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4 Stress clash hampers processing of noncanonical structures in reading

1 Introduction

Comprehending a written sentence necessarily involves recourse to grammatical knowledge at several linguistic levels. The linearly ordered lexical items that are conveniently demarcated by blanks must be parsed into a sufficiently coherent, hierarchical syntactic representation in order to be assigned the proper meaning. At the same time, readers generate a phonological representation that they might put to use in oral reading. Unlike segmental phonology, which is relatively well represented in the orthographic code, prosody is not explicitly coded. Prosodic features such as phrasing and accentuation must be derived from, and ideally reflect, the lexical, syntactic, and focus-structural analysis of the word string.

Obviously, sentences vary in their linguistic complexity and, correspondingly, the cognitive resources needed for processing differ. More often than not, complexity at the syntactic or discourse structural level engenders complexity at the prosodic level, as indicated by the insertion of prosodic phrase boundaries or the realization of accents at positions that would remain unaccented in simple canonical structures. Moreover, independent of the effects of syntactic and discourse structure on prosodic complexity, the phonological representation of a written sentence may be complex all by itself. For segmental phonology, this is vividly demonstrated by tongue twisters and the difficulty they bring about in reading even if their syntax is relatively simple (McCutchen & Perfetti, 1982; Wilshire, 1999).

The present study is concerned with prosodic complexity resulting from deviance from the favored rhythmic alternation of stressed and unstressed syllables, focusing specifically on the effect of stress clash, i.e. the adjacency of two syllables bearing lexical stress. We report on an oral reading experiment showing that, under conditions of cognitive duress, the preference for rhythmic alternation of strong and weak syllables (cf. Schlüter, 2005; Selkirk, 1984) prohibits the proper placement of contrastive accents required for a representation in which phonological structure conforms with syntactic and focus-structural representations. The experiment suggests that preferences for local prosodic well-formedness may override more global syntactic and discourse structural constraints, and that prosodic properties of sentences may critically contribute to the cognitive load during the analysis of written text. This interpretation would be at odds with conceptions of grammar and language processing in which the phonological component is assumed to merely interpret the syntactic and focus-structural conditions.

Before reporting on the experiment in section 2, we will provide some background on the grammar of prosodic prominence and its relation to syntax and focus structure, as applied to Germanic languages (section 1.1). Section 1.2 and 1.3 introduce the experimental task, viz. unprepared oral reading, and the linguistic construction under examination, i.e. elliptic coordinations of the right-node-raising type (RNR).

1.1 Prosodic prominence and linguistic rhythm

Prominence patterns in oral language emerge from the interplay of various forces. The lexicon specifies which syllable of a given word is assigned main stress and which syllables receive secondary or no stress. There is no clear phonetic correlate of stress – its phonetic realization crucially depends on the prosodic context. In general however, stressed syllables show longer duration, higher intensity and more pitch modulation than unstressed ones (Beckman & Pierrehumbert, 1986). On the supra-lexical level, syntactic and focus-structural conditions determine which words receive phrase or sentence accent. Accent is realized by a clear deflection in pitch on or near the stressed syllable of the designated word. Phrase accent is thus more prominent than word stress. If a sentence like (1-a) is uttered out of the blue, the words ‘boy’ and ‘biscuits’ typically receive accent (lexical stress is marked by underlining, accent is marked by small caps). ‘Biscuits’ is assigned the strongest prominence in the sentence (the nuclear accent), which is realized as a pitch accent on or near the syllable carrying main lexical stress (the first syllable in the case of ‘biscuits’). Nuclear accent on the verb (1-b) is possible only under certain discourse structural conditions, i.e. if the accented verb is contrasted with some other predicate in the context, as would be the case if (1-b) was uttered as a clarification to (1-a).

(1) a. [$_S$ [$_{NP}$ The little BOY] [$_{VP}$ likes [$_{NP}$ BIScuits.]]]

b. [$_S$ [$_{NP}$ The little boy] [$_{VP}$ aDORES [$_{NP}$ biscuits.]]]

The literature on sentence phonology attributes such a pattern to the workings of the syntax-phonology interface (Selkirk, 1995; Truckenbrodt, 2006, 2007). Here, we follow an Optimality Theoretic (OT) account in which accent assignment is captured by the interaction of violable constraints regulating the mapping between i) focus structure and phonology, and ii) syntax and phonology. The latter require the assignment of accents to lexically headed XPs (StressXP) and furthermore demand that the rightmost accent be strongest (Rightmost). Within the verb phrase, accent on the object argument fulfills StressXP for both the object NP and the VP as a whole since the NP is a proper constituent of the VP. Accent on the verb without accent on the object, however, would violate StressXP due to the lack of accent on the NP constituent (cf. Truckenbrodt (2007) for details of this analysis).

(2) a. StressXP: Each lexically headed XP contains an accent.

b. Rightmost: The rightmost accent within a prosodic or intonational phrase is strongest.[1]

If (1-a) provides the context for a clarification in the form of a statement like (1-b), accent on the verb is required in order to reflect the contrast of the verbs and the givenness of the remaining sentence. This focus-structural condition can be captured by the constraint Stress-Focus (Féry & Samek-Lodovici, 2006; Samek-Lodovici, 2005; Selkirk, 1995; Zubizarreta, 1998), which, in a nutshell, demands accent on contrasted or focused material. As evidenced by (1-b), Stress-Focus may override syntax-driven accent assignment.

(3) Stress-Focus: A focused phrase has the highest prosodic prominence.

Matters are complicated by a general preference for rhythmic alternation of strong (i.e. stressed) and weak (i.e. unstressed) syllables (Alber, 2005; Hayes, 1995; Kager, 1989; Liberman & Prince, 1977; Schlüter, 2005; Selkirk, 1984). This preference (formulated in OT terms as the constraint *Clash) operates against stress clashes (i.e. sequences of adjacent syllables bearing lexical stress), which are avoided whenever more rhythmic alternatives are available.

*Clash may require readjustments of lexically specified stress patterns to allow for rhythmic alternation of strong and weak syllables, as exemplified in the phrase *i<u>deal</u>* + *<u>part</u>ner* → *<u>i</u>deal* <u>PART</u>*ner*.

However, such readjustments are clearly restricted. In the case of (1-a) the stress clash between the verb ‘like’ and the following object ‘biscuits’ cannot be resolved by shifting the accent onto the last syllable of the object. Instead, the stress clash is tolerated in (1-a). As a rule, metrical readjustments triggered by *Clash do not concern words that bear main phrase or sentence accent but may only affect unaccented (or more weakly accented) neighboring words (Grabe &

1 This constraint is equivalent to Head Phrase (HP/HI) (Féry & Samek-Lodovici, 2006), which demands that heads of prosodic or intonational phrases appear close to their right edge.

Warren, 1995; Hayes, 1995) (but see Berg (2008) for emphatic stress shift). In other words, accents that are assigned due to StressXP may not be altered by the desire for rhythmic alternation.

Independent of accentuation, stress shift is also blocked if a prosodic phrase boundary intervenes between two adjacent stressed syllables. This is typically the case between the subject and the verb phrases in sentences like (4) (Selkirk, 1995). Here, the gerund phrase in subject position is separated from the verb phrase by a prosodic phrase boundary. Consequently, stress on the following monosyllabic verb does not trigger stress shift on 'TV' .

(4) (Watching CABLE tv) (harms children's health).

In summary, accent assignment driven by focus may override syntax-driven accent assignment (as exemplified in (1)), which in turn restricts the application of rhythmic readjustments. We will therefore subscribe to the hierarchy of constraints affecting the location and patterning of prosodic prominences formulated in (5):

(5) Stress-Focus ≫ StressXP ≫ *Clash

The hierarchy in (5) corresponds with the size of the domains over which the constraints exert their influence. Stress-Focus evaluates the discourse context while StressXP acts on a considerably smaller level, i.e. the level of the syntactic XP. *Clash only takes local information into account, operating on the level of the syllable sequence. Accordingly, the grammar of prosodic prominence is shaped by the interaction of weak local with strong global constraints. This state of affairs has interesting psycholinguistic implications.

Language processing proceeds in an incremental way. That is, the language processing mechanism builds linguistic representations based on the piecemeal access to the input as soon as it becomes available (cf. Pickering & Gompel (2006) and references therein). In the case of a contextless sentence, the parser initially has access only to local (lexical) information – the sequence of syllables or words that have to be integrated into more global representations such as syntactic phrases. The propositions expressed in phrases or sentences then build the base for the discourse setting. Hence, information access in (contextless) language comprehension proceeds from local information to global information.

Following this rationale, a constraint like *Clash, its weak role in the grammar notwithstanding, may have a more immediate influence on incremental structure building compared to constraints like StressXP and Stress-Focus that operate on larger domains.

Ergo, there is a certain tension between the hierarchy of constraints in grammar on the one hand and the order of access to their respective domains in language comprehension on the other. In view of these considerations, we hypothesize that *Clash, despite its low rank in grammar, may have a crucial role in language processing in affecting early stages of structure building.

Note that the constraints in (5) are geared towards the assignment of prosodic structure, i.e. the pattern of prosodic prominence. They are therefore irrelevant for auditory sentence comprehension, in which prosody is already an integral part of the input. In auditory language comprehension, prosody has to be interpreted, not assigned to the input (cf. Cutler et al. (1997) for the role of prosody in auditory sentence processing). Processing written language, however, does involve prosodification of the input string. This is especially obvious in the case of oral reading.

1.2 Oral reading

Fluent oral reading involves both sentence comprehension and sentence production. As for comprehension, readers have to parse the word string into a sufficiently coherent syntactic representation in line with the discourse context. At the same time, readers produce speech using prosody that conforms to the syntactic analysis and the focus-structural setting of the text (Kondo & Mazuka, 1996; Koriat et al., 2002; Kreiner, 2005; Wheeldon, 2000).

The simultaneity of language comprehension (syntactic parsing) and production (prosodification) in oral reading suggests that these processes might interact. The role of prosody is especially intricate in this task: there is no overt correlate of prosody in the graphemic string.[2] As neither syllables nor lexical stress or accent are marked orthographically, readers have to deduce these phonological features on the basis of i) the lexical and syntactic information derived from the word string, and ii) the focus-structural representation extrapolated from the syntactic and semantic analysis of the text. Unprepared readers have been shown to produce prosody in accordance with these representations (Koriat et al., 2002; Kreiner, 2005). The conformity of reading prosody with the syntactic and focus-structural facts indicates the dependence of prosody on the syntactic and focus-

2 Commas are not a reliable, undisputed cue to prosodic phrasing either. Chafe (1988) argues convincingly that the commas in the phrase *'red, white, and blue'* do not correlate with prosodic breaks, while the commas in *'Abernathy came, Chippendale saw, and Higginbottom conquered'* do. Punctuation rules do not refer to phonological weight or phrase length, but prosodic phrasing does.

structural analysis. Also, in research on reading development, the prosodic appropriateness of read text is used as a diagnostic for reading comprehension and reading skill in general (Schwanenflugel et al., 2004). This would suggest that reading prosody is only constructed on the basis of considerable syntactic and semantic pre-processing.

On the other hand, there is evidence that prosody derived from the written string is used by readers to make syntactic parsing decisions. That is, prosody constructed during reading is recycled and used in a way similar to prosody in auditory sentence comprehension (Fodor, 2002) where it might disambiguate otherwise ambiguous word strings. Various reading studies have demonstrated the impact of implicit prosodic factors on sentence comprehension in silent reading (Augurzky, 2006; Bader, 1998; Fodor, 1998, 2002; Hwang & Schafer, 2009; Stolterfoht et al., 2007). These studies are concerned with the role of phrase accent and prosodic phrasing in resolving syntactic ambiguities. Results by Kentner (2012) suggest a role of stress-based linguistic rhythm in sentence comprehension, too. In the face of a syntactically ambiguous word string that involves a stress clash in one reading but not in the other, the parser favors the analysis of the rhythmically nonoffending reading.

Therefore, instead of a unidirectional dependence of prosody on the syntactic and focus-structural analysis, there is good reason to assume an interrelationship of prosody with these representations in reading.

The fact that reading prosody gives an insight into the syntactic and focus-structural analysis makes oral reading a perfect test environment for examining the interaction of phonological, syntactic, and discourse structural processes in language processing. For this, we study RNR-type elliptic coordination structures, which feature an interesting interplay of syntax, focus structure and prosody.

1.3 The right-node-raising construction

1.3.1 Focus structure and prosody of RNR

The so-called right-node-raising construction[3] (henceforth: RNR) is a type of elliptic coordination structure in which an element that overtly appears at the right

3 Following Hartmann (2000), Phillips (1996), and Wilder (1997), we consider RNR to involve deletion rather than raising of the target of ellipsis. Various facts speak against a movement analysis of RNR, chief among them the observation that nonconstituents may be the target of ellipsis in this construction (cf. (i)).

periphery of the second conjunct is understood as part of both the first and second conjuncts. This element, i.e. the target of ellipsis, is represented by crossed-out letters in (6).

(6) Peter kauft ~~Kekse~~ und Hans isst Kekse.
Peter buys ~~biscuits~~ and Hans eats biscuits.
Peter is buying and Hans is eating biscuits.

Hartmann (2000) and Féry & Hartmann (2005) formulate the conditions that must be met in order for RNR to be applicable. First, the element preceding the target of ellipsis has to be stressable. Hence, the modal verb in (7) must not appear in its reduced form, otherwise RNR is impossible.

(7) I think that {I would / *I'd} and I know that {he will / *he'll} buy the pictures.

Secondly, the conjuncts must exhibit a parallel syntactic and focus structure and the pre-elliptic parts of the two conjuncts must allow for a contrastive interpretation.

Correspondingly, RNR sentences display a complex focus structure with contrastive focus embedded in a broad presentational focus (Féry & Samek-Lodovici, 2006; Selkirk, 2002). Since they represent material that is new to the discourse, the two conjuncts including the target of ellipsis are instances of broad presentational focus. Moreover, the pre-elliptical elements in both conjuncts are semantically contrasted and correspondingly bear contrastive focus. We follow Selkirk (2002) in marking broad presentational focus by *foc* and contrastive focus by Foc. In (8) the focus structure with embedded contrastive focus is represented for (6).

(8) [Peter [kauft]$_{\text{FOC}}$ ~~Kekse~~]$_{\text{foc}}$ und [Hans [isst]$_{\text{FOC}}$ Kekse]$_{\text{foc}}$

The focus structure of (8) thus differs from the nonelliptical counterpart with the same basic constituent order in (9). This structure may represent a contrast between the two conjuncts. The two verbs, however, cannot contrast in (9) as they differ with respect to transitivity.

(i) Peter verspricht seinem [ ] und Maria verspricht ihrem [Kind ein Geschenk].
Peter promises his [ ] and Maria promises her [child a present].
Peter promises a present to his child and Maria promises a present to her child.

(9) [[Peter lacht]$_{FOC}$und [Hans isst Kekse]$_{FOC}$]$_{foc}$
Peter is laughing and Hans is eating biscuits.

The focus structure determines the prosodic realization of the RNR sentence, which differs from the prosody of comparable nonelliptic sentences. As discussed above, contrastively focused elements are assigned prosodic prominence due to Stress-Focus. Accordingly, in (8) the contrastively focused verbs are accented, while in (9), StressXP determines the position of accent in the second conjunct, i.e. nuclear stress falls on the object. While production studies on RNR prosody (Féry & Hartmann, 2005; Kentner, 2007; Kentner et al., 2008; Selkirk, 2002) may differ on details of the prosodic phrasing of RNR, they agree that the pre-elliptic element is the location of the nuclear accent.

The following Tableau reflects these basic facts as derived from the grammatical interface of syntax and information structure with prosody.

Table 1: Prosody of 2nd conjunct in nonelliptic (9) and RNR sentences (8).

		/[H. isst Kekse]$_{foc}$/	Stress-Focus	StressXP
a.	☞	H. isst KEKSE		
b.		H. ISST Kekse		*!
		/[H. [isst]$_{FOC}$ Kekse]$_{foc}$/	Stress-Focus	StressXP
a′.		H. isst KEKSE	*!	
b′.	☞	H. ISST Kekse		*

1.3.2 Processing RNR

There is currently only little psycholinguistic evidence concerning the processing of RNR sentences. Processing RNR sentences can be considered a relatively complex task because of the required nonlocal interpretation of the elliptic target. As for auditory sentence comprehension, processing difficulty due to the ellipsis may be alleviated by the characteristic RNR prosody. The contrastive accent on the verb, deviating from typical nuclear accent in nonelliptic contexts, signals the contrast and, correspondingly, the ellipsis. However, as Kentner et al. (2008) find, processing ease depends not only on the contrastive accent but also on the strength of the prosodic break at the conjunction. Listeners were shown to benefit from a clear prosodic break before the conjunction, a type of phrasing that speakers seem to avoid. Since prosody is not provided in the written modality, processing the RNR-type ellipsis in reading may turn out to be particularly difficult.

To our knowledge, there is no study as yet examining RNR in written language processing.

We may however conjecture the following concerning the processing of RNR structures in reading: In the case of a RNR sentence like (8), the ellipsis is implicitly marked by the fact that the argument structure of the transitive verb 'kauft' in the first conjunct is not satisfied locally. Assuming that the reader observes the imperative of parallelism in coordinations, the parser could, already at the conjunction, predict a verb phrase or a complete sentence to form the second conjunct. Moreover, the only way to construct a fully grammatical coordination structure is to project a transitive VP, the object of which simultaneously functions as the object of the first conjunct. Hence, already at the conjunction, readers might recognize the ellipsis and predict the contrast that is characteristic of RNR. Note, however, that forming such a long-distance dependency imposes high processing costs due to the strain on memory capacity (e.g. Hawkins, 1994). If the parser can bear these costs, readers should be able to assign contrastive accent to the verb in the second conjunct. However, the high strain on the processing mechanism might make the analysis relatively vulnerable.

In fact, various studies have demonstrated the difficulty associated with processing noncanonical structures that induce high memory costs (cf. the literature on nested structures like center embedding). In such a situation, the parser might resort to some sort of shallow processing (Ferreira, 2003; Sanford & Sturt, 2002). Shallow processing implies ignorance towards structural information that would be required in order to form a fully specified grammatical representation. Instead the parser will make do with less than perfect comprehension. Gibson & Thomas (1999) put forward the 'high memory cost pruning hypothesis' stating that syntactic predictions incurring the most memory load are forgotten if processing costs exceed a certain threshold, i.e. at points of high memory complexity during the parse.

Dependency Locality Theory (DLT, Gibson, 2000) is used here to determine the point associated with the highest memory complexity in parsing RNR structures.[4] There are two components to the DLT: a storage cost component and a prediction cost component. Both components contribute additively to the cognitive costs at any given point in a sentence. According to the prediction component, each syntactic head that needs to be predicted in order to complete the current input as a grammatical sentence incurs memory costs. According to the storage cost

4 Other distance-based accounts of syntactic and parsing complexity are formulated in Hawkins (1994) and Joshi (1990).

component, memory costs increase with every new discourse referent intervening between a word and the dependent to be integrated with it.

Concerning RNR sentences like (8) (cf. Figure 1), the elliptic first conjunct incurs relatively high prediction costs, in that a second, transitive VP including an object NP needs to be projected (two syntactic heads) once the conjunction is reached. The point of greatest difficulty, however, is at the verb in the second conjunct (*isst*). At this position, the second verb needs to be integrated with its preceding subject *Hans*. Furthermore, the contrast to the verb in the first conjunct needs to be computed across two new discourse referents (*Hans* and *isst*). Also, two NPs are predicted at *isst*, i.e. the coincident object of the first and the second conjunct.

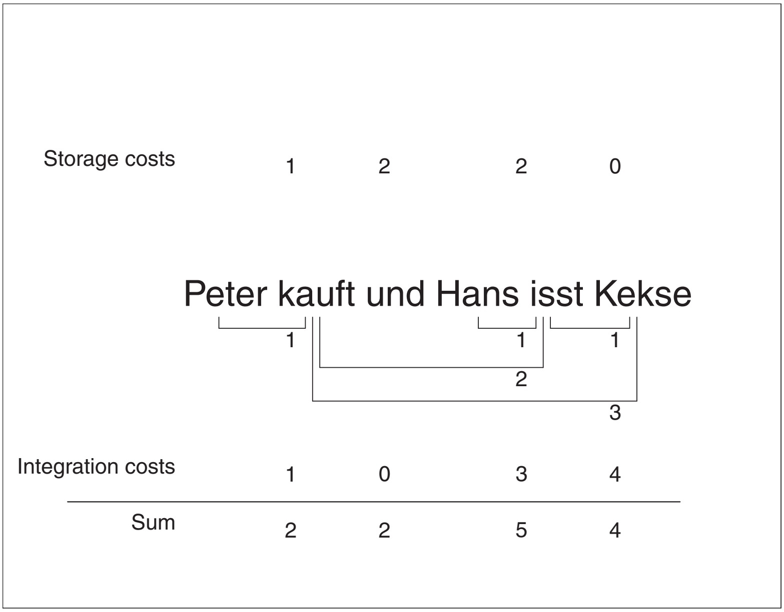

Figure 1: DLT predictions for (8) (Translation: *Peter is buying and Hans is eating biscuits.*). The highest processing costs are predicted for *isst* in the second conjunct.

With these considerations in mind, we turn to the role of rhythmic preferences and their interaction with other constraints regulating prosodic prominence in written sentence processing. Given the rather weak standing of *CLASH in the grammar of prosodification, one might ask whether this constraint is merely a stylistic force or whether it has a functional role beyond the amelioration of prosodic structure. As stated above, *CLASH may be considered important as it evaluates relevant features of the written input more immediately than the concurring constraints StressXP and Stress-Focus, simply because the relevant domain, i.e. syllables, are among the earliest information available to the processing mechanism (Ashby & Martin, 2008; Ashby & Rayner, 2004). As discussed above, language processing proceeds incrementally, so local information may be more readily available to the processor than higher level information, which necessitates an overview of the more global context. Also, global information that is based on long-distance dependencies (i.e. distant memory traces) is likely to be forgotten by a parser that has to cope with high processing demands.

Before we examine the role of *Clash experimentally, we make the following assumptions: In speech production, selecting the points of prosodic prominence (accents) is more difficult when elements that may function as the target of prosodic prominence (stressed syllables) cluster together. We therefore conjecture that the formation of a mental representation involving a violation of *Clash is cognitively costly and may thus hamper processing (see also the neurophysiological account of the cognitive complexity of stress clash configurations by Schlüter (2005)).

Likewise, producing accents at positions that would remain unaccented in canonical sentences is considered a costly operation (cf. Reinhart, 2006): That is, a violation of StressXP, which is mandatory in the type of RNR under study here, causes cognitive duress. Corresondingly, the cognitive costs associated with reading/producing a RNR sentence are higher than those associated with producing nonelliptic coordinations. Arguably, stress clash configurations increase the cognitive load associated with RNR. According to Gibson's memory complexity metric, the analysis is most vulnerable at the second verb. We study the influence of *Clash at this critical position.

2 Experiment

In order to scrutinize the effects of StressXP and Stress-Focus and their interaction with *Clash in reading, we use RNR and comparable nonelliptic coordinations as a test environment. Juxtaposing RNR and nonelliptic coordinations makes the workings of Stress-Focus and StressXP transparent (cf. the Tableau above). Varying the rhythmic environment allows us to gauge the influence of *Clash in reading.

Given the close compliance of accentuation and contrast that is formulated in the grammatical constraint Stress-Focus, reading prosody is a good way to test whether readers indeed form the contrast and correspondingly parse the ellipsis.

We therefore use the realization of accent as the dependent variable for determining whether readers process a valid RNR construction.

2.1 Method

2.1.1 Design and material

The objects of investigation are elliptic (RNR) and nonelliptic coordinations with the same basic constituent order. Aside from prosody, the verb in the first conjunct distinguishes elliptic and nonelliptic versions. The latter are characterized by an obligatorily intransitive verb while the former are identified by a transitive verb in the first conjunct. Prosodically, the versions differ with respect to the location of nuclear accent in the VP of the second conjunct. Nonelliptic versions feature nuclear accent on the object while elliptic versions display nuclear accent on the verb. The rhythmic environment is varied on the words preceding and following the critical verb in the second conjunct inducing either rhythmically alternating sequences or stress clashes to either side. The subject preceding the verb in the second conjunct is trisyllabic with either initial or final stress. The object is minimally disyllabic with lexical stress either on the initial or the second syllable.

The experiment has thus a 2×2×2 factorial design with the factors ‘ellipsis’ (RNR vs. nonelliptic), ‘rhythmic environment to the left (ClashL)’ (trisyllabic subject with initial or final stress) and ‘rhythmic environment to the right (ClashR)’ (object with initial or noninitial stress). For this, 28 sets of sentences in eight conditions were constructed. Table 2 shows an example set (the full list of experimental sentences is listed in the appendix).

2.1.2 Participants

24 female first year undergraduate students from the University of Potsdam took part in the experiment. All are native speakers of German and naïve as to the purpose of the experiment. They either received course credit or were paid 5 Euros for their participation.

2.1.3 Experimental procedure

The experimental sentences were divided into four lists using a Latin square design such that conditions were maximally counterbalanced across lists and each

Table 2: Factors with coding and sentence materials (example). Stressed syllables are underlined, expected accent is marked by small caps.

	Ellipsis	ClashL	ClashR	example
a.	−1	1	1	Karl lacht und der Dirigent isst KuCHEN.
b.	−1	−1	1	Karl lacht und der Musiker isst KuCHEN.
c.	−1	1	−1	Karl lacht und der Dirigent isst GEBÄCK.
d.	−1	−1	−1	Karl lacht und der Musiker isst GEBÄCK.
e.	1	1	1	Karl holt und der Dirigent ISST Kuchen.
f.	1	−1	1	Karl holt und der Musiker ISST Kuchen.
g.	1	1	−1	Karl holt und der Dirigent ISST Gebäck.
h.	1	−1	−1	Karl holt und der Musiker ISST Gebäck.

Translation: *Karl is* {a–d: *laughing*; e–h: *bringing*} *and the* {a,c,e,g: *conductor*; b,d,f,h: *musician*} *is eating* {a,b,e,f: *cake*; c,d,g,h: *pastries*}.

participant would see at most two sentences from each of the 28 sets. The items were fed into a DMDX presentation (Forster & Forster, 2003) together with 65 unrelated fillers and pseudo-randomized for each subject using the Mix randomization tool (Casteren & Davis, 2006) such that sentences of the same condition had a minimum distance of eight and sentences of the same experiment had a minimum distance of three items. The experiment was set up as an unprepared reading design in which participants read each sentence aloud without advance preparation as soon as it appeared on screen.

The experiment took place in an acoustically shielded room with an AT4033a studio microphone. Each participant was seated in front of a 15" computer screen with the microphone placed approximately 30 cm from the participant's mouth. A keyboard was placed on a table in front of the subject. Recordings were made on a computer using the RecordVocal function of DMDX and a C-Media Wave sound card at a sampling rate of 44.1 kHz with 16 bit resolution. The DMDX presentation was programmed for each item as follows: First, only the first one or two words (the sentence initial subject noun phrase or proper name) were presented on the screen. Participants were told to familiarize themselves briefly with these words. They were instructed to then press the space bar, inducing the presentation of the entire sentence. Participants were asked to start reading out the sentence as soon as it appeared on screen and to do so as fluently as possible. The spacebar press automatically initiated the recording. After a fixed recording time of five seconds, the procedure was repeated for the next item. For each sentence, only one realization per subject was recorded. No corrections were recorded in the case of hesitations or slips of the tongue.

2.1.4 Data analysis

All in all, (24 · 28 =)672 experimental sentences were recorded. The sentences were independently judged by two students who were blind to the conditions and the purpose of the experiment. Their task was i) to note slips of the tongue and disfluencies, and ii) to determine for each sentence whether nuclear accent was realized on the verb or on the object. The judges were paid for their work. 85 sentences (13 %) were marked by at least one of the judges as nonfluent or as containing slips of the tongue. Concerning the position of nuclear accent, the judges agreed on 510 of the 587 fluent sentences (87 %). The sound files of the 587 flawless sentences were hand-annotated by a phonetically trained student who was blind to the purpose of the experiment and to the judgments of her fellow students. The second conjunct was segmented into words and syllables and labeled accordingly. In the following section, we report the results from the set of consistently judged sentences. Separate analyses for the two judges yield comparable results.

2.2 Results

2.2.1 Flawed sentences

The number of flawed sentences is relatively high (n = 85, 13 %), which can be partly explained by the task (unprepared reading) and the length and complexity of the sentences. In order to check whether the distribution of flawed sentences is systematically related to the controlled factors of the experiment, we fitted a generalized linear model with binomial link function (Bates & Sarkar, 2007; Gelman & Hill, 2007; Quené & Van den Bergh, 2004).

The fixed factors of this model are i) 'ellipsis' (elliptic vs. nonelliptic), ii) 'the rhythmic environment to the left' (initial vs. final stress on the subject of the second conjunct), and iii) 'the rhythmic environment to the right' (initial vs. noninitial stress on the object of the critical verb). Flawed versus fluent realization was used as the binomial dependent variable; variance due to individual participants and items was taken into account by including these factors as grouping variables. In order to avoid correlations of the fixed factors in the statistical models, orthogonal or contrast coding was applied (factor 'ellipsis': elliptic = 1, nonelliptic = −1; factor 'ClashL': clash = 1, no clash = −1; factor 'ClashR': clash = 1, no clash = −1). No significant effect was found for either of the fixed factors, nor for the interaction (all z-values are distinctly < 2) suggesting that the controlled variables do not systematically influence the distribution of flawed sentences.

2.2.2 Phonetic analysis of judgment data

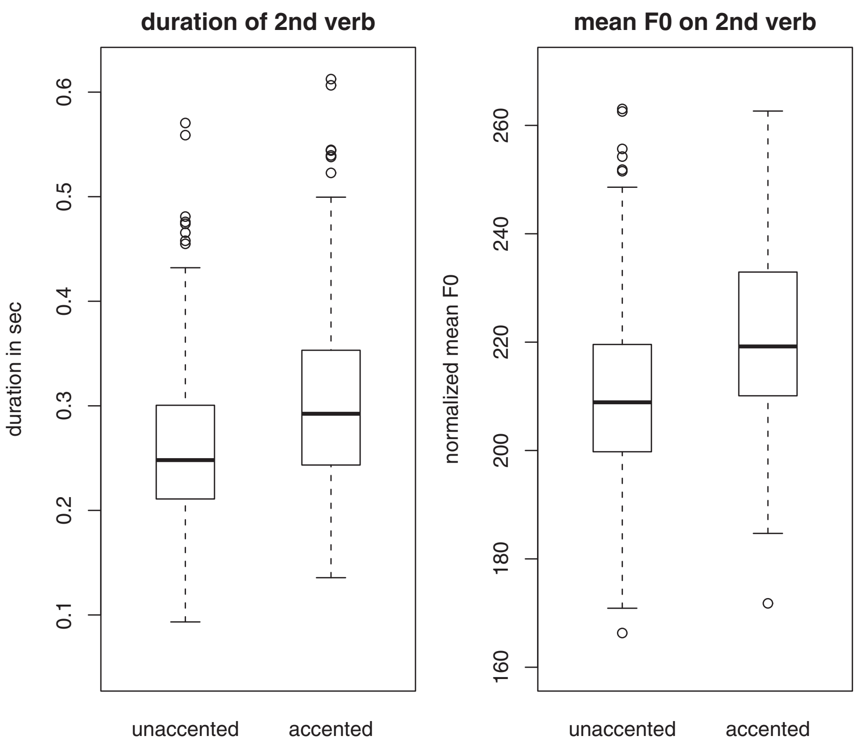

Figure 2: Box plots showing median and interquartile ranges for duration (left panel) and mean normalized F0 (right panel) of the critical verbs in the second conjunct, broken down by perceived accentuation.

A phonetic validation of the judgments on accentuation is required, as listeners may perceive prominence patterns on syllable sequences in context even in the absence of definite acoustic cues for them (e.g. Dilley & McAuley, 2008). Syllable durations and mean pitch on the critical verb in the second conjunct were compared for realizations with perceived nuclear accent on the object and nuclear accent on the verb. The F0 values for the verb were normalized prior to analysis. The normalizing factor used is the mean F0 across speakers on the verb divided by the utterance wide mean F0 of each individual sentence.

The results (cf. Figure 2) reveal longer durations and a higher mean F0 for those verbs that were perceived as bearing nuclear accent. Verbs in this condition were on average 50 ms longer and around 11 Hz higher in mean F0 compared to unaccented versions. These differences are comparable to the ones reported in the literature on the acoustics of accented versus unaccented syllables (Baumann et al., 2006; Eady et al., 1986; Féry & Kügler, 2008).

Linear mixed effects models confirm the phonetic difference between verbs with versus without perceived nuclear accent. The dependent variables ‘mean F0’ (in Hz) and ‘duration’ (in ms) were logarithmized for inferential statistics to adjust for the skew in the data. Using participant and item as random effects, the model evaluating the duration of the verb against the perceived accentuation reveals a significant effect (Coefficient estimate: 0.129, SE: 0.017, t-value[5] = 7.487). A comparable model with logarithmized mean F0 as dependent variable yields a complementary effect (Coeff. estimate: 0.0437, SE: 0.0093, t-value = 4.7). The phonetic analyses thus confirm the reliability of the judgment data on the perception of nuclear accent.

2.2.3 Placement of nuclear accent

In total, the verb in the second conjunct was perceived as bearing nuclear accent in 40 % of the cases. As expected, readers produced significantly more accents on the verb in RNR conditions (on average 54 % of the accents were on the verb in RNR conditions). However, in roughly 27 % of the cases, readers produced a nuclear accent on the verb in nonelliptic sentences. Conversely, in 46 % of the cases readers failed to produce a nuclear accent on the verb where it was required. Crucially, aside from the syntactic construction, the distribution of accents is also determined by the rhythmic environment. Fewer nuclear accents were realized on the verb when they would clash with adjacent stressed syllables. Readers produce particularly few nuclear accents on the verb if the following object bears initial stress (roughly 13 % fewer accents as compared to rhythmically unoffending environments). The bar plot in Figure 3 shows the results concerning the judgments on the fluent sentences. The bars represent percentages of perceived nuclear accent on the verb in the second conjunct broken down by elliptic (right panel) versus nonelliptic (left panel) conditions. A generalized linear model with participants and items as random effects evaluating perceived nuclear accent position against the crossed fixed factors confirms the significant effects for the factor ellipsis and the rhythmic environment to the right (cf. Table 3). The effect for the left environment and the interactions remain nonsignificant.

5 t-values greater than |2| mean statistical significance at the level of $\alpha = 0.05$.

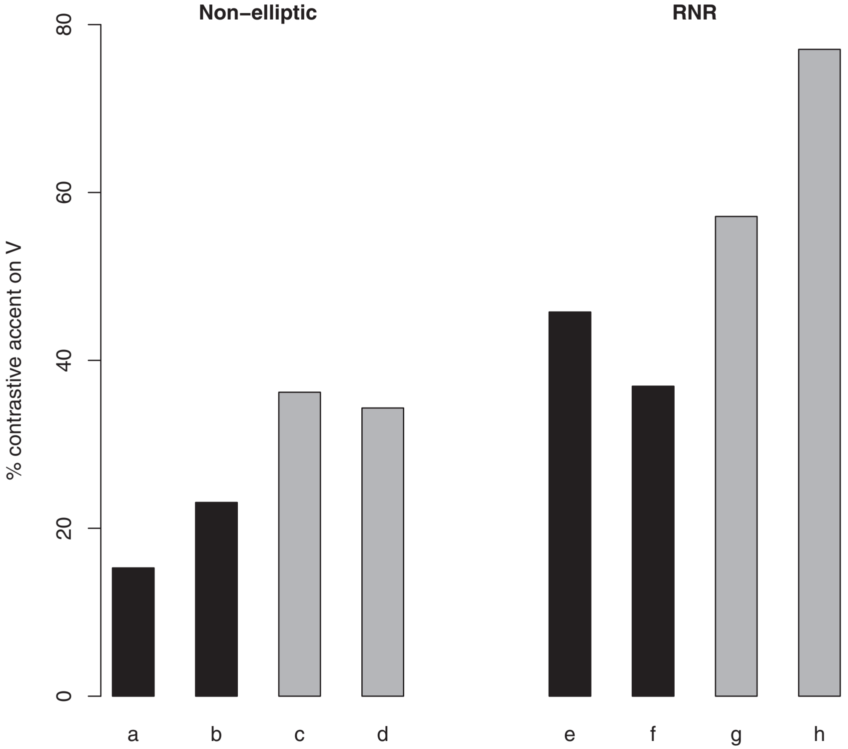

Figure 3: Bar plot showing percentages of verbs bearing contrastive accent in nonelliptic versus elliptic (RNR) sentences by experimental condition. Black bars represent conditions with stress clash configuration between the verb and following object (ClashR = 1).

Table 3: Results of generalized linear model evaluating perceived nuclear accent against crossed fixed factors.

Coefficient	Estimate	Std. Error	z-value	p-value
Ellipsis	0.8707	0.1208	7.209	< 0.001*
ClashRight	−0.6789	0.1194	−5.686	< 0.001*
ClashLeft	−0.1583	0.1168	−1.356	0.175
Ellips:ClashR	−0.1105	0.1160	−0.952	0.341
Ellips:ClashL	−0.1271	0.1182	−1.076	0.282
ClashR:ClashL	0.2298	0.1982	1.159	0.246
Ell:ClashR:ClashL	0.1539	0.1550	0.993	0.321

Summarizing the results, we find that i) readers realized contrastive nuclear accent on the verb more often in sentences that were devised as RNR, and ii) that fewer nuclear accents were realized on the critical verb if the following object had lexical stress on the initial syllable.

3 Discussion and conclusion

The results confirm that the manipulation concerning the transitivity of the verb in the first conjunct and, correspondingly, the ellipsis did work. Readers were clearly more prone to produce a contrastive nuclear accent on the second verb when the argument structure of the first conjunct was incomplete. This suggests that readers did realize the presence of an ellipsis more often than not.

However, not all readers consistently produced contrastive accents in such situations, verifying that the sentence type (RNR) and the task (unprepared reading) are cognitively demanding. A key reason for the failure to contrastively accent the second verb in elliptic sentences – besides the difficulty of parsing a long-distance dependency in unprepared reading – lies in the rhythmic environment, as confirmed by the significant influence of the stress location on the object (ClashR) on accent placement. Initial stress on the object together with the stressed verb induces a stress clash configuration. But why should the clash be responsible for the failure to realize contrastive accent on the verb? The possible answer lies in the cognitive costs associated with stress clashes and the immediacy of their evaluation by the parser. As hypothesized at the outset, producing noncanonical nuclear accents in a stress clash environment is cognitively costly: potential targets of the accent (stressed syllables) cluster together and hence complicate the selection of the grammatically prescribed accent position. The clash thus adds to the cognitive demands associated with processing the long-distance dependency. The violation of *Clash might be tipping the scales and forcing the reader to drop the RNR analysis in favor of a nonelliptic analysis with nuclear accent on the object. That is, the processing costs associated with the stress clash make readers ignore (or forget about) the incomplete argument structure in the first conjunct, which otherwise makes them predict and, correspondingly, realize the contrast. This interpretation of the results is in line with the 'high memory cost pruning' hypothesis (Gibson & Thomas, 1999). In forgetting about the structural dependency between the elliptic first VP and the VP in the second conjunct, the parser gets rid of the most costly memory traces at points of excessive cognitive complexity. As a consequence, the ellipsis is ignored and the second conjunct is processed as it would be in nonelliptic coordinations, with nuclear accent on the object. The results might also be interpreted in light of recent work on grammatical illusions, i.e. sentences which are acceptable (and appear to be grammatical) but turn out to be ungrammatical on closer inspection.[6] As Haider (2011) notes, grammatical illusions are characterized by local wellformedness but are globally deviant. Apparently, this characterization also holds for the RNR sentences that were realized without contrastive accent on the verb (10). The prosodic rendition in (10) fails to mark the contrast between the verbs that is a prerequisite for the ellipsis.

(10) #Hans kauft und Peter isst KEKSE.
Hans is buying and Peter is eating BISCUITS.

However, the second conjunct is perfectly wellformed as long as the requirements of the first conjunct are disregarded. The transitive VP *isst Kekse* bears nuclear accent on the object, just as would be expected in canonical transitive VPs. Conversely, the required contrastive accentuation on the verb is less wellformed locally (cf. the violation STRESS-XP and, if applicable, *CLASH) and licit only under global pressure (satisfaction of STRESS-FOCUS).

In this context, it is important to remember that readers could already predict the ellipsis and hence the requirements of STRESS-FOCUS at the conjunction on the basis of the unsatisfied argument structure of the first verb. Lookahead should be critical to sentence comprehension, since readers need to use it in order to construct a syntactically wellformed and coherent analysis of the written string online. Crucially, the extent and potency of the lookahead is significantly constrained by the local rhythmic environment.

Interestingly, the rhythmic environment to the left of the critical verb does not seem to affect accent realization. This lack of an effect is explicable with recourse to the phonological phrasing that comes with the syntactic structure of the second conjunct. The constituent to the left of the critical verb is the subject of the second conjunct. The subject projects its own XP and, according to standard assumptions on the syntax-prosody interface, might therefore be separated from the verb phrase by a phonological phrase boundary. As evidenced by (4) above, the adjacency of stressed syllables is generally tolerated by *CLASH if a prosodic boundary intervenes. This suggests that the syntax-driven insertion of prosodic phrase boundaries took place before the stress clash could hamper processing.

6 A famous example of a grammatical illusion is the utterance **More people visited Vienna than I did*. Various examples can be found in Haider (2011).

It seems that the processing costs normally associated with stress clash are not incurred in the context of prosodic phrase boundaries.

The rhythmic effect to the right of the critical verb indicates that *Clash, which is traditionally understood as a production-oriented constraint, may interfere with comprehension when violated. The cognitive complexity of stress clashes is explained with recourse to production: producing accents in stress clash environments is complex because selecting the appropriate syllable for accentuation is difficult when potential targets cluster together. The results of the experiment, however, suggest that stress clash configurations in written text influence comprehension. The cognitively costly stress clash representation critically aggravates the already complex focus-structural and syntactic analysis of elliptic sentences.

This state of affairs is hardly compatible with the conception of a uni-directional relation between syntactic and prosodic processes in written sentence comprehension. Rather, it calls for a more interactive view of these processes. The experimental results confirm the suggestion that the simultaneity of comprehension and production in oral reading indeed implies an interrelationship. This is also in line with findings from silent reading that have shown the significance of rhythmic effects for sentence comprehension (Kentner, 2012).

Aside from these principled considerations concerning the architecture of the human language processing mechanism and its access to different domains of grammar, the current experiment raises methodological issues: The complexity of, and hence the predicted parsing difficulty associated with experimental sentences is standardly manipulated at the level of syntactic structure in psycholinguistic research. This study illustrates that prosodic properties of sentences may critically contribute to the cognitive complexity and thus should be taken into account in experiment design.

In summary, the most important conclusion to be drawn from this experiment is that forced deviance from rhythmic alternation may affect readers' performance on noncanonical sentences at points of high cognitive complexity. In such situations, the violation of merely weak prosodic constraints may lead to fatal pruning of memory traces that are necessary for the full syntactic and focus-structural representation and, hence, to misinterpretation.

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Appendix

List of items used in the experiment:

1. Der Maurer {holt, lächelt} und {der Admiral, die Lehrerin} isst {Kuchen, Gebäck} mit Marzipan.
2. Der Reiseveranstalter {mietet, schwitzt} und {die Agentur, der Arbeiter} putzt {Ferienhäuser, Versammlungsräume} auf Usedom.
3. Der Angestellte {meldet, redet} und {der Fabrikant, der Bauleiter} prüft {Ausfälle, Verluste} durch Diebstähle.
4. Der Zeuge {meldet, redet} und {der Detektiv, der Aufseher} sucht {Tatverdächtige, Verdächtige} im Keller.
5. Der Dozent {kauft, lacht} und {der Gitarrist, der Handwerker} raubt {Ölgemälde, Gemälde} von Picasso.
6. Der Kunde {kauft, lacht} und {der Amateur, der Hersteller} bringt {Stahlträger, Gerüstteile} aus Japan.
7. Der Mönch {sammelt, schweigt} und {der Kardinal, der Prediger} kauft {Goldmünzen, Gebrauchtwagen} aus Irland.
8. Der Lehrling {stapelt, streikt} und {der Philosoph, der Ausbilder} streicht {Rahmen, Verschalungen} aus Holz.
9. Die Sängerin {lobt, weint} und {der Pianist, die Königin} ehrt {Musiker, Gewinner} des Wettbewerbs.
10. Die Vorsitzende {lobt, weint} und {das Dekanat, der Manager} fördert {Bürgerinitiativen, Verantwortliche} aus Norwegen.
11. Der Zirkusartist {liebt, kämpft} und {der Germanist, der Zuschauer} schreibt {Briefe, Gedichte} in Schönschrift.
12. Die Boxerin {liebt, kämpft} und {der Fotograf, der Kritiker} liest {Bücher, Erzählungen} von Kleist.
13. Die Ingenieurin {plant, schläft} und {die Gärtnerei, der Holzhändler} bepflanzt {Parkanlagen, Gewerbegebiete} in Bremen.
14. Der Bürgermeister {plant, schläft} und {der Kommandant, die Künstlerin} filmt {Probebohrungen, Beschlagnahmungen} im Niemandsland.

15. Der Küchenchef {schneidet, flüstert} und {der Astronaut, der Kundschafter} probiert {Truthahn, Gemüse} mit Füllung.
16. Der Kochlehrling {schneidet, flüstert} und {der Absolvent, die Kellnerin} serviert {Lendenbraten, Geschnetzeltes} vom Schwein.
17. Der Händler {druckt, grinst} und {der Demokrat, der Komiker} verteilt {Flugblätter, Beschwerdebriefe} gegen Terroristen.
18. Der Direktor {druckt, grinst} und {der Monarchist, der Inhaber} sortiert {Geldscheine, Verträge} für Bankkunden.
19. Die Soldatin {holt, lächelt} und {der General, der Hausmeister} testet {Fahrräder, Gewehre} aus Holland.
20. Die Studentin {mietet, schwitzt} und {der Assistent, der Busfahrer} steuert {Reisebusse, Geländewagen} von BMW.
21. Der Hotelgast {ordnet, wandert} und {der Kapitän, der Optiker} stempelt {Unterlagen, Behördenbriefe} für Bedürftige.
22. Der Rentner {ordnet, wandert} und {der Musikant, der Musiker} sammelt {Schallplatten, Gerümpel} der Beatles.
23. Der Dorfpolizist {sammelt, schweigt} und {der Journalist, der Buchhalter} ordnet {Anzeigen, Verlustanzeigen} wegen Diebstahls.
24. Der Hersteller {stapelt, streikt} und {der Germanist, der Pfadfinder} lackiert {Türschilder, Gewinde} für Stammkunden.
25. Der Gewerkschafter {fordert, nickt} und {die Agentur, der Botschafter} erhält {Sonderzahlungen, Verzehrgutscheine} auf Vertrauensbasis.
26. Der Minister {fordert, nickt} und {das Tribunal, der Machthaber} beschließt {Lohnerhöhungen, Gesetzesänderungen} für Werftarbeiter.
27. Der Fabrikarbeiter {säubert, jammert} und {der Archivar, die Künstlerin} schmuggelt {Porzellanvasen, Gefässe} mit Henkel.
28. Der Hilfsarbeiter {säubert, jammert} und {der Diplomat, der Botschafter} liefert {Sanduhren, Geräte} aus England.

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