small irregularities in rhythm are only detectable and assessable if the focus is on metrical structure (e.g., Knaus et al., 2007; Rothermich et al., 2012; Schmidt-Kassow & Kotz, 2009b), this explicit prosodic task was important to direct the participants' attention to the metrical features of the sentences. After key response, the next trial started with an intertrial interval of 2000 ms. Between blocks, participants were offered a short break to rest their eyes. All procedures were performed in compliance with relevant laws and institutional guidelines.

2.3. Participants

Seventeen (nine women) right-handed monolingual native speakers of English with normal or corrected-to-normal vision participated in the experiment. None of the participants had hearing deficits. Their mean age was 24 years (age range 20–30 years). Each participant was paid for taking part. All participants gave their informed consent to this study and privacy rights were thoroughly obeyed.

2.4. ERP recording

An electroencephalogram (EEG) was recorded from 24 Ag/AgCl electrodes, mounted on an elastic cap (EasyCap), with a *NeuroScan SynAmps* (Compumedics) amplifier. The C2 electrode served as ground electrode and the left mastoid electrode served as on-line reference. EEG recordings were re-referenced off-line to averaged mastoids. Four electrodes measured the electrooculogram (EOG), i.e., horizontal and vertical eye movements, in order to control for eye movements and blinks. EEG and EOG were recorded continuously with a sampling rate of 500 Hz and filtered offline with a 0.3–20 Hz bandpass filter. This filter was chosen in order to remove slow drifts from the signal. By using this filter setting, stimulus-independent differences that might occur between compared conditions can be avoided without performing a baseline correction (cf. Wolff, Schlesewsky, Hirotani, & Bornkessel-Schlesewsky, 2008, for a similar method of data analysis). All electrode impedances were kept below 5 kΩ.

For data analysis, all individual EEG recordings were automatically scanned for artefacts from eye or body movements, and artefacts with an amplitude above 40 microvolt were removed from the data set. Subsequently, all single-trial waveforms were individually screened for further artefacts. As a result of these inspections, 2.8% of the critical stimuli contained in the comparison of shifted and unshifted words, 3.4% of the critical stimuli for all other comparisons, and 3.7% of the filler items were excluded from analysis.

2.5. Data analyses

Behavioural data were analysed by calculating the arithmetical mean of all responses for each condition. Therefore, each of the four possible response levels was allocated to a numerical value: 1 = natural, 2 = rather natural, 3 = rather unnatural, and 4 = unnatural. The arithmetical means were analysed using a Wilcoxon signed-rank test. In order to prevent movement artefacts, this evaluation response was given with a delay after the offset of each sentence (see Section 2.2). As the measured reaction times were thus not meaningful, they are not reported here.

For the EEG data, the following Regions of Interest (ROIs) were statistically analysed using multifactorial repeated-measures ANOVAs with the factors Region: (i) frontal (F3, FZ, F4), central (C3, CZ, C4), parietal (P3, PZ, P4); (ii) left anterior (F3, FC1, FC5), right anterior (F4, FC2, FC6), left posterior (P3, CP1, CP5), and right posterior (P4, CP2, CP6) and TargetStress (initial stress vs. final stress, for the comparison in Section 3.2.1) or RhythmCondition (well-formed vs. ill-formed, for the comparisons in Sections 3.2.2 and 3.2.3), respectively. Grand averages were calculated from two positions: (i) from the onset of the premodifier up to 1000 ms and (ii) from the onset of the head noun up to 1200 ms, both with a pre-stimulus baseline of 200 ms. Based upon visual inspection of the grand average curves and on hypotheses taken from the literature on rhythmical processing (Bohn et al., 2013; Domahs, Kehrein, Knaus, Wiese, & Schlesewsky, 2009; Domahs et al., 2008; Knaus et al., 2007; Magne et al., 2007; Rothermich et al., 2010; Schmidt-Kassow & Kotz, 2009a), time windows for each paired comparison were chosen for analysis. The specific time windows are reported in the Results section. Reported results will refer mainly to the quadrant regions. For effects with more than one degree of freedom, Huynh-Feldt (1976) corrections were applied to p-values.

3. Results

3.1. Behavioural data

The Wilcoxon signed-rank test revealed that CLASH was evaluated as less natural than SHIFT (mean 2.39 (SD .51) vs. mean 1.99 (SD .40); $Z(16) = -2.77$, $p = .006$). Furthermore, its arithmetical mean value shows that it was considered as least natural in comparison to all other conditions (on a scale from 1 = natural to 4 = unnatural). On the contrary, sentences of the critical condition LAPSE were evaluated almost as natural as its control condition NO SHIFT (mean 2.24 (SD .35) vs. mean 2.23 (SD .45); $Z(16) = -.05$, $p > .05$). A comparison of the two deviation conditions CLASH and LAPSE showed that CLASH was evaluated as less natural than LAPSE (mean 2.24 (SD .35) vs. mean 2.39 (SD .51); $Z(16) = -2.86$, $p = .004$).

3.2. ERP data

Figs. 2–4 show that biphasic patterns were found for (i) stress shifted items in comparison to unshifted items (SHIFT_C1 vs. NOSHIFT_C1) and (ii) for both rhythmically ill-formed structures CLASH (CLASH_C2 vs. SHIFT_C2) and LAPSE (LAPSE_C2 vs. NOSHIFT_C2). These will be reported in the following sections in more detail.

A comparison of correct and incorrect filler conditions revealed a similar biphasic effect pattern consisting of an N400 between 400 and 600 ms ($F(1, 16) = 38.59$, $p = .000$) and a following positivity between 700 and 1300 ms ($F(1, 16) = 18.67$, $p = .001$). The N400 effect found is interpreted to reflect the increased costs in lexical retrieval due to stress violation in the included verbs. This result confirms that participants were able to detect and evaluate clear deviations of word stress.

Note that the comparisons regarding rhythmic influences are measured from the onset of the context trigger item, i.e., the second word of the used two-word-structures. This is necessary because the rhythmic properties cannot be evaluated on the basis of the premodifier alone but only on the basis of the premodifier-head-construction. Moreover, by comparing identical head nouns preceded by shifted or unshifted modifiers, lexical differences inherent to the nouns can be excluded as factors influencing the observed ERP effects. Rather, the effects found can be ascribed to the rhythmical deviation.

3.2.1. Premodifiers with and without SHIFT

In premodifier-head-constructions, stress retraction becomes evident before the shift trigger is encountered. Therefore, it is interesting to investigate the effect of stress retraction on prosodic processing. If English lexical words with stress shift potential possess lexical stress, a shift from the default position to the initial position should be perceived as deviant. If however stress positions are not specified lexically but are flexible and context-dependent (cf. Grabe & Warren, 1995, see Section 1), stress shifts should not lead to violation effects. In order to investigate the status of stress in these special lexical items, grand averages of shifted and unshifted premodifiers were compared.

As can be seen in Fig. 2, this comparison revealed a biphasic pattern. In the first two time windows (120 to 220 ms and 280 to 360 ms), a significant positivity for SHIFT in comparison to NO SHIFT occurred (120 to 220 ms: $F(1, 16) = 6.82$, $p = .019$; 280 to 360 ms: $F(1, 16) = 10.75$, $p = .005$). For the time window from 120 to 220 ms, there was a significant interaction between the factors TargetStress and Region ($F(3, 48) = 5.40$, $p = .01$). A post hoc analysis revealed a more pronounced positivity in left frontal region compared to the right frontal region (left anterior: $F(1, 16) = 9.26$, $p = .008$; right anterior: $F(1, 16) = 8.26$, $p = .011$; left posterior: $F(1, 16) = 3.86$, $p = .067$; right posterior: $F(1, 16) = 2.35$, $p = .145$). The positivities are followed by a pronounced negativity effect between 500 and 750 ms for words with shifted word stress ($F(1, 16) = 16.55$, $p = .001$).

3.2.2. Comparison between CLASH and SHIFT

The comparison of the conditions CLASH and SHIFT (*champàgne cócktails* vs. *chàmpagne cócktails*) elicited a positivity in an early time window between 30 and 180 ms followed by a late positive component between 450 and 850 ms for CLASH. Analyses utilising repeated measures ANOVAs revealed a significant general positivity (main effect for the factor RhythmCondition: $F(1, 16) = 14.89$, $p = .001$) but no interaction between Region and RhythmCondition.

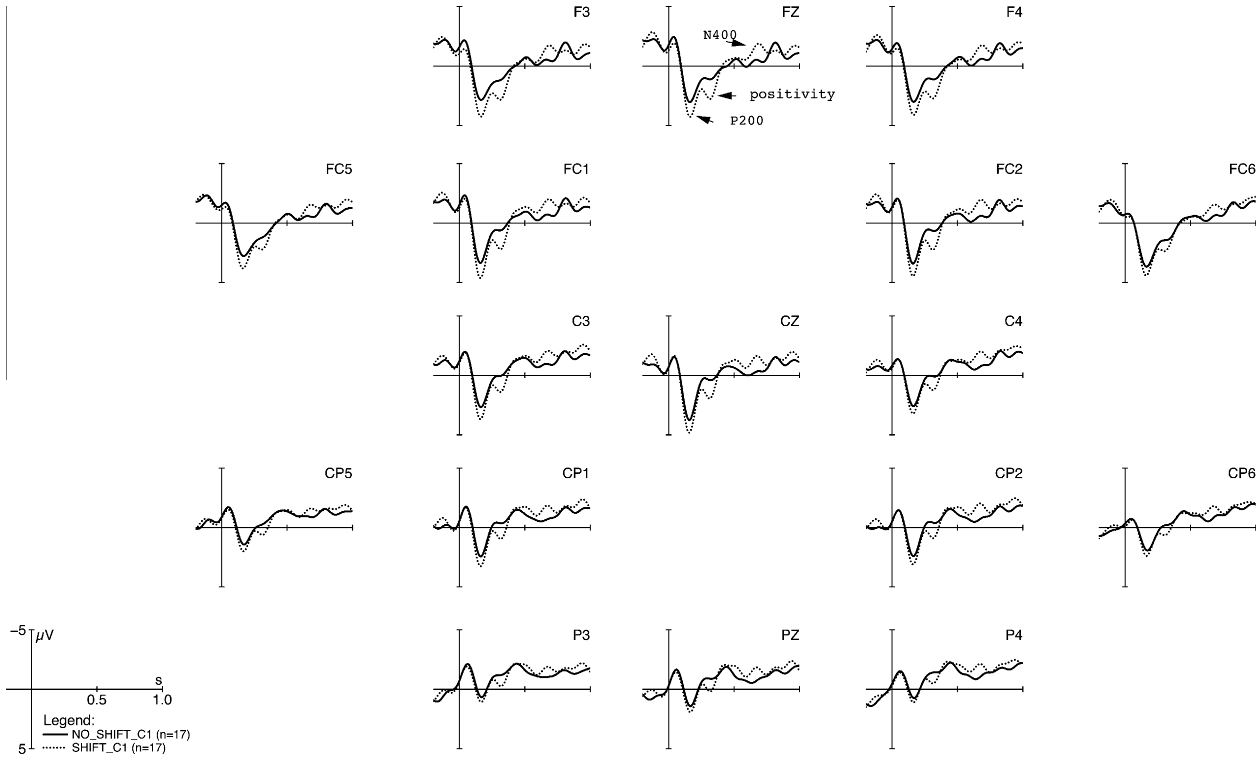

Fig. 2. Grand averages of event-related potentials obtained for the conditions SHIFT (dashed line) and NO SHIFT (solid line) measured from 200 ms prior the modifier onset up to 1000 ms.

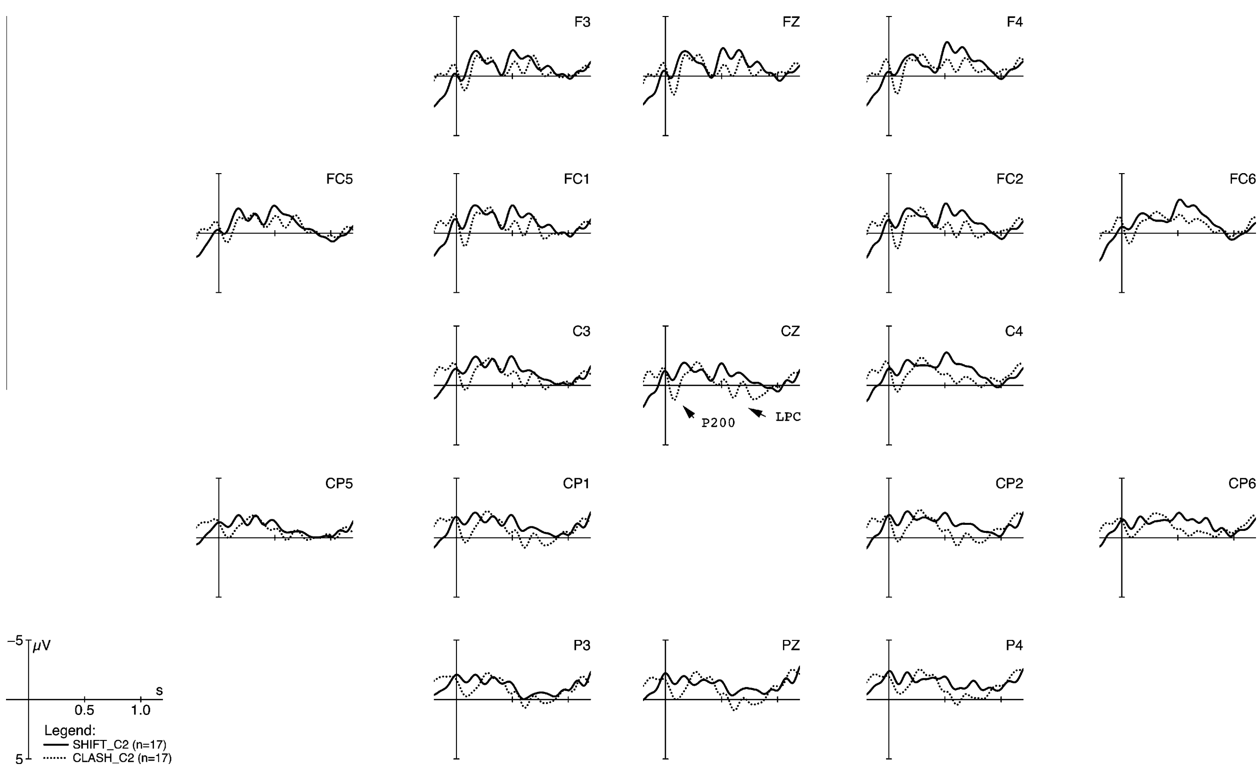

Fig. 3. Grand averages of event-related potentials obtained for the conditions CLASH (dashed line) and control condition SHIFT (solid line) measured from 200 ms prior the noun onset up to 1200 ms.

An expected negativity obtained for CLASH between 250 and 330 ms did not reach statistical significance but revealed a non-significant trend in this direction ($F(1, 16) = 2.24$, $p = .154$). Statistical analyses of the last time window showed that stress clashes lead to a pronounced positivity effect ($F(1, 16) = 11.72$, $p = .003$).

3.2.3. Comparison between LAPSE and NO SHIFT

For this comparison it is important to note that the position of stress is the final syllable of the head noun instead of the initial syllable as in the comparison of CLASH and SHIFT. Convergent with previous work that showed stressed syllables to be crucial in

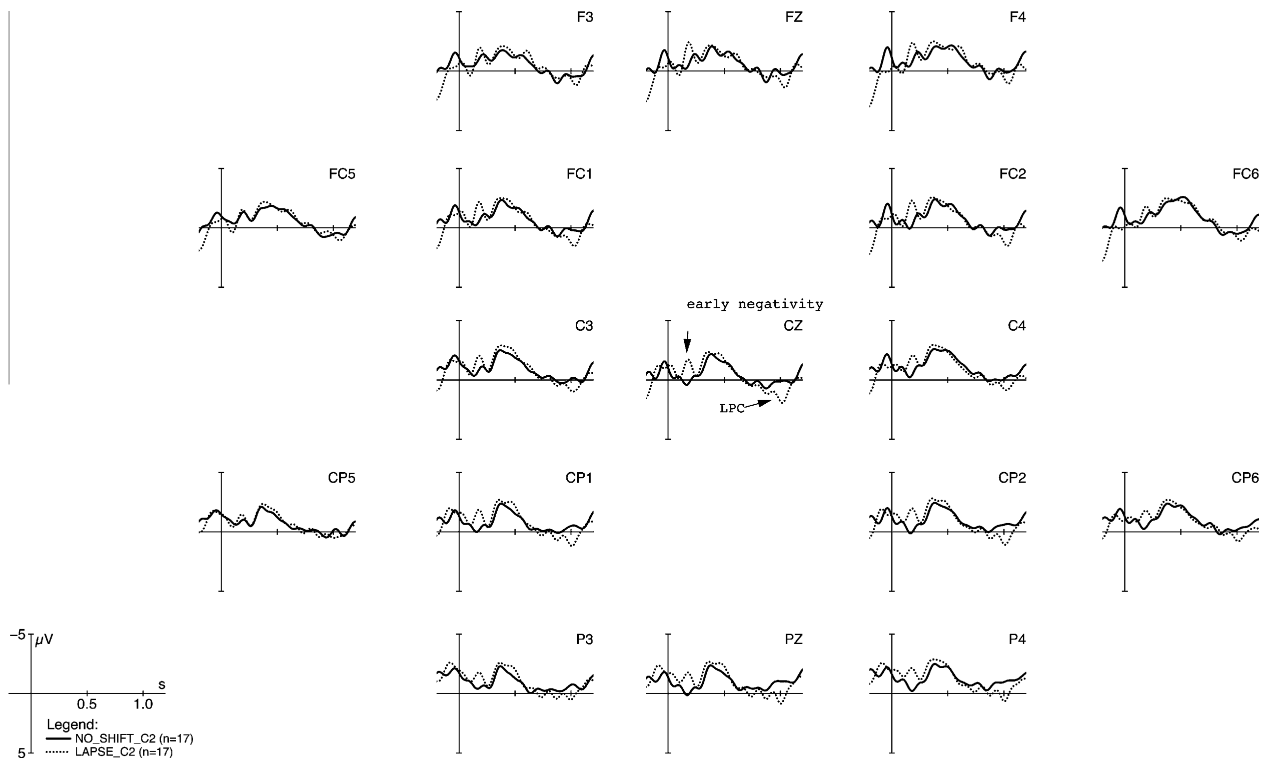

Fig. 4. Grand averages of event-related potentials obtained for the conditions LAPSE (dashed line) and control condition NO SHIFT (solid line) measured from 200 ms prior the noun onset up to 1200 ms.

lexical and prosodic processing (Cutler & Norris, 1988: *Metrical Segmentation Strategy*; Domahs et al., 2008), the present effects seem to be time-locked with the onset of the stressed syllable and not with the word's onset. Hence, the obtained effects occur in later time windows than in the comparison of conditions with initial stress. Following time windows were chosen: from 120 to 220 ms and from 900 to 1100 ms. Statistical analyses of the first time window showed a significant negativity effect for the condition LAPSE ($F(1, 16) = 11.71$, $p = .003$) but no interaction between the factors Region and RhythmCondition. This negativity effect is followed by a late positivity for the critical condition LAPSE. There was only a main effect for the factor RhythmCondition ($F(1, 16) = 8.31$, $p = .011$) but no significant interaction between RhythmCondition and Region.

Table 3 displays an overview of the chosen time windows and the significant results for all conducted comparisons.

4. Discussion

The present study investigated the processing of rhythmically alternating structures and rhythmical deviations in form of stress clashes and stress lapses by utilising event-related potentials. Since stress clashes are assumed to be a possible albeit rare rhythmically deviating structure in English, this study tried to clarify whether they are processed differently from shifted structures and from other deviations like stress lapses that are, according to theory, less problematic than clashes.

A further aim of the study was to examine whether rhythmic deviations can even be detected in a more natural, not strictly regular environment that does not provide a high predictability of the overall metrical structure. In contrast to the material used in studies by Böcker, Bastiaansen, Vroomen, Brunia, and de Gelder (1999), Schmidt-Kassow and Kotz (2009a), and Rothermich et al. (2010, 2012), the sentences used in the present study consisted of words with varying stress patterns leading to irregular sequences of stressed and unstressed syllables. More specifically, it was tested whether the investigated deviations evoke similar components as in the studies reported in Section 1.

A further aim was to clarify whether words with varying stress positions have a default stress pattern or receive context-dependent stress from the respective metrical context (as suggested by Grabe & Warren, 1995). If the latter is the case, we predicted that stress shifts should not elicit an N400 effect, as shifted stress patterns would not be processed as lexical violations.

Table 3
ERP effects in different time windows for three different comparisons.

Comparison	Early positivity	Negativity	Late positivity	Critical phrases
SHIFT & NO SHIFT	120–220 ms* (frontal) 280–360 ms**	500–750 ms***	–	Chàmpagne vs. champagne
CLASH & SHIFT	30–180 ms***	250–330 ms n.s.	450–850 ms**	Champàgne <u>cócktails</u> vs. chàmpagne <u>cócktails</u>
LAPSE & NO SHIFT	–	120–220 ms **	900–1100 ms**	Chàmpagne <u>desséérts</u> vs. champàgne <u>desséérts</u>

Underlined words (<u>*chàmpagne*</u>) indicate the onset of plotting and averaging processes.
* Statistical significance is indicated by $p < .05$.
** Statistical significance is indicated by $p < .01$.
*** Statistical significance is indicated by $p < .001$.

Finally, behavioural data can give insight into the question whether even phonetically clear deviations are perceived and evaluated as well-formed and how this conscious evaluation differs from the unconscious brain responses measured by means of ERPs.

The shift target item (premodifier) precedes the triggering head noun and therefore shows leftward stress shift. For this reason, rhythmic deviations can only be detected by the onset of the following head noun, while the premodifier offers the possibility to investigate the effect of stress shift on the lexical retrieval of words without knowledge of rhythmical motivation. Lexical and rhythmical deviations are discussed separately, together with the respective behavioural data.

4.1. Differences between shifted and unshifted premodifiers

In the comparison of items with shifted and unshifted stress, words with shifted stress elicited both positivity and negativity effects. The first effect is an early positivity occurring between 120 and 220 ms post word onset and is topographically most pronounced in the frontal region. Due to its latency and topography, we interpret this early positivity as a P200 effect evoked by the physical/acoustic properties of the initially stressed word which is canonically stressed on the final syllable. The P200 has been described as an auditory evoked potential (AEP) reflecting perceptual processing (Böcker et al., 1999; Hillyard & Picton, 1987). Phonetic analyses of the presented premodifiers varying in stress position revealed that stressed initial syllables bear higher F_0 than the unstressed initial syllables in words with unshifted stress. Moreover, this pitch rise is the first one in the presented sentences, because the premodifiers are only preceded by the unstressed definite article *the*. The interpretation of the early positivity as an instance of a P200 effect is in line with findings reported by Heim and Alter (2006) who obtained a similar early frontal positivity effect for sentence initial pitch accents. It is further supported by several studies showing the P200's sensitivity to physical properties like pitch and that pitch contours can be detected even within the initial syllable (Friedrich, Alter, & Kotz, 2001; Shahin, Roberts, Pantev, Trainor, & Ross, 2005).

The second positivity effect evoked by the SHIFT condition is probably also evoked by the stressed initial syllables. Stressed syllables are an important cue for speech segmentation and thus more attention is directed towards them in the incoming speech signal (Cutler & Norris, 1988; Domahs et al., 2008; Pitt & Samuel, 1990). This attentional process probably evoked the second positivity, which might therefore be classified as a P3a, reflecting a stimulus-driven attention mechanism (cf. Jongsma, Desain, & Honing, 2004; Polich, 2007; Polich & Criado, 2006).

Finally, comparisons between SHIFT and NO SHIFT conditions revealed a negativity effect for SHIFT between 500 and 750 ms. Its latency and distribution suggests this component to be an instance of the N400 family reflecting the deviation from the canonical stress pattern. This deviation may have led to increased costs in lexical retrieval, independent from task setting, i.e., implicit or explicit tasks. Such an interpretation is supported by findings of previous studies (Bohn et al., 2013; Domahs, Genc, Knaus, Wiese, & Kabak, 2012; Friedrich et al., 2004; Knaus et al., 2007; Magne et al., 2007; van Donselaar, Koster, & Cutler, 2005). These studies showed that metrical properties of words strongly influence lexical retrieval. That a mismatch between perceived and stored information regarding the metrical structure of words leads to higher costs and problems in word recognition has also been demonstrated by various production studies (Cutler & Clifton, 1984; Kelly & Bock, 1988), perception studies (van Leyden & van Heuven, 1996), and eye tracking studies (Breen & Clifton, 2011). These results confirm that the metrical structure of lexical items is part of the stored default representation.

Some studies suggest that leftward stress shifts, i.e., changes from an iambic to a trochaic structure, are less problematic to produce than shifts creating an iambic structure in English (Breen & Clifton, 2011; Cutler & Clifton, 1984). Moreover, English listeners tend to perceive initial stress irrespective of whether it is actually produced or not (van Leyden & van Heuven, 1996). This is explained by the familiar phenomenon of rhythmically induced leftward stress shifts as investigated in this study and the strong bias towards trochaic forms in English in general. The behavioural data found for shifted vs. unshifted structures in the present study provide support for this assumption: sentences of the SHIFT condition were evaluated as most natural in comparison to all other conditions, even more natural than the sentences of NO SHIFT, in which neither rhythmical nor lexical stress deviations are present. These results of the behavioural data suggest that English listeners are indeed familiar with leftward stress shift. The discrepancy between the positive behavioural evaluation of shifted words and the ERP results shows that although there seems to be a certain familiarity with leftward stress shift in English, the N400 effect reflects a clear impairment on word recognition when the perceived metrical structure deviates from the stored information. Moreover, the significantly different effects for SHIFT and NO SHIFT confirm that our participants did not over-generalise to perceive generally initial stress in all presented items. From this finding we can conclude that words with potential stress variation consist of a default lexical stress pattern. The assumption of context-dependent stress assignment (Grabe & Warren, 1995) is not confirmed due to the occurrence of the N400 effect.

4.2. Differences between rhythmically well-formed and deviant structures

In the comparisons of SHIFT and CLASH as well as of NO SHIFT and LAPSE that were measured from the onset of the trigger items (head nouns), patterns consisting of an early and a late component are observed for both rhythmically deviant structures.

4.2.1. CLASH in comparison to SHIFT

The CLASH condition (*champàgne cócktails*) reveals two positivity effects in comparison to the SHIFT condition (*chàmpagne cócktails*). The first positivity effect occurs in an early time window between 30 and 180 ms after onset of the head nouns. This positivity effect is most likely evoked by the prominence of the first syllable and we interpret this positivity as a reflection of the deviation from expected signal properties: the preceding word is a potential stress shift word which remained unshifted, evoking the hearer's expectation of a noun with an initial unstressed syllable to follow. If the following syllable is stressed, as it is the case in the condition CLASH, phonetic and metric expectations are violated. A previous study on rhythmic and melodic processing showed that expectancy and predictability of an upcoming stimulus can influence auditory processing in very early stages (Neuhaus & Knösche, 2006), reflected by very early positivity effects (labeled as P1 and P2). Further support comes from studies in which metrically incongruous words elicited an early positivity in comparison to expectable and congruous words. These studies interpreted the very early positivity as a P200 effect (Böcker et al., 1999; Marie et al., 2011) which can be influenced by the pitch contour of the first syllable (Friedrich et al., 2001). In the light of these findings, the early positivity evoked by the CLASH condition might be considered as a P200 effect: as soon as the syllable following the finally stressed premodifier can be identified as stressed, a violation of phonetic expectations is detected, as the upcoming stressed syllable leads to a rhythmical deviation in the prosodic structure. This identification happens very fast due to pitch information of the first syllable. This early identification can explain the very early onset of this positivity effect.

Alternatively, the early positivity effect could also be interpreted as a P3a effect as described in various studies as a reflection of expectancy violations (Jongsma et al., 2004; Regnault, Bigand, & Besson, 2001). However, due to different task settings and the early onset of the positivity effect found here, it can rather be interpreted as a P200 effect reflecting the automatic processing of phonetic cues which help in detecting a mismatch between the expectation of a specific stress pattern in a given rhythmic context and the encountered deviating stress pattern. However, this early effect could also be due to the processing of the preceding words which differ in their stress pattern. However, if this was the case, a similar early positivity should be detectable for LAPSE in comparison to NO SHIFT, since the preceding words are the identical items which are used in the CLASH & SHIFT comparison. Therefore, an effect elicited by the processing of the preceding words should be found in both comparisons as the preceding words are phonetically identical and should therefore have a comparable influence. However, in the comparison of LAPSE and NO SHIFT, no early positivity effect is found (see Fig. 4). For this reason, the early positivity found for CLASH in comparison to SHIFT is most likely elicited by the rhythmical deviation of CLASH.

In a later time window between 450 and 850 ms, a very pronounced positive component was observed for CLASH. Related studies (Domahs et al., 2008; Knaus et al., 2007) described a comparable late positivity effect as a member of the P300 family reflecting the evaluation of heard sentences. The component found here is also interpreted to be evoked by the evaluation of the prosodic naturalness of the heard sentences and to reflect the evaluation process related to task requirements. Recall that the participants were asked to evaluate the naturalness of the sentences heard. Various studies interpreted late positive components with similar latencies as a reflection of task-specificity and task-sensitivity (Picton, 1992; Coulson, King, & Kutas, 1998; Bohn et al., 2013; Domahs et al., 2008; Knaus et al., 2007; Magne et al., 2007; Marie et al., 2011; Schmidt-Kassow & Kotz, 2009a,b). Thus, the late positive component found here seems to be clearly related to the evaluation task, involving the detection of a mismatch between expectancy and perceived input. This interpretation is further supported by the behavioural data: participants evaluated the sentences of the CLASH condition as significantly less natural than the correct control condition SHIFT. Although shifted words deviate from their default structure, this deviation seems to be more acceptable than the rhythmic deviation in form of a stress clash. Moreover, by applying the RR, potential stress clash structures are turned into a trochaic structure, the biased form in English in contrast to the iamb. Hence, English listeners seem to accept and even prefer deviations from lexical default stress in order to obtain a trochaic structure, but only if the rhythmical context triggers this deviation. Hence, violations of lexical stress seem to be licensed by rhythmic demands.

4.2.2. LAPSE in comparison to NO SHIFT

The condition involving stress lapses not only shows a late positive component but also a preceding early negativity for LAPSE in comparison to NO SHIFT (see Fig. 4). This negativity most likely reflects the error detection in the rhythmical structure of these sentences, i.e., the violation of the PRA (see Section 1). The stress shift in the preceding disyllabic word (e.g., *chàmpagne*) not only allows but has to be licensed by a following strong syllable. Hence, an unstressed initial syllable in the following noun leads to a violation of the PRA and thus an unfulfilled expectation. The early latency of this negativity effect points to a general error detection mechanism which is also sensitive to violations of the rhythmical structure (cf. Bohn et al., 2013; Rothermich et al., 2010, 2012): the first constituent of the compound ends in a weak syllable, fostering the expectation of a subsequent strong syllable which is not met. This interpretation as an instance of a general rule-governed error detection mechanism activated by a rhythmic irregularity is supported by similar results of previous studies focusing on rhythmic deviations (e.g., Bohn et al., 2013; Rothermich et al., 2010, 2012; Schmidt-Kassow & Kotz 2009a). It is noteworthy that a similar component does not only occur in the context of language processing but was also observed in different areas outside of linguistic processes, e.g., in deviations in tone sequences (Abecasis et al., 2005; Brochard et al., 2003; Geiser et al., 2009), in melodic musical sequences (Koelsch et al., 2000; Patel, Gibson, Ratner, Besson, & Holcomb, 1998; Brattico, Tervaniemi, Näätänen, & Perez, 2006), as well as in violations of arithmetic rules (Jost, Beinhoff, Henninghausen, & Rösler, 2004; Núñez-Peña & Honrubia-Serrano, 2004). In all these studies, incongruous patterns elicited an early frontal negativity. Hence, the functional interpretation of this negativity is – comparable to the LAN – that it mirrors the recognition of deviations and violations in regular structures.

As the early negativity seems to reflect rather a general than a language-specific error detection mechanism, it is noteworthy that related studies were able to elicit this negativity for rhythmic irregularities irrespective of a matching rhythmic task, i.e., independent of attentional focus towards the rhythmic structure (Rothermich et al., 2010; Schmidt-Kassow & Kotz, 2009a). These findings support the independent processing of metrical and rhythmic structures and suggest that the negativity found in the present study might also be elicited if it were presented with a different or even without a specific task. This hypothesis is supported by the fact that the given task leads the participants' attention towards the sentences' global rhythm and meter than towards the critical phrase. Hence, the early negativity reflects the detection of rhythmic deviations from the PRA irrespective of task requirements.

As the PRA is also violated by clash structures, this negativity effect should occur in the CLASH condition as well. However, although there is a trend for such an effect, mean voltage changes do not differ significantly from the SHIFT condition. One possible explanation for the lack of the negativity effect is that it is overridden by the occurrence of a preceding enhanced positivity effect in this comparison (see Fig. 3).

The early negativity is followed by a late positive component which again might reflect the mismatch between built-up expectancy and the perceived prosodic structure, possibly resulting in a re-analysis of the metrical structure. In the LAPSE condition, stress shift to the initial syllable of the premodifier promotes the expectancy of a head noun carrying initial stress to follow which is not met.

Given that both rhythmic deviations evoke a more pronounced late positive component in comparison to their correct control condition suggests that the amplitude of this effect reflects not only a probable re-analysis, but also that both deviation types are similarly ill-formed for English listeners. In the study on the same rhythmic deviations in German (Bohn et al., 2013), in contrast, the amplitude of the positivity is very pronounced for LAPSE but reduced for CLASH. This asymmetry is interpreted as a reflection of the degree of complexity and difficulty, i.e., the resolvability of the given task: the easier the evaluation, the stronger the positivity effect. In German, structures containing stress lapses seem to be easier to evaluate as unnatural while stress clashes seem to be harder to detect and thus to categorize. This might be due to the structure and word order of potential stress shift items in German: lexical and rhythmic deviations are combined in one single word in the LAPSE condition (e.g., *Féi.er* <u>*absàgen*</u> 'cancel party'), while the CLASH structures contain only the rhythmic deviation but a correct lexical stress pattern (e.g., *Ter.mín* <u>*àbsagen*</u> 'cancel appointment'). In English, the resolvability of the given task seems to be similar for CLASH and LAPSE structures, reflected in the comparable amplitude of the elicited late positive components: Both rhythmically deviating structures seem to be easier to evaluate as unnatural, although it has been suggested that stress lapses are less problematic than stress clashes in English (see Section 1). However, a look at the results of the behavioural data shows that sentences containing clashes were evaluated as least natural by the participants. This difference between the rhythmic deviations is not reflected in the electrophysiological data.

As already mentioned above, the late positive component might additionally show the re-analysis process of the metric structure. Support for this view comes from studies which showed that this late positive component represents attentional and task-specific evaluation as well as a reanalysis mechanism (Domahs et al., 2008; Schmidt-Kassow & Kotz, 2009a,b). Support for the task-relatedness of this component comes from various studies which interpret the late positive component as a reflection of task-specificity and task-sensitivity (cf. Coulson et al., 1998; Domahs et al., 2008, 2009, 2012; Knaus et al., 2007; Magne et al., 2007; Marie et al., 2011; Picton, 1992; Schmidt-Kassow & Kotz, 2009a; Schmidt-Kassow & Kotz, 2009b). Thus, the positivities elicited here would probably not occur when using an implicit task.

The overall results demonstrate that speech processing in the brain is sensitive to rhythmic deviations and to the difference between stress shifted and unshifted words, although previous production and perception studies suggest that stress shifts are rather a purely perceptual phenomenon. The obtained results demonstrate that predictions about the metric and rhythmic structure of the incoming speech signal can be built up by even one single word and lead to problems in language processing if these predictions are not met. What is even more important is the fact that rhythmic deviations are also detectable in a rhythmically natural context which does not consist of a repeating trochaic structure, as in the studies by Schmidt-Kassow and Kotz (2009a,b) and Rothermich et al. (2010). This shows that the brain builds up certain rhythmic expectations according to the RR and the PRA and is thus able to detect deviations like clashes and lapses even in contexts that do not contain strong cues about the rhythmic structure of the incoming speech signal.

5. Conclusion

The present study confirms that rhythmical and lexical irregularities are perceived and processed differently from well-formed structures, and that the phenomenon of rhythmically induced stress shifts plays an important role in the processing of English. The N400 effect found for shifted items provides evidence for lexical default stress instead of context-dependent stress in potential stress shift targets. Moreover, due to strong rhythmic expectancies, English speakers are – even in natural contexts – very sensitive to (preventable) irregularities as reflected by the components obtained. The overall results not only support and complement the findings of previous studies but also disentangle lexical and rhythmical influences on language processing. Hence, the electrophysiological reactions observed in the present study demonstrate the role of the RR, as postulated by metrical theory, in the processing of English.

Statement of significance to the neurobiology of language

This study shows neuronal reflections of rhythmical processing during language processing. The results confirm that rhythmic regularity is advantageous for language processing and shows that rhythmic regularity helps building up predictions about the structure of the following incoming speech signal.

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How information structure influences the processing of rhythmic irregularities: ERP evidence from German phrases

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Early negativity

ABSTRACT

This study explores the influence of focus and givenness on the cognitive processing of rhythmic irregularities occurring in natural speech. Previous ERP studies showed that even subtle rhythmic deviations are detected by the brain if attention is directed towards the rhythmic structure. By using question–answer pairs, it was investigated whether subtle rhythmic irregularities in form of stress clashes (two adjacent stressed syllables) and stress lapses (two adjacent unstressed syllables) are still perceived when presented in post-focus position in an answer sentence and attention is directed away from them, towards the meaning of the element in narrow focus position by the preceding wh-question. Moreover, by visually presenting the lexical-semantic input of the deviating structure in the question, the influence of rhythmical and lexical properties in these two forms of rhythmic deviations are disentangled. While words in the present stress clash condition do not deviate from lexical stress, stress lapses contain deviations from metrical and lexical stress. The data reveal an early negativity effect for stress clashes but not for stress lapses, supporting the assumption that they are processed differently. The absence of a negative component for stress lapses indicates that the metrical deviation alone is not salient enough to be registered in non-focus position. Moreover, the lack of a late positive component suggests that subtle rhythmic deviations are less perceivable and hence more acceptable when presented in non-focus position. Thus, these results show that attentional shift induced by information structure influences the degree of the processing of rhythm.

1. Introduction

In order to be effective in verbal communication, utterances are commonly organized in a way which helps the listener to decode the received utterance as fast and correctly as possible. One feature of language that helps to mark the most important information of an utterance is information structure. According to Chafe (1976, 1994), information structure[1] is understood as information packaging that supports and satisfies the interlocutors' communicative needs by highlighting and optimizing the form of discourse elements by assigning an information status to each constituent of an utterance. This status helps the interlocutors to identify the most relevant information in the utterance by dividing the constituents into *given* and *new* information. While given information is already known to the listener and represented by constituents that are already established in the discourse and have been introduced before (i.e., also lexically given, cf. Baumann and Riester, 2012), new information most often refers to elements that are introduced into the discourse for the first time (Prince, 1992; Büring, 2013). Thus, given information builds the background whereas new information is in the foreground or focus of the utterance. The information status can be indicated in several ways: by word order (given information is often preceding new information), by syntactic constructions (e.g., it-cleft structures in English), by using specific lexical items or particles (e.g., full noun phrases for new information vs. pronouns for given information), and by prosodic cues. Although there are language-dependent differences in the marking of information status, prosody is used in several Germanic languages in order to differentiate between new and given information (cf. Ladd, 1996; Cruttenden, 2006). New or most relevant parts of information can be emphasized by bearing the strongest accent of a sentence, while given and

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[1] In the literature referring to information structure, numerous terms can be found for the division of information e.g., *background–foreground*, *theme – rheme*, *given – new*, and *topic – comment* (see e.g., Féry and Krifka (2008); Prince (1992)). The present paper will mainly concentrate on the terms *focus* and *givenness*, therefore only the most relevant definitions will be discussed and given here.

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background information is usually unaccented. It has been shown that accenting new information and de-accenting given information facilitates the decoding process for listeners: inappropriate accenting of given information leads to an accelerated comprehension whereas accented items are identified as appropriate new information faster and more securely. Thus, prosodic marking of information is advantageous for speech comprehension because listeners are clearly sensitive towards the relationship between prosody and information status (e.g., Terken and Nooteboom, 1987; Dahan et al., 2002; Birch and Clifton, 1995; Heim and Alter, 2006; Breen et al., 2010; Schumacher and Baumann, 2010).

Another way of highlighting new information prosodically is to apply contrastive or answer stress, and thereby narrowing down focus to this single part of the utterance. In broad or wide focus, on the other hand, a neutral intonational contour with utterance-final nuclear pitch accent is assigned because the entire sentence is focused uniformly (Ladd, 1996; Büring, 2013). Thus, the focus breadth can help to identify the most relevant information and thereby mark it as most salient, so that the listeners' attention is directed more strongly towards this part of the utterance.

Previous studies were able to show that information in focus position receives higher attention and is processed more deeply, whereas information in non-focus position receives less attention and is hence processed in less detail and less elaborately (cf. Cutler and Fodor, 1979; Birch and Rayner, 1997; Wang et al., 2011, 2012). Further, a recent study by Domahs and colleagues (Domahs et al., 2015) on the processing of lexical stress violations in focus and non-focus position showed that only phonetically clearly marked errors are detected when presented in non-focus position. This is in line with research showing that not all linguistic entities are processed to the same extent during language comprehension. The depth of processing, i.e., the degree of complete processing, often depends on the importance and markedness of the linguistic information. Thus, information distinguished as important, for instance by narrow focus and prosodic markers, is processed more deeply and more comprehensively whereas unfocused and unimportant information receives an incomplete and rather shallow analysis (e.g., Sanford and Sturt, 2002; Ferreira et al., 2002). This latter form of processing can also be described as a “good enough” strategy used for efficiency reasons in language comprehension: the language input is only processed to the degree sufficient for comprehension (Ferreira et al., 2002). Deeper processing, in contrast, is attained when the input is highlighted, i.e., by prosodic marking and narrow focus (cf. Wang et al., 2009, 2011).

For the processing of spoken language, the function of prosody is not only to mark the information structural status of a linguistic unit. It also provides information crucial for lexical access (in languages with lexical stress) and metrical aspects like metric stress, i.e., the rhythmically alternating structure of stressed and unstressed syllables. Studies revealed that a regular sequence of strong-weak syllables is essential for language acquisition (Jusczyk, 1999; Nazzi and Ramus, 2003). It is particularly beneficial for speech perception and segmentation, as it leads attention to stressed syllables in speech processing by building up expectations about when the next stressed syllable might appear (Cutler and Foss, 1977; Grosjean and Gee, 1987; Cutler and Norris, 1988; Pitt and Samuel, 1990; Mattys, 2000; Rothermich et al., 2013). Rhythmic irregularities cause a decelerated reaction, i.e., they need more time to be perceived and processed, compared to rhythmically regular structures (Pitt and Samuel, 1990; Bohn et al., 2013). In speech production, irregular rhythmic structures increase the speech error probability and thus slow down the production process (Tilsen, 2011).

Sometimes, a regular lexical stress pattern has to be altered for the benefit of a regular rhythmic structure, especially in the case of so-called stress clashes of two adjacent stressed syllables (Selkirk, 1984). In order to separate the stressed syllables, a so-called stress shift may take place. By shifting stress, however, a deviation from the correct lexical stress pattern occurs. Despite this fact and although the application of stress shifts is optional, such shifts, also known as the Rhythm Rule (RR, Liberman and Prince, 1977), seem to operate highly systematically in stress-timed languages such as German (Wagner and Fischenbeck, 2002; Bohn et al., 2011). Hence, there seem to be (rhythmic) factors which override the preservation of canonical lexical stress in order to avoid a stress clash structure (Selkirk, 1995).

In recent years, a number of studies measuring event-related potentials (ERPs) illustrated the importance of both lexical and rhythmical well-formedness for language processing (Knaus et al., 2007; Magne et al., 2007; Domahs et al., 2008; Schmidt-Kassow and Kotz, 2009a, 2009b; Rothermich et al., 2010, 2012; Marie et al., 2011; Bohn et al., 2013; Henrich et al., 2014). These studies showed that the brain clearly reacts to lexical and metrical stress violations if an expected structure is not met. In most of these studies, an unexpected stress placement was reflected by a negativity followed by a late positivity effect.

While deviations from lexical stress result in an N400 effect interpreted to reflect increased costs for lexical retrieval (Knaus et al., 2007; Magne et al., 2007; Marie et al., 2011; Bohn et al., 2013; Henrich et al., 2014), studies investigating metrical and rhythmical deviations found an early negativity effect reflecting a general rule-based error-detection, i.e., a subcomponent of a left anterior negativity (LAN) (Schmidt-Kassow and Kotz, 2009a; Rothermich et al., 2010, 2012; Bohn et al., 2013; Henrich et al., 2014).

In a study on lexical and rhythmical stress irregularities in German, Bohn et al. (2013) investigated simple rhythmic irregularities in the form of stress clashes (e.g., *Sie soll den Termín àbsagen* ‘She is supposed to cancel the appointment’), as well as items that contained deviations from both, lexical and rhythmical stress, in the form of stress lapses (e.g., *Sie soll die Féier absàgen* ‘She is supposed to cancel the party’). The critical rhythmical structures were presented auditorily within a sentence context and without a special focus setting, i.e., in wide focus. Thus, the participants' attention was not narrowed down to the critical structure within the sentence. The given task, however, directed the overall attention towards prosody, since the participants had to evaluate the prosodic naturalness of the overall sentence heard. In this study, both of the negativity effects described above were found, an early LAN-like component for stress clashes (e.g., *Sie soll den Termín àbsagen* ‘She is supposed to cancel the appointment’), as well as a centro-parietal N400 effect for stress lapses of two adjacent weak syllables which additionally contain a deviation from lexical stress (e.g., *Sie soll die Féier absàgen* ‘She is supposed to cancel the party’). Crucially, identical deviations from the canonical lexical stress pattern did not elicit an N400 effect when the shift appeared to obtain a regular rhythmic structure (e.g., *Sie soll den Termín absàgen* ‘She is supposed to cancel the appointment’). The deviation from lexical stress hence seems to be acceptable and unproblematic for processing when rhythmically licensed. However, correct lexical stress is perceived as erroneous when the rhythmical structure of the phrase demands a shifted stress pattern. In both cases, rhythmical criteria seem to be the triggering factor for the effects. However, since two different negative components were elicited by the two different rhythmic deviations, the exact nature of these two negative components found by Bohn et al. (2013) is not completely clarified.

The early negativity found for stress clashes, i.e., for rhythmic deviations, should be elicited independent of the participants' attention towards the rhythmical structure of the sentences and independent of given task settings. Thus, it should neither be influenced by the information status nor the attentional status, i.e., whether the participants' focus is directed towards the overall sentence or to a single event in the utterance. Moreover, it should be found irrespective whether the deviation occurs in lexically given or new material (cf. Bohn et al., 2013; Rothermich et al., 2010). However, as Domahs et al. (2015) showed that only phonetically salient lexical violations are detectable when presented in non-focus position, rhythmic deviations realized as stress clashes and stress lapses might be too subtle to be perceivable if completely unfocused, i.e., when presented in post-focus position. It has not yet been verified whether the negativity found for stress lapses is indeed an N400. If so, it should not be found if the deviation occurs within pre-activated, i.e., lexically given, items (cf. Knaus et al., 2007; Domahs et al., 2015). Both negativity types were followed by a late positive component reflecting the task-dependent evaluation of the sentences.

1.1. The present study

The present study thus concentrates on the question whether subtle rhythmic deviations are detectable if perceived in non-focus position and elicit the same biphasic component pattern consisting of an early negativity and a late positivity as in the Bohn et al. (2013) study. Moreover, the manipulation of focus provides the possibility to disentangle the two negative components elicited by stress clashes and stress lapses that differ in latency and topography. Stress clash structures preserving the correct lexical stress pattern of a phrasal verb (e.g., *Termín àbsagen* 'cancel the appointment') elicited an early frontal negativity while stress lapse structures which additionally distort the lexical stress pattern (e.g., *Féier absàgen* 'cancel the party') led to a centro-parietal negativity at around 400 ms.

The influence of information structure and status on the detection of subtle rhythmic deviations was tested by using question–answer pairs as stimuli in the present study. As a wh-question as in (1) narrows attention towards the structure that corresponds to the wh-element in the answer, attention is shifted away from the critical rhythmic structure and instead centered on the preceding constituent by inducing narrow focus. In contrast, in the study by Bohn et al. (2013), no explicit question preceded the sentence, so that the entire sentence, not a single phrase, was focused. To clarify the difference, (2) shows the question that would (theoretically) fit the study design in Bohn et al. (2013).

(1) Narrow focus (on object NP)
Question: *Was soll sie absagen?* ('What is she supposed to cancel?')
Answer: *Sie soll* ***die Feier*** *absagen*. ('She is supposed to cancel **the party**')

(2) Wide/broad focus
Question: *Was passiert?* ('What is happening?') [not presented]
Answer: ***Sie soll die Feier absagen***. ('**She is supposed to cancel the party**')

In the question–answer pair illustrated in (1), the wh-constituent *was* ('what') requires specific information from the response. This new information is represented by an object noun phrase (in bold letters) in the following answer sentence. This constituent has focus status, i.e., focus is narrowed on this NP. This way, attention is directed more strongly towards the meaning of this particular constituent and not on the critical rhythmical structure represented by the following phrasal verb in post-focus position (cf. Büring, 2013; see also Table 1). The rest of the response refers to information already given in the question and thus forms (less important and thus rather unattended) background information. Moreover, by introducing the critical phrasal verb (in underlined letters) in the question, the lexical-semantic content of this structure is already given and activated when the listener hears it in the answer sentence. In the previous study by Bohn et al. (2013), on the other hand, the critical item was not lexically given but newly introduced when the sentence was auditorily presented to the participants. Moreover, due to wide focus, the participants' attention was distributed over the entire sentence. At the end of each response, participants were asked to evaluate the overall naturalness of the sentence heard. The task demands were therefore identical to those in the previous study (Bohn et al., 2013). Hence, possible differences in the perception of the rhythmical irregularities are exclusively due to the differences in information structure and status.

Table 1
Experimental conditions and filler items. The words written in bold letters indicate the critical phonological phrase, words written in capital letters indicate the word bearing nuclear stress.

Condition	Example
Wh question (visually)	**WAS** soll sie **absagen**? WHAT is she supposed to cancel?
Correct SHIFT (auditorily)	Sie soll den **TER'MIN ab'sagen**, wie besprochen. She is supposed to cancel the APPOINTMENT, as discussed.
Wh question (visually)	**WAS** soll sie **absagen**? WHAT is she supposed to cancel?
Correct NO SHIFT	Sie soll die **'FEIER 'absagen**, wie besprochen. She is supposed to cancel the PARTY, as discussed.
Wh question (visually)	**WAS** soll sie **absagen**? WHAT is she supposed to cancel?
CLASH	Sie soll den **TER'MIN 'absagen**, wie besprochen. She is supposed to cancel the APPOINTMENT, as discussed.
Wh question (visually)	**WAS** soll sie **absagen**? WHAT is she supposed to cancel?
LAPSE	Sie soll die **'FEIER ab'sagen**, wie besprochen. She is supposed to cancel the PARTY, as discussed.
Question (visually)	Soll sie das ANGEBOT **reduzieren**? Is she supposed to reduce the OFFER?
Filler correct	Sie soll die **'PREISE redu'zieren**, wie immer. She is supposed to reduce the PRICES, as usual.
Question (visually)	Soll sie das ANGEBOT **reduzieren**? Is she supposed to reduce the OFFER?
Filler incorrect	Sie soll die **'PREISE re'duzieren**, wie immer. She is supposed to reduce the PRICES, as usual.

This way, it can be investigated how attention, lexical givenness, and focus breadth (narrow vs. wide) influence the following aspects: (i) The perceivability and processing of stress clashes and stress lapses when presented in post-focus position. Is the early negativity found for stress clashes by Bohn et al. (2013) still elicited when attention is shifted towards the meaning of a preceding element in focus position? (ii) The influence of givenness on lexical processing. If the N400 found for lapse structures is mainly elicited by the included lexical stress deviation, can it still be found when lexical retrieval is already accomplished when the deviating structure is encountered? (iii) The modified context and hence the altered attention of the participants should shed further light on the attentional task-sensitivity of the late positive component (LPC) found in Bohn et al. (2013) as well as in related previous ERP studies (Domahs et al., 2008, 2015; Schmidt-Kassow and Kotz, 2009a, 2009b; Rothermich et al., 2012). Is the aforementioned question indeed sufficient enough to reduce the participants' attention towards the narrow focus object in the auditorily presented sentence, so that rhythmically deviations are not detectable anymore?

1.2. Hypotheses

Due to narrow focus on the object NP, subtle rhythmic irregularities realized on the following verb might be difficult to detect and hence not be perceivable, although the evaluation task directs attention – at least to some extent – to the overall structure of the sentence heard. However, we assume that the direct post-focus position influences the conscious perceivability of the critical rhythmic irregularity since non-focus information might be processed less elaborately. This could be seen in higher acceptability rates in the behavioral data. The shift of attention might also influence the ERP components. So far, it is not completely clear whether the lexical stress violation or the rhythmically dispreferred pattern, or both, are responsible for the negativity effect found for stress lapse structures in Bohn et al. (2013). If this negativity in fact reflects higher costs in lexical retrieval, it should be absent in the present study due to the phrasal verb's activation in the preceding question context. An early LAN-like effect might be elicited irrespective of lexical givenness, attention and task settings if it indeed reflects an error detection response. Therefore, we expect to find an early negative component for structures which contain exclusively a rhythmic irregularity, i.e., for stress clashes. With regard to the late positive component, this effect is expected to be absent due to the distraction of attention away from the given task to judge the sentences' prosodic naturalness towards the constituent holding new information in narrow focus position.

2. Methods

2.1. Participants

Twenty-six (16 women) right-handed monolingual native German speakers with a mean age of 24 years (age range 20–30 years) participated in the experiment. All participants had normal or corrected-to-normal vision, and none of them reported hearing deficits. Each subject was paid for participation in the study. Informed consent was obtained from all participants and privacy rights were always observed.

2.2. Stimuli

In order to compare the present results to the results found in the previous study (Bohn et al., 2013), the set of stimuli was kept identical. Thus, stimuli comprised four conditions, each containing 30 phonological phrases consisting of a disyllabic noun (trigger) and a trisyllabic phrasal verb stressed on the initial syllable in isolation (e.g., *ábsagen* 'cancel'; stress shift target). Two different noun groups with different lexical stress patterns were chosen to trigger either a shift or a non-shift in the trisyllabic phrasal verb. Both groups consisted of disyllabic nouns with lexical stress either on the initial (Group NO SHIFT) or the final (group SHIFT) syllable. For the correct control condition NO SHIFT, in which stress shift is unnecessary, the phrasal verbs were paired with initially stressed disyllabic nouns (e.g., *Féi.er* 'party'). For the correct control condition SHIFT, in which a stress shift is triggered by the noun, disyllabic nouns with final stress (e.g., *Ter.mín* 'appointment') were paired with the phrasal verbs. Both noun groups were combined with one compatible phrasal verb to evoke both possible stress patterns in the phrasal verb (NO SHIFT: *Féi.er àbsagen* vs. SHIFT: *Ter.mín absàgen* 'to cancel the party vs. the appointment'). Each noun pair (e.g., *Termín* – *Féier*) that was combined with a single phrasal verb (e.g., *absagen*) was controlled and matched for frequency. The frequency of the verbs was also controlled, using the CELEX database (Baayen et al., 1995). All 30 phonological phrases of each condition were embedded into a carrier sentence with invariant structure to ensure that the target phrases were located at identical prosodic phrase positions. The critical conditions CLASH and LAPSE were constructed via cross-splicing. That is, the object NP and the phrasal verb of the two naturally spoken and recorded conditions SHIFT and NO SHIFT were cut and spliced together without manipulating phonetic parameters (for a detailed description see Bohn et al. (2013)). Table 1 illustrates the stimuli and the manipulations. 60 filler sentences, 30 with correct and 30 with incorrect stress patterns of quadrisyllabic verbs were further included.

In contrast to the study by Bohn et al. (2013), the stimulus material was extended by introducing an additional narrow focus question (wh-question) prior to each sentence. To this end, a context question was constructed for each critical sentence. This context question was a wh-question that led the answer focus onto the object NP preceding the critical phrasal verb. Due to narrow focus, the object NP is identified as the most prominent constituent of the phrase that contains nuclear stress (cf. Büring, 2013; Dehé, 2002; Truckenbrodt, 2006). Moreover, the wh-question included the phrasal verbs that become active before they are presented with well-formed or deviating rhythmical structure in the answer sentence.

In order to achieve a certain amount of structural variability, a different question type was used for the filler sentences. Their context did not contain a wh-phrase but an NP which differed lexically from the one presented in the following auditory sentence and hence led to contrastive focus on the object NP. The different types of question–answer pairs are illustrated in Table 1.

2.3. Procedure

240 stimuli (30 per critical condition and 120 fillers) were presented in five blocks, each containing 48 sentences, of approximately eight minutes each. The 60 filler sentences were presented twice in order to achieve a more balanced ratio of critical sentences and filler sentences. The order of experimental and filler sentences was pseudo-randomized, and each phrasal verb appeared only once per condition within each block. In order to avoid sequence effects, the block order varied between participants. Participants were seated in front of a computer screen in a dimly lit, sound-attenuating room during the experiment. Before the first experimental block started, a short practice phase was conducted to acquaint the participants with the upcoming procedure. After that, the first experimental block started with the request to click any key to begin the experiment. Each trial was introduced by a context question that appeared on the screen for 2000 ms. Then a fixation cross appeared for 500 ms, followed by the auditory presentation of an answer sentence via two loudspeakers. After the offset of the sentence, a question mark appeared on the screen for 2000 ms. During this time participants were asked to evaluate the sentences and were allowed to blink and move their eyes. The participants' task was to decide as accurately and as quickly as possible whether the auditorily presented sentences sounded natural or not by pressing one of four buttons. The assignment of buttons to four possible answers (natural, rather natural, rather unnatural, and unnatural) was counterbalanced across participants. The next trial started after 2000 ms with a new fixation cross. Between separate blocks, participants were offered a short break of approximately one minute to rest their eyes. All procedures were performed in compliance with relevant laws and institutional guidelines.

2.4. ERP recordings

An electroencephalogram (EEG) was recorded from overall 23 Ag/AgCl electrodes with a *BrainVision* (Brain Products GmbH) amplifier. The C2 electrode served as ground and four electrodes measured the electrooculogram, i.e., horizontal and vertical eye movements. Two auricle electrodes served as references and were placed at the left and right mastoids. EEG and EOG were recorded with a sampling rate of 500 Hz and filtered offline with a 0.3–20 Hz bandpass filter. All electrode impedances were kept below 5 kΩ. To control for artifacts from eye or body movements, all individual EEG recordings were scanned automatically and manually prior to data analysis. Artifacts with an amplitude above 40 mV were excluded automatically, a subsequent visual screening excluded any further artifacts. In total, 2.9% of the critical stimuli and 4.2% of the filler items had to be excluded from analysis.

2.5. Data analyses

Behavioral data were analyzed by calculating the means of all responses for each condition. Each of the four possible response levels was allocated to a numerical value: 1=natural, 2=rather natural, 3=rather unnatural, and 4=unnatural. Data were further analyzed with an ANOVA that included the factors RHYTHM CONDITION (preceding stressed or unstressed syllable) and WELL-FORMEDNESS (words stressed correctly in SHIFT and NO SHIFT or incorrectly in LAPSE and CLASH). Since the group of participants was identical to the one in the previous study (Bohn et al., 2013), it was possible to include EXPERIMENT (wide focus/no focus question in the previous study versus narrow focus and wh-question in the present study) as a third factor. Moreover, paired contrasts were analyzed using a Wilcoxon signed-rank test, conducted with a Bonferroni correction for the *p*-values. In order to prevent movement artifacts, the evaluation response was given with a short delay after the offset of each sentence. Measured reaction times are thus not meaningful and therefore not reported here.

For the EEG data, a multifactorial repeated-measures ANOVA was carried out with the factors REGION (left anterior (F3, F7, and FC5), right anterior (F4, F8, and FC6), left posterior (P3, P7, and CP5), and right posterior (P4, P8, and CP6)), WELL-FORMEDNESS (well-formed vs. ill-formed), and EXPERIMENT (wide focus in the previous study vs. narrow focus in the present study) separately for the two critical rhythm conditions CLASH and LAPSE. This was necessary due to the latency differences between the effects elicited by these two conditions. Therefore, it was not possible to include RHYTHM CONDITION as a further factor of the multifactorial ANOVA, in contrast to the behavioral data analysis. Averages were calculated from the phrasal verb's onset up to 1500 ms thereafter with a baseline of 200 ms preceding the onset. The time windows for each comparison were identical to the time windows in the previous study. In addition, a visual inspection of the grand average curves ensured that no further effects were missed. For effects with more than one degree of freedom, Huynh-Feldt (1976) corrections were applied to the *p*-values.

3. Results

3.1. Behavioral data

The ANOVA for the evaluation data revealed main effects for the factors EXPERIMENT, RHYTHM CONDITION, and WELL-FORMEDNESS [EXPERIMENT: $F(1, 25)=23.38$, $p=.000$; RHYTHM CONDITION: $F(1, 25)=122.76$, $p=.000$; WELL-FORMEDNESS: $F(1, 25)=81.25$, $p=.000$], as well as an interaction of the two factors RHYTHM CONDITION and WELL-FORMEDNESS [$F(1, 25)=100.00$, $p=.000$].

A further analysis of the means of all conditions from both experiments shows that all conditions were evaluated as more natural, hence more acceptable in the present study than in the previous study (on a scale from 1=natural to 4=unnatural; significance level set at $p<.0125$): SHIFT Exp 1 vs. SHIFT Exp 2(mean 1.68 (SD .24) vs. mean 1.56 (SD .25); $Z(26)=-2.99$, $p=.003$), NO SHIFT Exp 1 vs. NO SHIFT Exp 2 (mean 1.89 (SD .28) vs. mean 1.71 (SD .34); $Z(26)=-3.34$, $p=.001$), CLASH Exp 1 vs. CLASH Exp 2 (mean 1.74 (SD .26) vs. mean 1.59 (SD .26); $Z(26)=-3.48$, $p=.001$), LAPSE Exp 1 vs. LAPSE Exp 2 (mean 2.23 (SD .34) vs. mean 2.07 (SD .34); $Z(26)=-2.79$, $p=.005$). Thus, the context questions had an effect on the evaluations: By directing the focus and listeners' attention to the object NP, the prosodic structure of the phrasal verbs attracts less attention than in the previous study.

Analyses of the two comparisons between CLASH and SHIFT and LAPSE and NO SHIFT of the present study revealed that LAPSE was evaluated as less natural than NO SHIFT (mean 2.07 (SD .34) vs. mean 1.71 (SD .34); $Z(26)=-4.46$, $p=.000$). In contrast, sentences of the critical condition CLASH were evaluated almost as natural as its control condition SHIFT (mean 1.59 (SD .26) vs. mean 1.56 (SD .25); $Z(26)=-.87$, $p>.05$). A comparison of the two conditions involving rhythmic deviations, LAPSE and CLASH, showed that LAPSE was evaluated as less natural than CLASH (mean 2.07 (SD .34) vs. mean 1.59 (SD .26); $Z(26)=-4.46$, $p=.000$). The significance level for the p-values is set at $p<.017$ (Bonferroni corrected). Tables 2 and 3 give an overview of the most important results of the behavioral data.

3.2. ERP data

Figs 1 and 2 show the two comparisons between CLASH and SHIFT and LAPSE and NO SHIFT, respectively. In these comparisons, the preceding trigger noun is kept identical whereas the following phrasal verb either fulfills the rhythmic demands of this noun (control conditions SHIFT and NO SHIFT) or deviates from this demand (CLASH and LAPSE). Moreover, in order to compare potential differences between the effects elicited by the critical conditions CLASH and LAPSE, difference waves of these two comparisons were computed by subtracting control conditions from deviant conditions (see Fig. 3). Detailed results of the omnibus ANOVA will be discussed separately for the two rhythmically ill-formed structures and their control conditions. Further, difference waves that show the differences between the study by Bohn et al. (2013) and the present study were included for the two main comparisons CLASH and SHIFT/LAPSE and NO SHIFT (see Figs. 4 and 5). These difference waves illustrate the influence of the factor EXPERIMENT, i.e., of focus and attention, especially on the elicitation of the negative components.

For the ill-formed filler condition, two time windows reveal the same biphasic effect pattern consisting of a negativity effect between 250 and 470 ms [$F(1, 25)=24.84$, $p=.000$, $\eta^2 p=.14$] and a following positivity between 600 and 1200 ms [$F(1, 25)=79.41$, $p<.000$, $\eta^2 p=.27$] as in the previous study.

3.2.1. Comparison between CLASH and SHIFT

For the time window between 100 and 320 ms, the omnibus ANOVA showed a significant main effect for all three factors

Table 2
Behavioral data: mean evaluations of all responses for each condition from both studies. Comparisons are calculated between identical conditions from both studies (on a scale from 1=natural to 4=unnatural; significance level set at $p<.0125$).

Condition	*Evaluation (mean) Broad focus* (Bohn et al. 2013)	*Evaluation (mean) Narrow focus*	*p-value*
CLASH	1.74	1.59	$p=.001$
SHIFT	1.68	1.56	$p=.003$
LAPSE	2.23	2.07	$p=.005$
NO SHIFT	1.89	1.71	$p=.001$

Table 3
Behavioral data: comparisons between rhythmical deviations and their control conditions and between the critical rhythmical deviations in the present study (on a scale from 1=natural to 4=unnatural; significance level set at $p<.0125$).

Comparison	*Evaluation (mean) Narrow focus*	*p-value*
CLASH and SHIFT	1.59 vs. 1.56	$p>.05$ (n.s.)
LAPSE vs. NO SHIFT	2.07 vs. 1.71	$p=.000$
CLASH vs. LAPSE	1.59 vs. 2.07	$p=.000$

WELL-FORMEDNESS [$F(1, 25)=16.91$, $p=.000$, $\eta^2p=.06$], REGION [$F(3, 75)=15.08$, $p=.000$, $\eta^2p=.08$] and EXPERIMENT [$F(1, 25)=6.45$, $p=.018$, $\eta^2p=.04$]. There was no significant three way interaction [$F(3, 75)=2.31$, $p>.05$, $\eta^2p=.00$], but a significant interaction between the factors EXPERIMENT and REGION [$F(3, 75)=3.10$, $p=.057$, $\eta^2p=.01$]. The interaction with REGION is in line with the expectation to find an early left anterior negativity for the comparison of the conditions CLASH and SHIFT in both experiments, independent from the given focus. The post-hoc analysis of the interaction between REGION and EXPERIMENT by REGION in fact revealed a stronger occurrence of the early negativity in the frontal regions in the present study [left anterior: $F(1, 25)=8.60$, $p=.007$, $\eta^2p=.08$; right anterior: $F(1, 25)=15.67$, $p=.001$, $\eta^2p=.13$]. This analysis of the separate regions was calculated to test the hypothesis that the early negativity effect is a subcomponent of the LAN and should be found not only in the study by Bohn et al. (2013) but also in the present study (cf. Fig. 4).

The analysis of the second time window (850–1150) revealed significant main effects for the factors WELL-FORMEDNESS [$F(1, 25)=8.10$, $p=.009$, $\eta^2p=.01$] and REGION [$F(3, 75)=21.34$, $p=.000$, $\eta^2p=.09$] but not for EXPERIMENT [$F(1, 25)<1$, $p>.05$, $\eta^2p=.00$]. However, there was a statistically significant interaction between WELL-FORMEDNESS, REGION and EXPERIMENT [$F(3, 75)=3.02$, $p=.050$, $\eta^2p=.00$]. Resolving this interaction by EXPERIMENT, the post-hoc analyses showed that the positivity effect is significant in the previous study with broad focus [$F(1,25)=14.10$, $p<.001$, $\eta^2p=.06$], but not in the experiment with narrow focus [$F(1, 25)<1$, $p>.05$, $\eta^2p=.00$]. Post-hoc analyses by the factor REGION show that the positivity effect is significant in all four regions of interest in the previous study, with a slightly stronger anterior occurrence [left anterior: $F(1,25)=17.15$, $p<.001$, $\eta^2p=.10$; right anterior: $F(1,25)=14.90$, $p<.001$, $\eta^2p=.10$]. In contrast, no significant positivity effect is found in any region of interest in the present study.

3.2.2. Comparison between LAPSE and NO SHIFT

The analysis of the first time window from 400 to 750 ms showed significant main effects for the factors WELL-FORMEDNESS [$F(1, 25)=13.30$, $p=.001$, $\eta^2p=.03$], REGION [$F(3, 75)=6.53$, $p=.001$, $\eta^2p=.05$] and EXPERIMENT [$F(1, 25)=17.07$, $p=.000$, $\eta^2p=.13$]. The three way interaction did not reach statistical significance [$F(3, 75)<1$, $p>.05$, $\eta^2p=.00$], but there were significant two way interactions between the factors EXPERIMENT and WELL-FORMEDNESS [$F(1, 25)=15.28$, $p=.001$, $\eta^2p=.03$] and EXPERIMENT and REGION [$F(3, 75)=14.02$, $p=.000$, $\eta^2p=.03$]. Post-hoc comparisons of the condition LAPSE and its control condition NO SHIFT showed a significant effect for the factor WELL-FORMEDNESS only when presented within broad focus [broad focus: $F(1,25)=25.12$, $p<.000$, $\eta^2p=.10$; narrow focus: $F(1, 25)<1$, $p>.05$, $\eta^2p=.00$] (cf. Fig. 5).

For the second time window from 1050 to 1280 ms, the omnibus ANOVA revealed significant main effects for the factors WELL-FORMEDNESS [$F(1, 25)=12.43$, $p=.002$, $\eta^2p=.05$] and REGION [$F(3, 75)=27.17$, $p=.000$, $\eta^2p=.10$] but not for EXPERIMENT [$F(1, 25)=2.50$, $p>.05$, $\eta^2p=.01$]. There is no

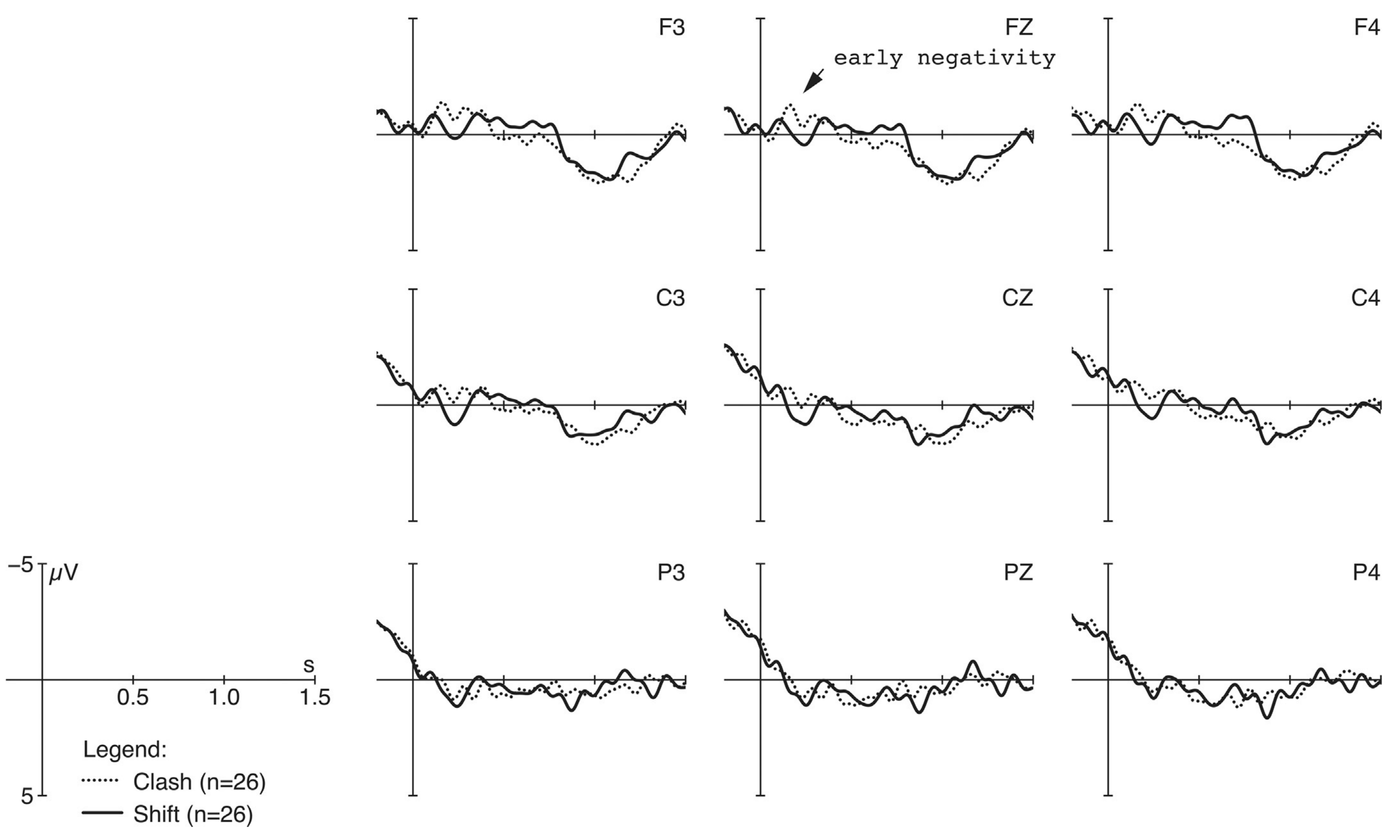

Fig. 1. Grand averages of event-related potentials obtained for the conditions CLASH and control condition SHIFT measured from 200 ms prior the verb onset up to 1500 ms.

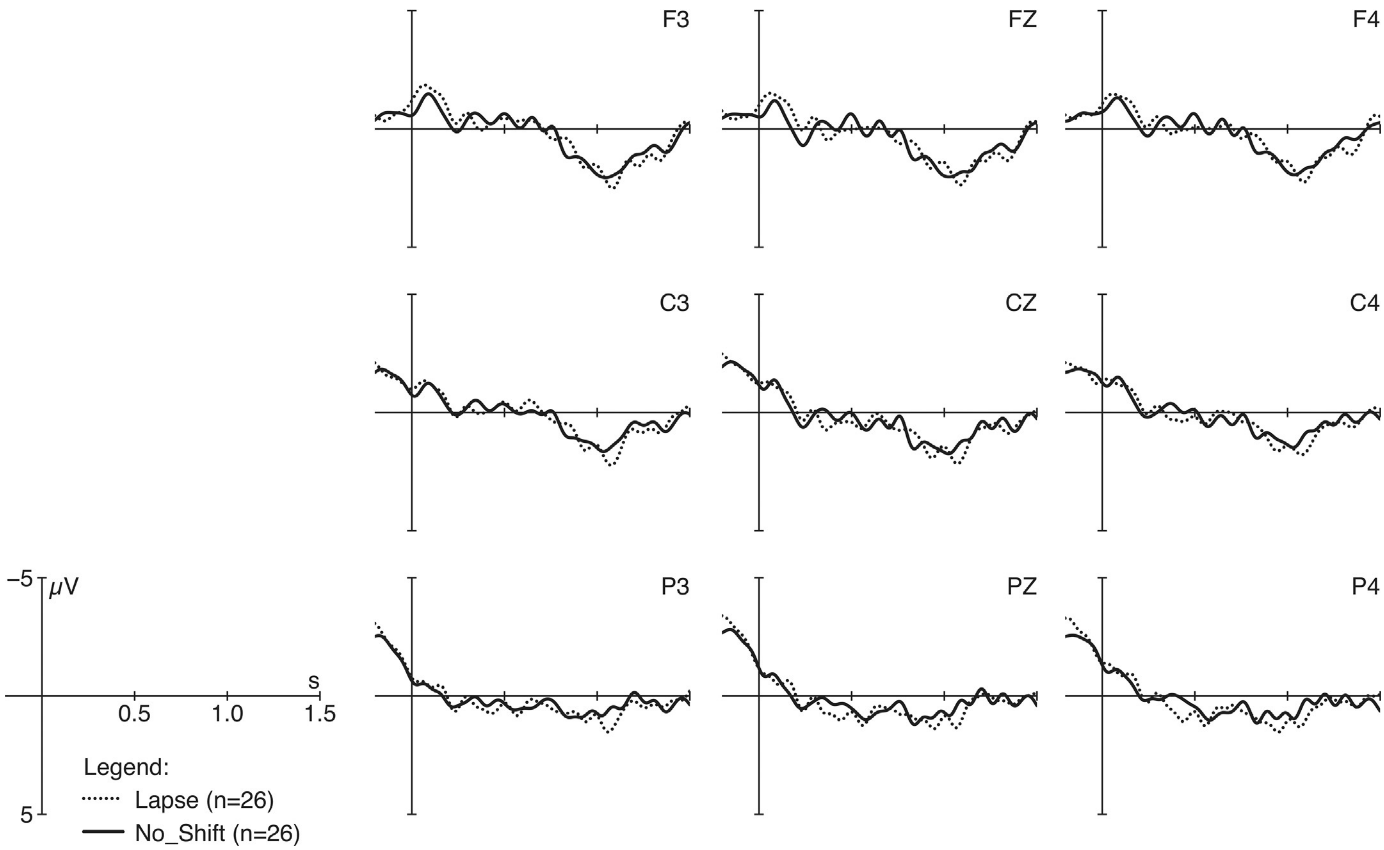

Fig. 2. Grand averages of event-related potentials obtained for the conditions LAPSE and control condition NO SHIFT measured from 200 ms prior the verb onset up to 1500 ms.

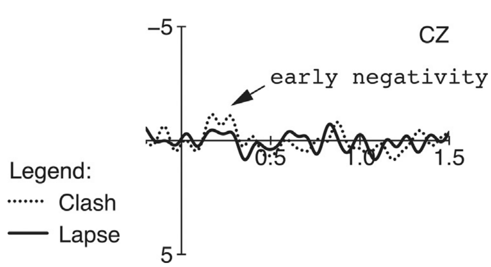

Fig. 3. ERP difference waves contrast the different negativity effects found for CLASH and control condition SHIFT (dotted) and LAPSE and control condition NO SHIFT (solid).

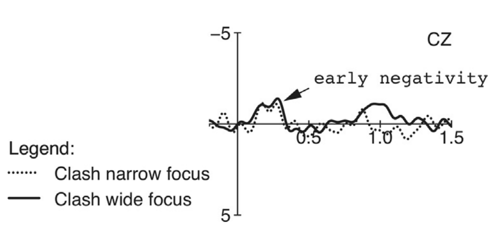

Fig. 4. ERP difference waves show the similarity in latency and topography of the early negativity effect found for CLASH and control condition SHIFT in wide focus (from Bohn et al. (2013); solid line) and narrow focus (present study; dotted line).

significant three way interaction [$F(3, 75) < 1$, $p > .05$, $\eta^2 p = .00$], but significant interactions are found between the factors EXPERIMENT and REGION [$F(3, 75) = 4.86$, $p = .014$, $\eta^2 p = .01$]. In order to verify that the positivity effect found in the previous study by Bohn et al. (2013) is not elicited in the present study, post-hoc analyses were calculated for each experiment with the factors WELL-FORMEDNESS and REGION. The results show that the positivity is indeed not elicited in the present study with narrow

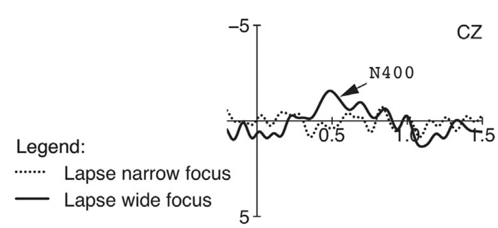

Fig. 5. ERP difference waves show the difference of the negativity effect found for LAPSE and control condition NO SHIFT in wide focus (from Bohn et al. (2013); solid line) and the missing negativity effect in narrow focus (present study; dotted line).

focus [$F(1, 25) = 2.94$, $p > .05$, $\eta^2 p = .02$]. Thus, the two time windows for the comparison of the conditions LAPSE and NO SHIFT showed no significant effects in the present study (cf. Fig. 2).

Finally, the two control conditions were tested against each other in order to control for effects purely elicited by lexical deviations. This comparison showed no significant differences in the grand averages. Table 4 illustrates all analyzed time windows for the two conditions including rhythmical deviations, CLASH and LAPSE, and their correct control conditions and gives an overview and comparison with the results found by Bohn et al. (2013).

4. Discussion

This study aimed at investigating the capability to detect rhythmically deviating structures and to disentangle the processing of lexical and rhythmical deviations by utilizing event-related potentials. It was designed to clarify whether and how information structure modulates the processing of rhythmic deviations, in particular when these are presented in unfocused position and

Table 4
Different types of ERP effects in different time windows (in ms) for all comparisons in narrow focus presentation (present study) and wide focus presentation (results of the comparative study by Bohn et al. (2013)). Statistical significance is indicated by *($p < .05$), **($p < .01$), and ***($p < .001$). Underlined words (àbsagen) indicate the critical word's onset for average calculation.

Comparison	*Experiment*	*Negativity*	*Positivity*	*Critical phrases*
CLASH vs. SHIFT	Broad focus (Bohn et al., 2013)	100–320**	850–1150***	Termín àbsagen vs. Termín absàgen
	Narrow focus	100–320**	850–1150 n.s.	
LAPSE vs. NO SHIFT	Broad focus (Bohn et al., 2013)	400–750***	1050–1280**	Féier absàgen vs. Féier àbsagen
	Narrow focus	400–750 n.s.	1050–1280 n.s.	

attention is thus directed towards another element in the presented sentence. The influence of the given-new structure was examined by presenting question-response pairs in which the question pre-activated the phrasal verbs that were subject to stress manipulation in the response. Hence, the contribution of lexical stress processing in rhythmic deviations could be unraveled. Finally, behavioral data provided insight into the question whether phonetically clear deviations are perceived and evaluated as ill-formed if the listeners' attention is drawn to another part of the presented sentence and the critical event is therefore processed in less detail.

The results show that only sentences containing stress clashes elicited an early negativity between 100 and 320 ms which is more pronounced in the anterior region, exactly as in the previous study (Bohn et al., 2013), whereas no effects were found for sentences containing stress lapses in comparison to its correct control condition. These findings support the assumption that the negativities for clash and lapse structures found in the previous study (Bohn et al., 2013) reflect different processes.

By virtue of visual presentation of a preceding context question, the listeners' attention was directed towards the object NP of the following auditorily presented sentence. The object phrase was clearly identifiable as the unit bearing nuclear stress. This excluded an erroneous interpretation of the phrasal verb as the unit bearing main stress and carrying focus status. Only under these circumstances, a stress clash could be interpreted as being tolerable. The presented rhythmic deviation had thus to be perceived as an error in the rhythmic structure. However, the behavioral data show that the sentences containing clash structures were evaluated almost as natural as its rhythmically well-formed control condition. This might be due to the aforementioned context question. Since the listeners' attention was directed to the meaning of the word preceding the rhythmically critical structure, the perception and detection of the deviation might have been impeded. Although the task led the participants' attention towards prosody in general, as they had to judge the overall sentence's naturalness, it is very likely that the context question narrowed the attention to the object NP so that the rhythmic deviation in the phrasal verb was processed in less detail and therefore not consciously perceivable for the listeners.

The fact that an early anterior negativity was found for CLASH in comparison to SHIFT nonetheless shows that perception and detection of rhythmically erroneous structures seems to proceed rather unconsciously and automatically, i.e., independently from unrestricted attentional focus on the rhythmic structure. Clash structures do not deviate from lexical stress or impede lexical retrieval of the critical phrasal verb. Thus, the negativity is not likely to reflect enhanced costs in lexical access. The elicited negativity supports the interpretation proposed in Bohn et al. (2013) as an instance of a general rule-governed error detection mechanism activated by a rhythmic irregularity, which has also been found in previous studies focusing on metric deviations (e.g., Schmidt-Kassow and Kotz 2009a; Rothermich et al., 2010, 2012). This component does not only occur in the processing of deviating linguistic sequences but is also elicited by violations of arithmetical rules (Jost et al., 2004; Núñez-Peña and Honrubia-Serrano, 2004), as well as by musical and tonal irregularities (Brochard et al., 2003; Abecasis et al., 2005; Geiser et al., 2009; Patel et al., 1998; Koelsch et al., 2000). Due to its anterior distribution and its domain-independent occurrence, this negativity can be interpreted as a subcomponent of an LAN (cf. Hoen and Dominey, 2000), reflecting the general recognition of deviations and violations in regular structures.

The extension of the experimental set-up to include a context question which distracts the listeners' attention away from the rhythmic deviation to the preceding object phrase, provides further information about the component's sensitivity towards attention and task setting. The study shows that this error-related negativity can be found irrespective whether a given task is directed towards the rhythmic structure, if attention is shaped by information structure. This is in line with results obtained in previous studies showing that this rather general than language-specific error-related negativity is elicited independently from special rhythmic or attentional task requirements (Schmidt-Kassow and Kotz, 2009a; Rothermich et al., 2010).

The absence of a negativity effect for sentences containing stress lapses indicates that the negativity effect found for this particular deviation type in Bohn et al. (2013) is mainly caused by increased costs in lexical retrieval due to the deviation from the canonical lexical stress pattern, i.e., an N400 effect. Recall that the phrasal verbs presented in the LAPSE condition not only deviate from a regular rhythmic but also from the lexical stress pattern. Due to the presentation in the context question, lexical access was completed by the time the critical phrasal verb was perceived in the auditorily presented response sentence. Thus, uncomplicated lexical retrieval results in the absence of an N400 effect. This interpretation is supported by studies showing that the visual presentation of a critical item prior to its auditory presentation can result in a lack of an N400 effect for words with deviating stress patterns. Without preceding visual presentation, however, the N400 effect occurred (Knaus et al., 2007; Domahs et al., 2015).

Several studies (e.g., Friedrich et al., 2004; Knaus et al., 2007; Magne et al., 2007) were able to show that the N400 effect for enhanced costs in lexical retrieval is not related to explicit attention. Hence, the circumstance that the critical verb was presented in post-focus position in the present study cannot be responsible for the complete lack of a negativity effect.

It cannot be excluded that the rhythmic irregularity in stress lapse structures contributed to the pronounced negativity effect found for LAPSE in Bohn et al. (2013). In this study, the participants' attention was not centered on a single constituent of the utterance but to the entire sentence so that the rhythmic deviation of a rhythmically unlicensed stress shift was presumably more salient than in the present study. Due to the manipulation of attention and a therewith induced shallow processing of the critical structure in the present study, its influence might have been too weak in order to elicit an effect by its own, i.e., an early metric negativity which was found for stress clashes. However, the behavioral data show that sentences containing stress lapses were evaluated as less natural and acceptable than its correct control condition NO SHIFT. Interestingly, it was also evaluated as less natural than the control condition SHIFT (mean 2.07 (SD .34) vs. mean 1.56 (SD .25); $Z(26) = -4.46$, $p = .000$). SHIFT contains the same deviation from lexical stress but is rhythmically licensed. This reveals a certain discrepancy between the behavioral and ERP results and between the two rhythmically ill-formed structures. Stress clashes are detected and processed automatically, resulting in an early negativity effect in the ERP response. In the given evaluation task, though, they are not treated as unacceptable deviations. In contrast, sentences containing stress lapses are evaluated as unacceptable due to comprising a rhythmic as well as a lexical violation. In the ERP response, however, the rhythmic deviation alone causes no greater problems and costs for processing.

In opposition to the previous study, no positivity effects were found for both comparisons. This absence of a late positive component sheds further light on this component's nature. The late positive component is interpreted to reflect the evaluation process and the task resolvability related to the given task requirements (Bohn et al. 2013). As the given task was kept identical in the previous and the present study, the lack of a difference between critical and control conditions illustrates the unproblematic evaluation of the sentences presented. That is, the participants evaluated both the critical and control conditions to be equally well-formed in the present study. This is supported by the behavioral data which show that all conditions are generally evaluated as more natural and acceptable compared to the previous study. This might be due to the attentional shift induced by the preceding context question. Recall that the given task was to evaluate the prosodic well-formedness of the overall sentence. The task itself is designed to draw attention to the prosodic structure of the whole sentence, also to the rhythmic deviations. However, the additionally presented context question narrowed the attention to the object NP in focus position. This focus manipulation led to a less detailed processing of the unfocused deviations. Thus, the rather subtle rhythmic deviations in form of clashes and lapses were less salient for the participants. Therefore, the deviations as well as the correct control conditions were resolvable and acceptable to a comparable extent, reflected in the non-appearance of a late positive component. That perceptual saliency is indeed influenced by focus and the position of a critical word within the higher prosodic structure is also shown by Domahs et al. (2015). In this study, violations from lexical stress were generally less perceivable in non-focus position and only phonetically clear errors elicited a late positive component.

This interpretation is further supported by the fact that an enhanced late positivity was elicited by filler items containing violations of canonical lexical stress (e.g., **redùzieren* 'to reduce') in comparison to correct filler items (e.g., *reduzìeren* 'to reduce'). Here, the deviation was clear enough to be perceived although the context question shifted the listeners' attention towards another part of the sentence as well. The absence of a late positive component for information in non-focus position further supports the assumption that information structure modulates the perception and processing of the rhythmic structure, as non-focused information regarding rhythmical properties receives less attention and is therefore processed in less detail. This finding is in line with previous studies which were able to show that syntactic as well as semantic input is processed less extensively if information structure guides attention towards focused information (Wang et al., 2011, 2012).

The overall results demonstrate that the brain is sensitive to rhythmic deviations in form of stress clashes and can detect them automatically, independently of attention. In contrast, deviations from lexical stress are not detected if focus is directed towards another part of the utterance, and if its lexical retrieval has been accomplished by the time the deviating pattern occurs. The absence of a late positive component shows that rhythmical as well as lexical deviations are perceivable, but processed in less detail when situated in non-focus position.

5. Conclusion

The present study shows that an attentional shift via a contextually induced narrow focus onto a preceding word reduces the cognitive responses to rhythmically marked structures and hence improves the acceptability of rhythmic irregularities during speech processing. Hence, a contextually induced shift of attention seems to make rhythmic irregularities less salient and perceptible. Nonetheless, the results found for stress clashes show that rather subtle rhythmic irregularities are detected during processing, even if the attention is detracted away from them and the remaining context is kept rhythmically natural, i.e., not strictly regular. This confirms the view that the detection and processing of stress clashes in German take place automatically. Moreover, the early negativity found for stress clashes supports the assumption that rhythmically deviating structures are distinguished from alternating structures. The absence of a negativity effect for stress lapses reveals that rhythmic irregularities in form of stress clashes and stress lapses are processed differently and that the measured negativities for these two deviations in Bohn et al. (2013) reflect indeed two distinct processes.

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9 Description of contribution

Research article 1

Bohn, K., Wiese, R., Domahs, U. (2011). The status of the Rhythm Rule within and across word boundaries in German. *Proceedings of the 17th International Congress of Phonetic Sciences,* 332 – 335.

Contribution: conception of experimental stimuli and experimental paradigm; data acquisition; data analysis; interpretation of results; sole preparation of the manuscript's first draft; preparation of the manuscript for publication

Research article 2

Bohn, K., Knaus, J., Wiese, R., Domahs, U. (2013). The influence of rhythmic (ir)regularities on speech processing: evidence from an ERP study on German phrases. *Neuropsychologia, 51*(4), 760 – 771.

Contribution: conception of experimental stimuli and experimental paradigm; data acquisition; data analysis; interpretation of results; sole preparation of the manuscript's first draft; preparation of the manuscript for publication

Research article 3

Henrich, K., Alter, K., Wiese, R., Domahs, U. (2014). The relevance of rhythmical alternation in language processing: An ERP study on English compounds. *Brain and Language, 136*, 19 – 30.

Contribution: conception of experimental stimuli and experimental paradigm; data acquisition; data analysis; interpretation of results; sole preparation of the manuscript's first draft; preparation of the manuscript for publication

Research article 4

Henrich, K., Wiese, R., Domahs U. (2015). How information structure influences the processing of rhythmic irregularities: ERP evidence from German phrases. *Neuropsychologia, 75*, 431 – 440.

Contribution: conception of experimental stimuli and experimental paradigm; data acquisition; data analysis; interpretation of results; sole preparation of the manuscript's first draft; preparation of the manuscript for publication

Study 5 (Research article in preparation)

Henrich, K., Wiese, R., Domahs U. (in preparation). Quantity counts: evidence from an ERP study on rhythmic deviations in German trisyllabic and quadrisyllabic compounds.

Contribution: conception of experimental stimuli and experimental paradigm; data acquisition; data analysis; interpretation of results; sole preparation of the manuscript's first draft

10 Appendix

10.1 Supplementary material Study 1

10.1.1 List with sentences for the production experiment

Die jährlichen Unterhaltskosten von 250 000 Mark für die Stadtmauer und 800 000 für die Stadtpfarrkirche mit Daniel sind noch die geringsten Posten.

In vielen Drogerien kann man mittlerweile seine Fotos abgeben, um sie an einem SB-Automaten entwickeln zu lassen.

Flößverein will Kunstdenkmal am Isarplatz loswerden.

Wie erwartet, wird Frank Schätzing auf der Buchmesse aus seinem neuen Roman vorlesen, auf welchen die Kritiker und Fans seit „Der Schwarm" bereits sehnsüchtig warten.

Für so eine Klage gibt es keine Grundlage, denn die Hauptfahrrinne ist kein Fanggebiet.

Wenn die Oma ihre Enkelkinder besuchen kommt, muss sie abends immer mehrere Bücher vorlesen, bis die Kinder endlich eingeschlafen sind.

Bei Schweißarbeiten im Hauptbahnhof von Hannover entzündeten sich Kabel.

Vor zwei Monaten erst hat Wilhelm Blume einen Geldbriefträger ermordet, nun, während draußen Barrikaden ganze Stadtteile abriegeln, plant Blume erneut einen Geldbriefträger in die Falle zu locken.

Zu seinem Geburtstag wird er sicher auch den Kaplan einladen, wie bereits im letzten Jahr.

Eine Besonderheit, nicht nur für Sammler und Liebhaber, bietet die Stadtsparkasse zum Weihnachtsfest.

Zu einem Weinfest sollte man immer auch Winzer einladen, die für besonders edle Tropfen bekannt sind.

Die Entscheidung im Stabhochsprung der Männer wurde angesichts des Dauerregens abgesagt und auf das internationale Meeting am kommenden Samstag in Nürnberg verlegt.

Ins Büro muss sie immer eine Bluse anziehen, zum Theaterbesuch am Abend kann sie jedoch endlich ihr schickes neues Kostüm anziehen, welches sie erst kürzlich in Mailand gekauft hat.

In Schmalkalden werde von diesem Wintersemester an erstmals an einer ostdeutschen Fachhochschule der Studiengang Volkswirtschaftslehre angeboten.

Leider mussten die Eheleute wegen schlechten Wetters ihre Feier absagen, da eine Feier im Garten geplant war.

Das gesamte Finanzmanagement beschäftigt, Direktor und Hilfsbuchhalter inbegriffen, nur acht Leute.

Die Verspätungen der Bahn führen bei Pendlern häufig zu Unannehmlichkeiten. So musste eine Geschäftsfrau einen wichtigen Termin absagen, der bereits seit Monaten geplant war.

Wenn das Waldschwimmbad am 15. Mai öffnet, beginnt ein Nonstop-Freizeitprogramm.

Die Praktikantin sollte so schnell wie möglich ihren neuen Vertrag abgeben, um keine Probleme mit der Verwaltung zu bekommen.

Dreisilbige Komposita	Partikelverb Shift
Viersilbige Komposita	Partikelverb No_Shift

10.1.2 Evaluation list for the perception experiment

Die folgende Liste enthält verschiedene Wörter und kurze Phrasen. Bei den viersilbigen Wörtern sind nur die ersten drei Silben wichtig, bei den Phrasen soll der Hauptakzent des Nomens sowie des folgenden Verbs gekennzeichnet werden. In jedem Wort bzw. jeder Phrase soll die als am stärksten empfundene Silbe gekennzeichnet werden (= 1), die anderen Silben sollen von dieser Silbe ausgehend abgestuft bewertet werden (= 2, 3). Jedes Wort soll für die Beurteilung maximal dreimal angehört werden.

1 3 2 1 2 3 2 1 3
Bsp: Waldspielplatz: Waldspielplatz <u>oder</u> Waldspielplatz oder Waldspielplatz

1 2 3 1 3 2 3 1 2
Vertrag abtippen: Vertrag abtippen <u>oder</u> Vertrag abtippen oder Vertrag abtippen

Bitte gib bei den folgenden Soundbeispielen die Betonungsabfolge so an, wie Du sie Deiner Meinung nach gehört hast (1≙ prominenteste Silbe /Hauptakzent, danach absteigend 2, 3). Beachte dabei, dass die Betonungsmuster verschiedener Sprecher nicht immer der Standardbetonung folgen müssen.

1. Stadtpfarrkirche
2. Sparkasse
3. Termin absagen
4. Hauptfahrrinne
5. Hochsprung
6. Kunstdenkmal
7. Fotos abgeben
8. Geldbriefträger 1
9. Schwimmbad
10. Roman vorlesen
11. Briefträger 1
12. Bahnhof
13. Stadtsparkasse
14. Vertrag abgeben
15. Fahrrinne
16. Briefträger 2
17. Kaplan einladen
18. Stabhochsprung
19. Bücher vorlesen
20. Fachhochschule
21. Buchhalter
22. Hauptbahnhof
23. Geldbriefträger 2
24. Winzer einladen
25. Hochschule
26. Hilfsbuchhalter
27. Denkmal
28. Waldschwimmbad
29. Pfarrkirche
30. Feier absagen

10.2 Supplementary material Study 2

10.2.1 Stimuli condition SHIFT

1. Sie soll den Kontakt abbrechen, wie besprochen.
2. Sie soll den Vertrag abgeben, wie besprochen.
3. Sie soll den Verlag abhören, wie abgemacht.
4. Sie soll den Termin absagen, wie besprochen.
5. Sie soll das Zitat abtippen, wie üblich.
6. Sie soll das Geschirr abwaschen, wie immer.
7. Sie soll den Altar abwischen, wie üblich.
8. Sie soll das Benzin abzapfen, wie üblich.
9. Sie soll den Notar anlächeln, wie immer.
10. Sie soll das Emblem annähen, wie besprochen.
11. Sie soll den Salat anrichten, wie abgemacht.
12. Sie soll den Vikar anrufen, wie abgemacht.
13. Sie soll das Kostüm anziehen, wie üblich.
14. Sie soll den Kamin anzünden, wie immer.
15. Sie soll den Spinat aufessen, wie immer.
16. Sie soll das Paket aufgeben, wie abgemacht.
17. Sie soll die Fabrik aufkaufen, wie besprochen.
18. Sie soll das Hotel aufmachen, wie immer.
19. Sie soll die Notiz aufschreiben, wie besprochen.
20. Sie soll das Gerüst aufstellen, wie abgemacht.
21. Sie soll das Gepäck ausladen, wie üblich.
22. Sie soll das Gedicht austeilen, wie abgemacht.
23. Sie soll das Getränk austrinken, wie immer.
24. Sie soll das Gesicht eincremen, wie üblich.
25. Sie soll den Likör einkaufen, wie abgemacht.
26. Sie soll den Kaplan einladen, wie üblich.
27. Sie soll die Bilanz einreichen, wie besprochen.
28. Sie soll den Pokal umstellen, wie besprochen.
29. Sie soll den Roman vorlesen, wie immer.
30. Sie soll die Briketts wegwerfen, wie üblich.

10.2.2 Stimuli condition NO SHIFT

1. Sie soll die Reise abbrechen, wie besprochen.
2. Sie soll die Fotos abgeben, wie besprochen.
3. Sie soll den Lehrer abhören, wie abgemacht.
4. Sie soll die Feier absagen, wie besprochen.
5. Sie soll die Texte abtippen, wie üblich.
6. Sie soll die Tasse abwaschen, wie immer.
7. Sie soll die Stühle abwischen, wie üblich.
8. Sie soll das Wasser abzapfen, wie üblich.
9. Sie soll das Baby anlächeln, wie immer.
10. Sie soll die Kordel annähen, wie besprochen.
11. Sie soll die Suppe anrichten, wie abgemacht.
12. Sie soll den Schreiner anrufen, wie abgemacht.
13. Sie soll die Bluse anziehen, wie üblich.
14. Sie soll den Ofen anzünden, wie immer.
15. Sie soll die Torte aufessen, wie immer.
16. Sie soll das Päckchen aufgeben, wie abgemacht.
17. Sie soll die Villa aufkaufen, wie besprochen.
18. Sie soll das Fenster aufmachen, wie immer.
19. Sie soll das Märchen aufschreiben, wie besprochen.
20. Sie soll die Bänke aufstellen, wie abgemacht.
21. Sie soll die Koffer ausladen, wie üblich.
22. Sie soll die Blätter austeilen, wie abgemacht.
23. Sie soll den Wodka austrinken, wie immer.
24. Sie soll die Hände eincremen, wie üblich.
25. Sie soll die Säfte einkaufen, wie abgemacht.
26. Sie soll den Winzer einladen, wie üblich.
27. Sie soll die Briefe einreichen, wie besprochen.
28. Sie soll die Schale umstellen, wie besprochen.
29. Sie soll die Bücher vorlesen, wie immer.
30. Sie soll die Flaschen wegwerfen, wie üblich.

10.2.3 Filler Items

1. Sie soll den Abzug abmontieren, wie abgemacht.
2. Sie soll die Haare abrasieren, wie üblich.
3. Sie soll die Uni absolvieren, wie besprochen.
4. Sie soll das Kleinkind adoptieren, wie besprochen.
5. Sie soll das Treffen arrangieren, wie abgemacht.
6. Sie soll das Rezept ausprobieren, wie abgemacht.
7. Sie soll den Bleistift ausradieren, wie üblich.
8. Sie soll die Hemden aussortieren, wie immer.
9. Sie soll den Begriff definieren, wie abgemacht.
10. Sie soll den Balkon dekorieren, wie immer.
11. Sie soll die Flöten dirigieren, wie üblich.
12. Sie soll die Klausur diskutieren, wie besprochen.
13. Sie soll die Helfer engagieren, wie abgemacht.
14. Sie soll den Urlaub finanzieren, wie immer.
15. Sie soll die Echtheit garantieren, wie abgemacht.
16. Sie soll den Sänger imitieren, wie üblich.
17. Sie soll die Rechnung kalkulieren, wie üblich.
18. Sie soll die Lieder komponieren, wie besprochen.
19. Sie soll die Brücke konstruieren, wie abgemacht.
20. Sie soll den Versuch kontrollieren, wie immer.
21. Sie soll den Fehler korrigieren, wie besprochen.
22. Sie soll den Prüfer kritisieren, wie üblich.
23. Sie soll die Sendung produzieren, wie immer.
24. Sie soll die Meinung propagieren, wie immer.
25. Sie soll die Preise reduzieren, wie abgemacht.
26. Sie soll den Palast renovieren, wie besprochen.
27. Sie soll die Heizung reparieren, wie abgemacht.
28. Sie soll dem König salutieren, wie üblich.
29. Sie soll die Pläne strukturieren, wie üblich.
30. Sie soll den Gehweg zementieren, wie abgemacht.

10.2.4 Acoustic Analysis

Syllable	Duration (ms)	p-value	Intensity (dB)	p-value	Pitch (Hz)	p-value
V1 (NS) vs. V1 (S)	251 vs. 225	*p* = 0.002	59.27 vs. 56.01	*p* = 0.000	186.86 vs. 186.35	*p* = 0.959
V2 (NS) vs. V2 (S)	247 vs. 268	*p* = 0.005	59.96 vs. 59.62	*p* = 0.382	190.74 vs. 192.72	*p* = 0.004
V3 (NS) vs.V3 (S)	231 vs. 270	*p* = 0.000	61.26 vs. 61.20	*p* = 0.704	188.33 vs. 191.03	*p* = 0.060

Table 1. Phonetic and statistical analysis of pairwise syllable comparisons for the conditions NO SHIFT (NS) und SHIFT (S).

10.3 Supplementary material Study 3

10.3.1 Stimuli condition SHIFT

1. The Bamboo scrapers are sharp.
2. The Bangkok Metro is crowded.
3. The cartoon heroes have superpowers.
4. The CD player is too loud.
5. The champagne cocktails are very pricey.
6. The CV templates are very helpful.
7. The Dundee airport is rather small.
8. The fifteen children eat ice-cream.
9. The ideal partners are hard to find.
10. The insane patients need special treatment.
11. The routine checkups are essential.
12. The sixteen women like the cinema.
13. The thirteen clients paid their bills.
14. The thirteen teachers are ambitious.
15. The TV dinner has to be microwaved.

10.3.2 Stimuli condition NO SHIFT

1. The bamboo canoes won the race.
2. The Bangkok cuisine is superb.
3. The cartoon awards are highly desired.
4. The CD release is planned for June.
5. The champagne desserts are very delicious.
6. The CV reviews are very helpful.
7. The Dundee canal is very old.
8. The fifteen balloons fly very high.
9. The ideal trainees are industrious.
10. The insane ideas are often the best
11. The routine repairs are fixed promptly.
12. The sixteen giraffes live in the zoo.
13. The thirteen cadets passed their finals.
14. The thirteen guitars are collector's items.
15. The TV campaign was very expensive.

10.3.3 Filler Items

1. I like to become a film-star.
2. I like to believe in miracles.
3. I like to bestow awards.
4. I like to canoe down the river.
5. I like to cement my position.
6. I like to combine different styles.
7. I like to compare prices.
8. I like to compete with others.
9. I like to complete crosswords.
10. I like to compose operas.
11. I like to convince my parents.
12. I like to debate environmental topics.
13. I like to defend my rights.
14. I like to describe my ideas.
15. I like to donate money.
16. I like to elect my class president.
17. I like to enjoy my holidays.
18. I like to explain difficult topics.
19. I like to ignite fires.
20. I like to impress my audience.
21. I like to improve my debating skills.
22. I like to invent new methods.
23. I like to invite good friends.
24. I like to narrate fairytales.
25. I like to obtain art.
26. I like to prepare dinners.
27. I like to receive my degree.
28. I like to relax in the sunshine.
29. I like to repair vintage cars.
30. I like to support my football team.

10.3.4 Acoustic Analysis

Syllable	Pitch (Hz)	p-value	Duration (ms)	p-value	Intensity (dB)	p-value
C1 (NS) vs. C1 (S)	229.37 244.85	p=0.015	286 254	n.s.	68.97 68.93	n.s.
C2 (NS) vs. C2 (S)	250.86 224.41	p=0.004	282 229	p=0.004	66.41 67.41	n.s.

Table 1. Phonetic and statistical analysis of pairwise syllable comparisons for the conditions NO SHIFT (NS) und SHIFT (S).

10.4. Supplementary material Study 4

10.4.1 Wh-questions: Experimental conditions

1. Was soll sie abbrechen?
2. Was soll sie abgeben?
3. Wen soll sie abhören?
4. Was soll sie absagen?
5. Was soll sie abtippen?
6. Was soll sie abwaschen?
7. Was soll sie abwischen?
8. Was soll sie abzapfen?
9. Wen soll sie anlächeln?
10. Was soll sie annähen?
11. Was soll sie anrichten?
12. Wen soll sie anrufen?
13. Was soll sie anziehen?
14. Was soll sie anzünden?
15. Was soll sie aufessen?
16. Was soll sie aufgeben?
17. Was soll sie aufkaufen?
18. Was soll sie aufmachen?
19. Was soll sie aufschreiben?
20. Was soll sie aufstellen?
21. Was soll sie ausladen?
22. Was soll sie austeilen?
23. Was soll sie austrinken?
24. Wen soll sie eincremen?
25. Was soll sie einkaufen?
26. Wen soll sie einladen?
27. Was soll sie einreichen?
28. Was soll sie umstellen?
29. Was soll sie vorlesen?
30. Was soll sie wegwerfen?

10.4.2 Wh-questions: Filler conditions

1. Soll sie die Dusche abmontieren?
2. Soll sie den Bart abrasieren?
3. Soll sie die Schule absolvieren?
4. Soll sie das Baby adoptieren?
5. Soll sie die Hochzeit arrangieren?
6. Soll sie das Fahrrad ausprobieren?
7. Soll sie den Fehler ausradieren?
8. Soll sie die Schuhe aussortieren?
9. Soll sie den Ausdruck definieren?
10. Soll sie den Garten dekorieren?
11. Soll sie die Chöre dirigieren?
12. Soll sie die Nachricht diskutieren?
13. Soll sie die Sänger engagieren?
14. Soll sie die Wohnung finanzieren?
15. Soll sie die Laufzeit garantieren?
16. Soll sie den Lehrer imitieren?
17. Soll sie den Beitrag kalkulieren?
18. Soll sie die Oper komponieren?
19. Soll sie das Hochhaus konstruieren?
20. Soll sie die Pläne kontrollieren?
21. Soll sie die Arbeit korrigieren?
22. Soll sie die Schüler kritisieren?
23. Soll sie die Filme produzieren?
24. Soll sie die Lügen propagieren?
25. Soll sie das Angebot reduzieren?
26. Soll sie die-Zimmer renovieren?
27. Soll sie die Dusche reparieren?
28. Soll sie dem Kaiser salutieren?
29. Soll sie den Versuch strukturieren?
30. Soll sie den Radweg zementieren?

10.5 Supplementary material Study 5

10.5.1 Stimuli condition SHIFT (trisyllabic condition)

1. Sie soll die neue Bahnzeitschrift lesen.
2. Sie soll den neuen Bankkaufmann ausbilden.
3. Sie soll das neue Baugrundstück ausmessen.
4. Sie soll den neuen Busfahrschein abholen.
5. Sie soll den neuen Chefvolkswirt einladen.
6. Sie soll den neuen Flachbildschirm aufstellen.
7. Sie soll den neuen Filzhausschuh anziehen.
8. Sie soll den neuen Großbaumarkt leiten.
9. Sie soll den neuen Hauptbahnhof ansehen.
10. Sie soll das neue Holzspielzeug aussuchen.
11. Sie soll das neue Kunstdenkmal pflegen.
12. Sie soll das neue Kraftfahrzeug anmelden.
13. Sie soll den neuen Kurzparkplatz planen.
14. Sie soll den neuen Landgasthof ausstatten.
15. Sie soll den neuen Notfahrplan aufhängen.
16. Sie soll die neue Rostbratwurst würzen.
17. Sie soll das neue Salzbergwerk ausrüsten.
18. Sie soll den neuen Schnellkochtopf testen.
19. Sie soll das neue Sportflugzeug fliegen.
20. Sie soll den neuen Staatshaushalt vorstellen.
21. Sie soll die neue Stadtrundfahrt ausrichten.
22. Sie soll die neue Stammmannschaft auswählen.
23. Sie soll den neuen Startzeitpunkt festlegen.
24. Sie soll das neue Strahltriebwerk einschalten.
25. Sie soll den neuen Tatzeitraum abschätzen.
26. Sie soll den neuen Textbaustein vorlesen.
27. Sie soll das neue Triebfahrwerk prüfen.
28. Sie soll den neuen Wachsmalstift nutzen.
29. Sie soll das neue Waldschwimmbad austesten.
30. Sie soll den neuen Wollhandschuh stricken.

10.5.2 Stimuli condition NO SHIFT (quadrisyllabic condition)

1. Sie soll die neue Modezeitschrift lesen.
2. Sie soll den neuen Handelskaufmann ausbilden.
3. Sie soll das neue Weidegrundstück ausmessen.
4. Sie soll den neuen Fährenfahrschein abholen.
5. Sie soll den neuen Landesvolkswirt einladen.
6. Sie soll den neuen Plasmabildschirm aufstellen.
7. Sie soll den neuen Lederhausschuh anziehen.
8. Sie soll den neuen Profibaumarkt leiten.
9. Sie soll den neuen Güterbahnhof ansehen.
10. Sie soll das neue Plastikspielzeug aussuchen.
11. Sie soll das neue Kriegerdenkmal pflegen.
12. Sie soll das neue Wasserfahrzeug anmelden.
13. Sie soll den neuen Mofaparkplatz planen.
14. Sie soll den neuen Wandergasthof ausstatten.
15. Sie soll den neuen Regelfahrplan aufhängen.
16. Sie soll die neue Rinderbratwurst würzen.
17. Sie soll das neue Silberbergwerk ausrüsten.
18. Sie soll den neuen Profikochtopf testen.
19. Sie soll das neue Wasserflugzeug fliegen.
20. Sie soll den neuen Bundeshaushalt vorstellen.
21. Sie soll die neue Alsterrundfahrt ausrichten.
22. Sie soll die neue Frauenmannschaft auswählen.
23. Sie soll den neuen Antrittszeitpunkt festlegen.
24. Sie soll das neue Kolbentriebwerk einschalten.
25. Sie soll den neuen Krisenzeitraum abschätzen.
26. Sie soll den neuen Werbebaustein vorlesen.
27. Sie soll das neue Schienenfahrwerk prüfen.
28. Sie soll den neuen Kohlemalstift nutzen.
29. Sie soll das neue Hallenschwimmbad austesten.
30. Sie soll den neuen Winterhandschuh stricken.

10.5.3 Stimuli condition SHIFT (quadrisyllabic condition)

1. Sie soll das neue Bergsteigeisen mitnehmen.
2. Sie soll den neuen Boxweltmeister küren.
3. Sie soll den neuen Dampfbackofen anmachen.
4. Sie soll das neue Drehdachfenster öffnen.
5. Sie soll die neue Dorfgrundschule einweihen.
6. Sie soll die neue Fachhochschule aufsuchen.
7. Sie soll das neue Feinwaschmittel einkaufen.
8. Sie soll den neuen Feldmaikäfer fangen.
9. Sie soll das neue Felsquellwasser trinken.
10. Sie soll den neuen Frachtflughafen meiden.
11. Sie soll den neuen Geldbriefträger einstellen.
12. Sie soll die neue Glastrinkflasche abwaschen.
13. Sie soll die neue Großbaustelle abfahren.
14. Sie soll die neue Handwaschpaste auftragen.
15. Sie soll die neue Hauptschlagader abbinden.
16. Sie soll den neuen Hilfspostboten anrufen.
17. Sie soll den neuen Kampfhubschrauber anfordern.
18. Sie soll den neuen Lastkraftwagen einparken.
19. Sie soll die neue Lernstichprobe anfordern.
20. Sie soll das neue Postwertzeichen einrahmen.
21. Sie soll den neuen Raumduftspender aufstellen.
22. Sie soll die neue Schmorbratpfanne testen.
23. Sie soll das neue Spannbettlaken waschen.
24. Sie soll die neue Sparmaßnahme prüfen.
25. Sie soll die neue Stadtsparkasse umbauen.
26. Sie soll die neue Stoffhandtasche nähen.
27. Sie soll die neue Strickstrumpfhose anziehen.
28. Sie soll den neuen Suchscheinwerfer einschalten.
29. Sie soll die neue Wachsmalkreide kaufen.
30. Sie soll das neue Wunschkennzeichen anbringen.

10.5.4 Stimuli condition NO SHIFT (pentasyllabic condition)

1. Sie soll das neue Klettersteigeisen mitnehmen.
2. Sie soll den neuen Tennisweltmeister küren.
3. Sie soll den neuen Minibackofen anmachen.
4. Sie soll das neue Gaubendachfenster öffnen.
5. Sie soll die neue Fördergrundschule einweihen.
6. Sie soll die neue Technikhochschule aufsuchen.
7. Sie soll das neue Flüssigwaschmittel einkaufen.
8. Sie soll den neuen Gartenmaikäfer fangen.
9. Sie soll das neue Tafelquellwasser trinken.
10. Sie soll den neuen Segelflughafen meiden.
11. Sie soll den neuen Firmenbriefträger einstellen.
12. Sie soll die neue Plastiktrinkflasche abwaschen.
13. Sie soll die neue Dauerbaustelle abfahren.
14. Sie soll die neue Körperwaschpaste auftragen.
15. Sie soll die neue Schenkelschlagader abbinden.
16. Sie soll den neuen Firmenpostboten anrufen.
17. Sie soll den neuen Rettungshubschrauber anfordern.
18. Sie soll den neuen Sonderkraftwagen einparken.
19. Sie soll die neue Lesestichprobe anfordern.
20. Sie soll das neue Sammlerwertzeichen einrahmen.
21. Sie soll den neuen Zimmerduftspender aufstellen.
22. Sie soll die neue Eisenbratpfanne testen.
23. Sie soll das neue Biberbettlaken waschen.
24. Sie soll die neue Sondermaßnahme prüfen.
25. Sie soll die neue Landessparkasse umbauen.
26. Sie soll die neue Lederhandtasche nähen.
27. Sie soll die neue Damenstrumpfhose anziehen.
28. Sie soll den neuen Autoscheinwerfer einschalten.
29. Sie soll die neue Straßenmalkreide kaufen.
30. Sie soll das neue Autokennzeichen anbringen.

10.5.5 Filler Items

1. Sie soll die neue Armbanduhr einstellen.
2. Sie soll den neuen Backsteinweg pflastern.
3. Sie soll den neuen Christbaumschmuck aufhängen.
4. Sie soll den neuen Denkmalschutz einhalten.
5. Sie soll den neuen Eislaufkurs leiten.
6. Sie soll das neue Erdnussöl abfüllen.
7. Sie soll das neue Fachwerkhaus ausbauen.
8. Sie soll den neuen Fallschirmsprung meistern.
9. Sie soll den neuen Fußballbund leiten.
10. Sie soll den neuen Glühweinstand öffnen.
11. Sie soll das neue Handballfeld einweihen.
12. Sie soll die neue Hausmannskost kochen.
13. Sie soll den neuen Heizölpreis ausrechnen.
14. Sie soll den neuen Hochschulchor einladen.
15. Sie soll die neue Kirchturmuhr umstellen.
16. Sie soll den neuen Kreuzbandriss schonen.
17. Sie soll die neue Kühlschranktür abwischen.
18. Sie soll das neue Kunststoffdach abzahlen.
19. Sie soll das neue Maibaumfest ausrichten.
20. Sie soll den neuen Rotweinfleck auswaschen.
21. Sie soll die neue Schneeballschlacht regeln.
22. Sie soll die neue Seilbahnfahrt zahlen.
23. Sie soll das neue Spieluhrwerk einbauen.
24. Sie soll die neue Sprengstoffart mischen.
25. Sie soll den neuen Steinzeitmenschen aufbahren.
26. Sie soll das neue Vollkornbrot backen.
27. Sie soll die neue Vollwertkost aufessen.
28. Sie soll das neue Wehrdienstamt schließen.
29. Sie soll den neuen Wohnheimplatz abgeben.
30. Sie soll den neuen Zahnarztstuhl aufbauen.

10.5.6 Acoustic Analysis

Syllable (constituent)	Duration (ms)	p-value	Intensity (dB)	p-value	Pitch (Hz)	p-value
B (NS) vs. B (S)	308 vs. 288	*p* = 0.005	52.17 vs. 51.47	*p* = 0.116	185.53 vs. 188.35	*p* = 0.011
C (NS) vs. C (S)	292 vs. 358	*p* = 0.000	50.07 vs. 51.05	*p* = 0.016	182.11 vs. 183.92	*p* = 0.028

Table 1. Phonetic and statistical analysis of pairwise syllable comparisons for the conditions NO SHIFT (NS) und SHIFT (S) for compounds with a monosyllabic C constituent.

Syllable (constituent)	Duration (ms)	p-value	Intensity (dB)	p-value	Pitch (Hz)	p-value
B (NS) vs. B (S)	321 vs. 296	*p* = 0.001	51.90 vs. 51.25	*p* = 0.199	182.17 vs. 186.37	*p* = 0.032
C1 (NS) vs. C1 (S)	246 vs. 271	*p* = 0.000	53.86 vs. 54.40	*p* = 0.037	178.38 vs. 181.29	*p* = 0.054
C2 (NS) vs. C2 (S)	146 vs. 157	*p* = 0.007	52.70 vs. 53.58	*p* = 0.009	176.44 vs. 182.84	*p* = 0.318

Table 2. Phonetic and statistical analysis of pairwise syllable comparisons for the conditions NO SHIFT (NS) und SHIFT (S) for compounds with a disyllabic C constituent.

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Erklärung

Hiermit versichere ich, dass ich die vorgelegte Dissertation mit dem Titel *It's all about the rhythm – A neurocognitive approach towards the Rhythm Rule in German and English* selbst und ohne fremde Hilfe verfasst, nicht andere als die in ihr angegebenen Quellen oder Hilfsmittel benutzt (einschließlich des World Wide Web und anderen elektronischen Text- und Datensammlungen), alle vollständig oder sinngemäß übernommene Zitate als solche gekennzeichnet sowie die Dissertation in der vorliegenden oder einer ähnlichen Form noch keiner anderen in- oder ausländischen Hochschule anlässlich eines Promotionsgesuches oder zu anderen Prüfungszwecken eingereicht habe.

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