Does branching direction determine prominence assignment? An empirical investigation of triconstituent compounds in English

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Abstract

This paper investigates the prominence patterns of nominal triconstituent compounds in English. The standard assumption for such NNN compounds is that the branching-direction is responsible for stress assignment. In left-branching compounds, i.e. those of the structure [[NN] N], the leftmost noun is assigned highest prominence whereas in right-branching compounds, i.e. [N [NN]], the second noun is the most prominent one (so-called 'Lexical Category Prominence Rule', e.g. Liberman and Prince 1977). This assumption has hardly ever been tested empirically in more detail. Using acoustic data from several hundred pertinent compounds from the Boston University Radio Speech Corpus, we found that the predictions of the Lexical Category Prominence Rule are borne out for the majority of the data. However, a considerable number of compounds do not behave as predicted and violate the Lexical Category Prominence Rule. The analysis of the aberrant cases shows that prominence assignment to triconstituent compounds is governed also by factors other than branching. These factors are suggested to be the same as those responsible for the assignment of leftward vs. rightward stress to biconstituent compounds.

Keywords: *Compound; branching-direction; stress assignment; Lexical Category Prominence Rule.*

1. Introduction

For a long time it was assumed that noun-noun (NN) compounds in English are categorically left-stressed (*e.g. Óxford Street*, *bús driver*) following the prediction of Chomsky and Halle's *Compound Stress Rule* (1968: 17). Later research (e.g. Fudge 1984; Liberman and Sproat 1992, 1994; Olsen 2000, 2001; Plag et al. 2008) has shown, however, that a considerable number of

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right-stressed compounds (e.g. *apple píe, silk tíe*) exists, a stress behaviour that is rather typical of phrases. The extent to which the Compound Stress Rule fails is unclear, and seems to depend on the kind of data one looks at. For example, Plag et al. (2007) find 10 % right stresses ($N = 4491$) in the CELEX lexical database (Baayen et al. 1995), while in Teschner and Whitley (2004) about 17 % of the 2599 noun-noun compounds listed are right-stressed. Both CELEX and Teschner and Whitley (2004) are based on dictionary data. In contrast, Sproat (1994: 88) counts 30 % right stresses in his 940 item sample from the Associated Press newswire. In a perception experiment using a random sample of 105 compounds from the Boston University Radio Speech Corpus (Ostendorf et al. 1996, a collection of news speech), Kunter (2009) finds 32.4 % right stresses. Of all NN compounds in that corpus ($N = 4341$), 34.2 % emerge as right-stressed in Kunter's (2009) automatic classification analysis based on pertinent acoustic parameters. Bell (2008) investigates a sample of 1000 NN compounds from the demographic corpus of the BNC (i.e. everyday conversations) and finds 32.6 % of these compounds to be consistently stressed on the right-hand constituent. Taken together, these figures demonstrate two things. First, dictionary-based data have a clear tendency to show significantly fewer instances of rightward stress than data from running speech or texts. Second, the number of violations of the Compound Stress Rule in the language is much higher than is usually admitted.

Accounts of the stress behaviour of compounds with more than two constituents, especially those of triconstituent compounds, have usually been built on the assumptions of the Compound Stress Rule in combination with the internal structure of the compound. Given the considerable variation found in the stress behaviour of NN compounds, which function as complex constituents in larger compounds, such accounts are seriously called into question.

The standard assumption spelled out in the literature is that the branching-direction is responsible for stress assignment in more complex compounds. Thus in left-branching compounds, the leftmost constituent is assigned highest prominence whereas in right-branching compounds, the second constituent is the most prominent one. This is captured in Liberman and Prince's (1977) 'Lexical Category Prominence Rule' (LCPR) and illustrated in the examples (1) and (2) below.[1]

(1)	Left-branching compounds	(2)	Right-branching compounds
	[[séat belt] law]		[team [lócker room]]
	[[crédit card] industry]		[morning [néwspaper]]
	[[láw degree] requirement]		[Boston [gáng members]]

However the predictions made by the LCPR have not been thoroughly tested against a large number of independently gathered data. Instead, one often finds the same self-selected examples repeated throughout the literature that illustrate the typical stress patterns assumed for left- and right-branching compounds, respectively (*e.g. [[láw degree] requirement]*, *[University [gránts committee]]*). Furthermore the generalizations seem to be based on the researchers' own intuition about stress (e.g. Carstairs-McCarthy 2002; Berg 2008), which may be rather problematic, as discussed in various studies (e.g. Bauer 1983a, 1983b; Plag 2006; Kunter and Plag 2007; Kunter 2009). It is therefore desirable to use more objective methods to account for the stress patterns of triconstituent compounds. One possibility, for instance, would be the measuring of the acoustic correlates of stress such as pitch, intensity and duration as employed in studies by Farnetani et al. (1988), Plag (2006) and Plag et al. (2008) regarding stress behaviour of NN compounds.

In view of this situation, the aim of this paper is to test the predictions of the LCPR against a large number of independently gathered data by means of acoustic measurements of pitch as found in pertinent forms in a speech corpus. The pitch analysis of some 500 triconstituent compounds from the Boston University Radio Speech Corpus (BURSC) shows that stress assignment in NNN compounds indeed goes into the direction of the LCPR predictions. However, the analysis also reveals a considerable number of compounds that do not seem to behave according to the LCPR predictions. The analysis of the aberrant cases shows that prominence assignment to triconstituent compounds is governed also by factors other than branching. These factors are suggested to be the same as those responsible for the assignment of leftward vs. rightward stress to biconstituent compounds.

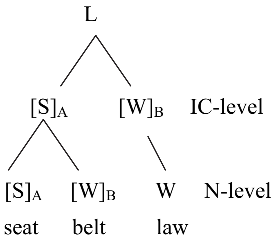
The paper is structured as follows. Section 2 provides a theoretical overview towards stress assignment in NNN compounds and takes a closer look at the LCPR prediction and its potential shortcomings. Section 3 describes the method used in this study and discusses the problems associated with it. In section 4, the results of the analyses are presented. Section 5 discusses these findings in the light of recent approaches to compound stress. The paper ends with a short conclusion and some issues for future research.

2. Prominence in triconstituent compounds: Existing hypotheses

According to the generative approach by Chomsky and Halle (1968), stress assignment in triconstituent compounds is governed by the same rule that assigns stress in NN compounds, namely the Compound Stress Rule. Due to its recursive nature and its cyclic application, the Compound Stress Rule assigns primary stress to the leftmost constituent in a left-branching compound. For a triconstituent compound with a right-hand complex member, however, it is generally assumed that stress falls on the second constituent of the whole compound. Since the classical Compound Stress Rule would not predict this stress pattern, Chomsky and Halle add a structural constraint to the Compound Stress Rule to derive the expected stress pattern for right-branching compounds (Chomsky and Halle 1968: 93, example 70).

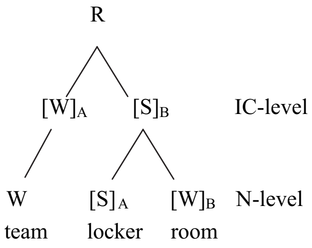
Liberman and Prince (1977) adopted Chomsky and Halle's generalizations and incorporated it into their own theory of stress within the framework of metrical phonology. Their version of the modified Compound Stress Rule, the Lexical Category Prominence Rule, labels metrical trees on the basis of strong-weak relations between two sister constituents. Thus, one constituent is always strong (S), i.e. more prominent,[2] with respect to its immediate sister constituent. In particular the Lexical Category Prominence Rule predicts: "In a configuration [$_C$AB$_C$]: if C is a lexical category, B is strong iff it branches" (Liberman and Prince 1977: 257). This is illustrated again in the two examples below. Thus, highest prominence is assigned to N1 in left-branching compounds and N2 in the right-branching compounds.

(3) Left-branching compound
(e.g. *séat belt law*)



L = Left-branching compound
IC = immediate constituent
N1= *seat*; N2 = *belt*; N3= *law*
W = weak; S= strong

(4) Right-branching compound
(e.g. *team lócker room*)



R = Right-branching compound
IC = immediate constituent
N1= *team*; N2 = *locker*; N3 = *room*
W = weak; S= strong

The LCPR predicts, as does the Compound Stress Rule, stress only in compounds, which means it applies only to lexical categories (hence the name of Liberman and Prince's rule). For stress assignment in phrasal categories, Liberman and Prince formulate a rule equivalent to Chomsky and Halle's Nuclear Stress Rule which assigns primary stress to the rightmost constituent in a phrase. "In a configuration [$_C$AB$_C$]: If C is a phrasal category, B is strong." (Liberman and Prince 1977: 257).

Yet, there are three major problems associated with the LCPR and its predictions. First, a crucial shortcoming of the LCPR is that it is based on the assumption that NN compounds are generally left-stressed. However, as mentioned in section 1, we also find a considerable number of right-stressed compounds in English. This fact, as well as the general assumption that relative prominence is preserved under embedding (Liberman and Prince 1977: 251), might cause some trouble for the LCPR and its prediction that highest prominence is generally assigned to N1 in left-branching compounds and N2 in right-branching compounds. With reference to that, one would rather expect that in the case of embedded right stressed compounds, left-branching compounds are stressed on N2 and right-branching compounds are stressed on N3. Some evidence that this might indeed be the case is provided by Olsen (2000: 65) and Giegerich (2008). Within a general discussion about the status of right prominent NN structures, Olsen argues that left and right prominent NN compounds occur embedded in triconstituent compounds (e.g [*silicon chíp*] *manufacturer*, [*oval óffice*] *visit*). Olsen, however, provides no examples for right-branching compounds with an embedded right prominent NN compound. Yet, such examples can be found in a study by Giegerich (2008) who provides examples of both left- and right-branching compounds with embedded right prominent NN compounds (e.g. [*toy cár*] *collection,* [*school óffice*] *manager, aluminium* [*garden shéd*], *university* [*spring térm*]).

Second, since right-stressed NN compounds provide evidence that node B can be strong although it is not branching, this fact might also have serious implications for stress assignment at the IC-level. In particular, one would not only expect to find left-branching compounds with highest prominence on N1 but also a number of compounds with highest prominence on N3. Such left-branching NNN compounds with highest prominence on N3 are indeed documented in the literature (e.g. Hayes 1995; Sproat 1994), and even by Liberman and Prince themselves. However, such cases are not referred to by these authors as exceptions to the LCPR prediction but are simply regarded as phrases, and thus governed by a different rule. However, apart from stress itself, Liberman and Prince provide no independent criteria that distinguish compounds from phrases, which calls into question their attempt to explain away apparent exceptions to the LCPR.

Third, in addition to these theoretical shortcomings of the LCPR, another problem is that the LCPR is only poorly empirically supported. The literature on stress assignment in triconstituent compounds is scarce and the LCPR predictions are primarily illustrated by the same self-selected examples repeated throughout the literature. The only study we are aware of which might be considered as providing empirical proof for the LCPR and its prediction is the one by Sproat (1994). However, Sproat (1994) takes the LCPR for granted and applies it to his (written) data, instead of actually testing it. In addition, the results are also based on an arbitrary and problematic assignment of phrasal vs. compound status to NNN structures. For instance, Sproat (1994: 82) assigns compound status to the NNN sequence *sump pump factory* whose prominence pattern is then governed by the LCPR, whereas *living* *room table* is assigned phrasal status based on the assumption that a semantic phrase structure rule such as “room + furniture” marks phrases. Due to being a phrase, *living room table* is then stressed on the constituent *table*. However, “room + furniture” structures are again only regarded as being phrases due to their right-stressed patterns, which renders the whole approach circular.

Besides the study by Sproat, only a few other studies are available that deal with stress assignment in NNN compounds, and their results indicate that the LCPR is problematic in its empirical predictions. For instance, Kvam (1990) investigated 40 stem-stem-stem constructions in a production experiment. Kvam found that the majority of the investigated compounds, namely 30 out of 40, was either exclusively or by the majority of the experimental subjects stressed on constituent N2. Yet, Kvam points out that only 10 of these compounds were also clearly right-branching, i.e. the group of compounds that should indeed have this stress pattern. Hence, only in 10 cases stress assignment could be directly related to the branching-direction of the compound. Based on his findings, Kvam concludes that stress does not necessarily serve to indicate constituency structure but that it is primarily a means of emphasis rather than basic meaning (Kvam 1990: 158). Unfortunately, Kvam does not provide any information on the criteria on which he based the selection of his test items nor does he explicitly state how he detected the stress pattern of a given compound. Finally, Kvam does not explicitly mention which of the compounds under investigation were stressed on which constituent, which would be necessary for a more thorough investigation of the problem.

Apart from Kvam’s study, additional evidence towards more variation in the stress assignment of NNN constructions is provided by Berg (2008). Taking an explorative approach by looking at a total of 642 stem-stem-stem combinations taken from the BNC, Berg finds that 57.2 % of the combinations are stressed on constituent N2, and 26.5 % on N1. Thus, Berg’s findings go in the same direction as Kvam’s results, revealing a general tendency for triconstituent compounds to be in their majority stressed on the second constituent, be they left- or right-branching. However, this tendency is statistically more significant for right-branching than for left-branching compounds, which is a finding that is more in line with the LCPR. In addition to that, Berg also provides information about a number of right-branching compounds with primary stress on constituent N1 and N3, as well as left-branching compounds with primary stress on N3. With reference to the LCPR prediction all of these compounds would be considered violations, either at the N-level or at the IC-level, although Berg does not explicitly refer to the LCPR and its predictions.

However, the assignment of the prominence pattern in Berg’s study is based on the author’s own intuition about stress as well as on the intuition of a few other judges (personal communication, November 2008). This method must be considered problematic, if applied impressionistically only. As studies regarding prominence assignment in NN compounds have shown, listeners tend to vary in their judgments (e.g. Bauer 1983a: 103; Kunter 2009). Assigning prominence to triconstituent compounds solely based on one's own intuition should be avoided and replaced by a more objective method, for example by a controlled rating procedure or by using measurements of the acoustic correlates of stress (e.g. Plag et al. 2008).

A totally different approach towards stress assignment in compounds is proposed by Selkirk (1984) who questions the LCPR and its predictions. Selkirk assumes that stress assignment in compounds is governed by semantic factors rather than by purely syntactic ones, with modifier-head structures being right-stressed (*e.g. cream chéese, town háll*) and argument-head structures being left-stressed (*e.g. schóol teacher, trásh removal*).[3] According to Selkirk right-branching triconstituent compounds are only right-stressed, i.e. stressed on the immediate constituent B, because a complex head as a whole can never stand in an argument-head relation to its single sister constituent A on the left. Within this context, Selkirk provides the example *law degree language requirement*, arguing that a word with an open argument position such as *requirement* must have that argument satisfied by a sister constituent. Thus *language* serves as the argument for *requirement*, and as a result *language requirement* does not have an open argument position left. Hence, the sister constituent A to a branching constituent B will never be an argument with respect to B because the empty argument slot of the head is always satisfied by the immediate sister constituent within the complex member itself (Selkirk 1984: 250). The relation between the single and the complex constituent in right-branching compounds is therefore always that of a loose adjunct relation which usually triggers right stress (Selkirk 1984: 250).

Selkirk's explanation for the stress behaviour of right-branching compounds also leads to a different stress prediction for left-branching modifier-head compounds.[4] According to Selkirk, left-branching compounds that have a modifier-head relation at the IC-level should be stressed on N3, as opposed to Liberman and Prince's theory, where left-branching compounds should be stressed on N1 but never on N3.[5]

However, a major problem associated with Selkirk's approach is that her explanation concerning right-branching compounds simply cannot be empirically tested. Since Selkirk states that argument-head compounds that are right-branching at the IC-level cannot be constructed, it is impossible to falsify her claim. One simply cannot test whether it is the modifier-head status or purely branching that is responsible for the assumed stress pattern in right-branching compounds.

From the situation just described the general question arises of how NNN structures are really stressed in English. To answer this question, the present paper will exclusively focus on the LCPR and its prediction for the prominence patterns of triconstituent compounds. Thus, we are trying to answer the question whether branching really determines prominence assignment in left- and right-branching NNN compounds. Are left-branching compounds really stressed on N1 and right-branching compounds on N2?

Before turning to the methodology used in the present analysis we must note that due to the general difficulties to clearly distinguish between NNN compounds and NNN phrases, we will remain agnostic with reference to the theoretical status of NNN structures for the rest of the paper.[6] The terms 'NNN structure' and 'NNN compound' will be used interchangeably.

3. Methodology

3.1. The data: The Boston University Radio Speech Corpus

The data used in this study are taken from the Boston University Radio Speech Corpus (BURSC), an audio corpus collected by Ostendorf et al. (1996). The corpus consists of radio news texts from seven professional FM radio news speakers (4 male and 3 female) all associated with the public radio station WBUR. The main portion of the corpus consists of more than seven hours of news recordings gained in the WBUR radio studio during actual broadcasts over a two year period. In addition to the live recordings, the corpus also consists of a portion of 24 news stories ("lab news portion") read by six of the seven speakers in a laboratory at the University of Boston. For these recordings, the speakers were first asked to read the news stories in their natural speech style and then, 30 minutes later, to read the same stories in their professional radio news style. Each story read by the news speakers has been digitized in paragraph size units, which typically include several sentences. All files are digitized at a 16 kHz sample rate using a 16 bit A/D (cf. Ostendorf et al. 1996).

The Boston University Radio Speech Corpus was chosen for this study because of the following reasons. First, the corpus was collected primarily to support text-to-speech synthesis, in particular the generation of prosodic patterns, and is thus ideally suited for the study of prosodic phenomena such as compound stress. Second, it contains data from the news genre, which we expected to contain a fair number of NNN compounds. Third, it was expected that professional news speakers tend to produce rather error-free speech. Finally, the corpus has already been used for research on stress assignment of two-constituent (i.e. NN) compounds in studies by Kunter and Plag (2007), Lappe and Plag (2007), and Plag et al. (2008), and proved to be highly suitable for this type of investigation. It was expected that the same would hold for the investigation of triconstituent compounds.

The data for the present study were manually extracted from the text files. In general all structures that formed a sequence of exactly three adjacent nouns within an NP were selected as potentially pertinent data. Some restrictions, however, were applied with reference to certain types of NNN sequences in order to ensure that the structures investigated conform as closely as possible to what most linguists would consider a triconstituent compound. Thus, NNN sequences containing initials such as *U.S. district judge* have been excluded from the analysis since the status of the abbreviation *U.S.* as a single noun-constituent is questionable.[7] In addition, we, rather conservatively, also excluded NNN structures that contained words other than English such as *Hillside hacienda*, *classroom blitz* or *San Antonio Spurs*. Furthermore, NNN structures with genitive inflections e.g. *tenant's right crisis* were not included in the analysis, and this policy was also applied to NNN sequences with proper names as the first two constituents like *Thomas Crown affair* and *John Hopkins University*. Neoclassical formations such as *biotechnology* were included in the analysis as one constituent.

The sampling procedure was as follows. Starting with the transcription of speaker F1, all NNN compounds that conformed to the above mentioned restrictions were extracted. For each type, only the first token was sampled such that additional tokens did not enter the analysis.[8] Plural and singular forms of one type were treated as one type. The data from the other speakers were sampled in the following sequence: F2, F3, M1, M2, M3, M4. Table 1 gives the distribution of the types sampled across speakers.

Table 1. *Number of types sampled across speakers*

F1	69 types
F2	57 types
F3	123 types
M1	57 types
M2	84 types
M3	20 types
M4	95 types

Applying the procedures just described, we ended up with a data set of 505 NNN structures.

3.2. *Branching direction*

In order to test the predictions of the LCPR, the 505 NNN structures extracted from the corpus had to be coded according to their internal structure, i.e. as either left- or right-branching. Crucially, the analysis of the branching direction was performed on the basis of the written transcript alone. Listening to the news stories was avoided in order not to confound the analysis of the branching direction with acoustic information on stress. How did we determine the branching direction of a given triconstituent compound? We performed a semantic analysis of all 505 compounds. The semantic analysis of the majority of these compounds was rather straightforward and led to a set of 448 either clearly left-branching, or clearly right-branching compounds, such as *[[seat belt] law]* or *[state [income tax]]*.

For 85 compounds among the 448 compounds an additional independent criterion was available to determine the branching direction, i.e. the orthographic representation. In these compounds two of the constituents were either written as one orthographic word or with a hyphen. Although the spelling of compounds varies among speakers, it is clear that a more intricate spelling, i.e. as one word or hyphenated, is an indication of a more word-like status of that combination.[9] Hence, we would expect that a more intricate spelling indicates the presence of a complex IC, as illustrated in, for example, *weekend series*, *wheelchair marathoners*, *Boston newspaper*, *company whistle-blowers*. We used this insight to verify our semantic analysis in the following way. We assigned a branching direction to this subset of compounds based on their spelling, and we then checked the results of the application of the spelling criterion against the results of the application of the semantic criterion. This resulted in a 100 % match between the two criteria.

The semantic analysis of the extracted compounds, however, did not always yield such clear-cut interpretations as the ones just mentioned. It turned out to be rather problematic for structurally ambiguous compounds. To give an example from Warren (1978: 16), the combination *silver knife handle* may be interpreted as left-branching ('the handle of a silver knife'), or as right-branching ('knife handle made of silver').

It is usually assumed that such ambiguity arises primarily when compounds occur in isolation. As soon as they are embedded in a natural speech context, one can usually interpret them unambiguously with reference to that context (see, for example, Meyer 1993; Plag 2003 for some discussion). It was for this reason that the number of truly ambiguous compounds was expected to be extremely small at first, since all compounds used in this study were embedded in a natural speech context. Nevertheless, it turned out that for 57 compounds of the 505 compounds even the context could not provide enough information to clearly disambiguate them. For instance, a Boston police officer may be an officer of the Boston police (left-branching), or it may be a police officer working in Boston (right-branching).[10]

These ambiguous compounds were excluded from the analysis, which reduced the number of items under investigation to 448 compounds. Of the 448 NNN compounds, 326 were classified as being left-branching, 122 as right-branching. The high proportion of left-branching compounds in contrast to right-branching compounds is not peculiar to our data. The result goes into the same direction as earlier findings by Marchand (1969), Warren

(1978) or, more recently, Berg (2006). Based on their findings these authors claim that left-branching compounds are more common than right-branching compounds in English, with left-branching compounds being the unmarked structure for triconstituent compounds.

3.3. Detecting prominence in triconstituent compounds

The major problem when dealing with stress in English compounds is how to detect the stress patterns of such forms. As already mentioned, thus far the generalizations about stress in triconstituent NNN compounds rely primarily on the researchers' own intuition about stress (e.g. Liberman and Sproat 1992; Sproat 1994). Yet this way of assigning stress is problematic. As noted in Bauer (1983), Plag (2006) and Kunter and Plag (2007) speakers often seem to have difficulties in classifying compounds as either left- or right-stressed and thus do not only vary within their own judgements but also among each other. These difficulties seem to be even more prevalent if compounds are embedded in a speech context (Plag 2006: 150). In view of this situation, one would like to have a more objective method in order to account for the stress patterns of compounds.

Such an objective method is the measurement of acoustic correlates of stress, such as pitch, intensity and duration, as it has been shown in various studies regarding stress in NN constructs (e.g. Farnetani et al. 1988; Ingram et al. 2003; Plag 2006; Kunter and Plag 2007). In all of these studies it turned out that of the three stress correlates mentioned above, pitch is the most important cue to compound stress. Farnetani et al. (1988) investigated minimal pairs such as *páper bag* and *paper bág* in order to detect the acoustic cues responsible for the different stress patterns of phrases and compounds. They found pitch to be the most reliable cue to compound stress, with duration playing a role only with reference to the distinction between the members of minimal pairs. In a more recent study of the acoustic correlates of compound stress by Kunter and Plag (2007), it is again pitch which turned out to be the best single correlate of compound stress. An earlier experimental study by Plag (2006), in which he analysed about 500 compounds, showed that calculating pitch differences is indeed suitable to test competing hypotheses regarding stress variation in NN compounds. Plag compared the pitch behaviour of compounds which were assumed to be left-stressed (e.g. argument-head compounds) with those which should be right-stressed (e.g. modifier-head compounds) and indeed found significant, and expected, differences in the pitch behaviour between these groups. On the basis of his findings, Plag was able to make clear statements with reference to the accurateness of the hypotheses tested.

On the basis of these previous findings about the acoustic cues to compound stress, the present paper uses pitch analyses to account for the stress patterns of triconstituent compounds. Measuring pitch involves a number of methodological problems, however, which need to be explained and discussed in some detail. First, one needs to find an appropriate method to measure pitch.

Ingram et al. (2003) and Plag (2006), for instance, measured the F0 value in the middle of the vowel of the main-stressed syllables in the two constituents and then calculated pitch differences between the left and right constituent of each compound. In choosing this point of measurement they tried to account for coarticulation effects caused by surrounding sounds (Plag 2006: 150). However, they had to deal with the technical problem of clearly separating the vocalic nucleus from preceding and following sounds, which is especially difficult in cases of liquids and nasals. Such sonorous sounds show similar acoustic properties to that of vowels, which makes a clear separation often impossible.

A potentially more adequate way of measuring pitch was proposed by Kunter and Plag (2007) and Plag et al. (2008), who, instead of measuring the F0 value in the middle of the vowel, calculated the mean F0 value over the sonorous part of the rime in the pertinent syllable. Such a procedure also takes care of the fact that accentual tonal targets need not be the vowels themselves (cf. Ladd 1996: 55).

Instead of using the mean one might also consider measuring the peaks of the pitch contour. Kunter (2009) showed, however, that the values of peaks and mean strongly correlate, so that both measurements are in principle eligible. We checked the correlation of peaks and means also for our data and found the highly significant correlation that was expected ($r = 0.926, p < 0.001$). There are, however, two advantages to using the means instead of the peaks. First, the means allow for manual checking and recalculation of the pitch for items with creaky voice phonation. Second, using peaks in automatic pitch tracking runs the danger that the algorithm confounds peaks associated with boundary tones with accentual tones. We therefore decided to follow Plag et al. (2008) and Kunter (2009) in using mean pitch, calculated over the sonorant part of the main stressed syllable of each compound constituent as the acoustic correlate of stress in this study.

A second problem with acoustic measurements occurs with reference to the intrinsic pitch of vowels. It is well-known that high vowels have a higher intrinsic pitch than lower vowels (e.g. Whalen and Levitt 1995). In an experimental setting one would therefore try to control for this factor and construct well-balanced stimuli, if possible. In corpus studies such as the present one this is impossible. We are confident, however, that the random sampling from the corpus alleviates this problem. Note also that many constituents have main stressed syllables that contain diphthongs, or vowels accompanied by sonorant material over which the mean is calculated, too. This also diminishes the potential effect of intrinsic vowel quality.

Third, using natural speech data involves the problem of potential influences of discourse factors such as contrastive stress and focus on the stress behaviour of compounds. Studies by Plag (2006) and Plag et al. (2008) have shown, however, that apart from instances of contrastive stress, such discourse factors do not seem decisive for stress assignment in compounds. Plag (2006) tested the effects of focus and the given/new distinction via clausal position and clause type. Although he found that the pitch values of the left and right constituents in each compound generally decreased from initial to final clausal position, no clear effects of the said factors on stress assignment could be detected. Plag et al. (2008) tested three hypotheses regarding stress variation in NN compounds against a large number of corpus data from the Boston University Radio Speech Corpus. They found, for instance, that argument-head compounds are not generally more left-stressed than modifier-head compounds. Instead, this effect is restricted to argument-head compounds with a deverbal head ending in *-er*. In order to rule out potential influences of discourse factors on their results, Plag et al. (2008) compared their findings to those of a study by Plag et al. (2007) in which the same hypotheses were tested against (mainly) dictionary data taken from the CELEX lexical data base (Baayen et al. 1995). The CELEX study revealed a similar effect for argument-head compounds ending in *-er* and also revealed fairly similar results with reference to the other two hypotheses. Hence no relevant differences in stress assignment between citation forms and speech corpus data were found.

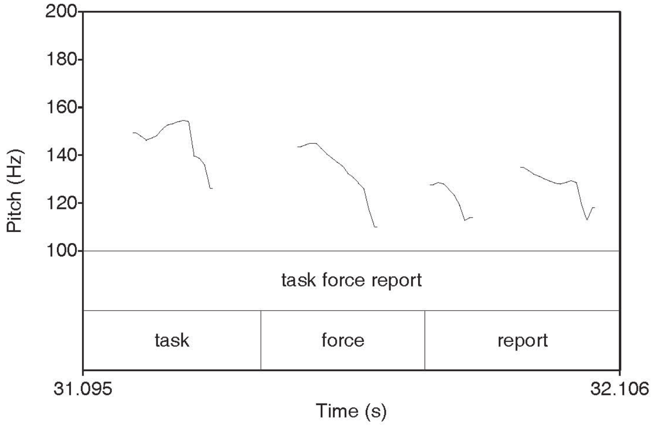
Based on these results and based on the fact that the 448 compounds were randomly sampled, potential effects caused by discourse factors were neglected in the present analysis.

3.4. Acoustic measurements

The 448 left- and right-branching compounds extracted from the corpus were annotated using the speech analysis software PRAAT (Boersma and Weenink 2007). Following the method employed by Plag et al. (2008), we first manually segmented the single constituents of each compound and second the sonorant part of the rime of the most prominent syllable in each of these compound constituents. The mean F0 value of the selected interval for each constituent was automatically measured with the help of a PRAAT-script. The script took the standard values proposed for a pitch analysis by the PRAAT programme as a baseline. Gender specific pitch ranges were considered by choosing pitch boundary settings of 75–300 Hz for male speakers and 100–500 Hz for female speakers. Automatic adjustments were made in cases of creaky voice or octave jumps, in case a pitch contour could be extracted only for half or less of an interval as well as if the minimal pitch extracted from a given interval was less than 0.5 semitones higher than the pitch floor setting. In cases in which adjustment was necessary due to the factors just mentioned, the settings for pitch floor and ceiling values were reduced automatically by one third, and the voicing threshold was reduced to increase the sensibility of the pitch extraction algorithm. The pitch measurement was repeated with the new settings up to three times. If after three adjustments it was still impossible to detect a pitch value, the items were excluded from the analysis (for more details regarding the algorithm applied see Kunter 2009). This was the case for six compounds, which reduced our data set to a final number of 442 items. For each triconstituent compound the script measured three pitch values, i.e. one for each constituent.

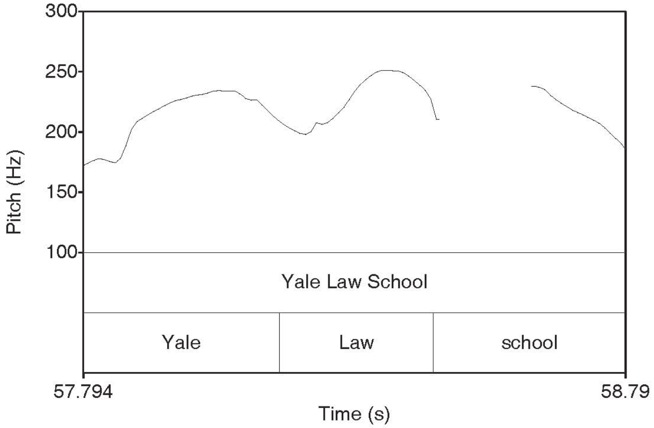
After measuring pitch, we calculated the pitch differences between each of the three constituents of the annotated compounds and at the same time logarithmically transformed the pitch difference from Hertz (‘Hz’) into semitones (‘ST’) in order to neutralize gender-specific pitch differences.[11] The three pitch differences calculated for each compound were labelled P1P2, P2P3 and P1P3. P1P2 designates the pitch difference between N1 and N2, P2P3 the difference between N2 and N3, and P1P3 between constituent N1 and N3. For better illustration of the measurements, the following two figures give the pitch tracks and the calculated pitch differences for a left- and a right-branching compound from our data set.

Calculating pitch differences raises the question of their interpretation with reference to the stress patterns of triconstituent compounds. For example, what do the pitch differences in the two examples in Figures 1 and 2 tell us



Pitch differences	P1P2	P2P3	P1P3
[[*tásk force*] *report*]	+1.58 ST	+1.05 ST	+2.63 ST

Figure 1. *Pitch track for task force report*



Pitch differences	P1P2	P2P3	P1P3
[Yale [láw school]]	-0.81 ST	+1.50 ST	+0.69 ST

Figure 2. *Pitch track for Yale law school*

about the stress patterns of these compounds? As discussed in Plag (2006) there are two different approaches towards their interpretation, i.e. a categorical approach and a relative approach. In a categorical approach a binary stress distinction would be assumed in which positive pitch differences would be interpreted as indicating left stress and negative pitch differences as indicating right stress. According to such an approach one would derive the following stress patterns for the examples given in Figures 1 and 2. In the left-branching compound *taskforce report* the pitch difference P1P2 between N1 (*task*) and N2 (*force*) is positive (+1.58 ST) which is interpreted in such a way that *task* is more prominent than *force*. The pitch difference between *force* and *report* is also positive (+1.05 ST), hence *force* is more prominent than *report*. Since *task* is more prominent than *force*, and more prominent than *report*, *task* is the most prominent constituent in this compound. In the case of the right-branching compound *Yale law school* the negative pitch difference P1P2 calculated between constituent 1 (*Yale*) and 2 (*law*) indicates that *law* is more prominent than *Yale*. The positive difference (P2P3) between *law* and *school* indicates again that *law* is more prominent, but this time with reference to the third constituent *school*. Thus *law* is the most prominent constituent in this compound.

The major problem with the categorical approach, however, is that it does not account for the fact that right-stressed compounds do not necessarily have a negative pitch difference, as has been shown by Ingram et al. (2003), Plag (2006) and Kunter and Plag (2007). Instead, rightward stress might also be indicated by a relatively small positive (instead of a negative) pitch difference. The reason for this might be a constant downstep of F0 over the course of an utterance (e.g. Pierrehumbert 1979; Liberman and Pierrehumbert 1984). This pitch declination seems also prevalent between constituents of compounds (cf. Farnetani et al. 1988), in that pitch generally decreases from the left constituent to the right constituent of a compound. As far as listeners are concerned, however, they seem to neutralize the F0 declination, making up for the less prominently pronounced constituent in a rightward-stressed compound (Plag 2006: 151). Thus, the problem with the categorical approach is that it is unclear where the dividing line should be placed (if there is such a categorical point in the first place).

In order to circumvent such problems, one would rather need to take a relative approach according to which statistically significant differences in pitch between different groups of compounds indicate their having different stress patterns. This approach was succesfully employed, for instance, by Plag (2006). Plag tested the hypothesis that argument-head compounds should be generally left-stressed whereas modifier-head compounds should be right-stressed. Thus, he compared the mean values of the calculated pitch differences of both types of compounds and looked for statistically significant differences. The analysis indeed revealed a significantly higher mean for the pitch difference of argument-head compounds (t (29.46) = 4.6371, $p < 0.001$) compared to that of modifier-head compounds, indicating that argument-head compounds are generally more left-stressed than modifier-head compounds. The results are visualized by the boxplots in Figure 3 (from Plag 2006: 154).

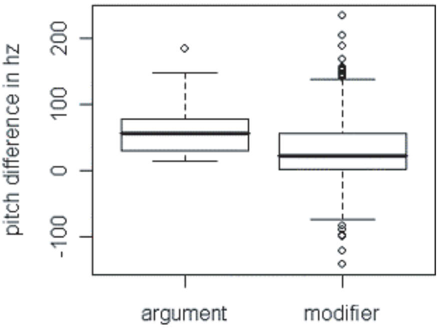


Figure 3. *Argument-head vs. modifier-head compounds: Relative approach (from Plag 2006: 154)*

The relative approach also has the advantage that variation within a group of compounds is clearly visible. As can be seen in Figure 3, a considerable number of modifier-head compounds also shows a clearly positive pitch difference which indicates that not all modifier-head compounds are right-stressed. In addition the graph reveals that there is much more variation among the group of modifier-head compounds than for argument-head compounds. Thus the relative approach allows for a more sophisticated analysis of compound stress than the absolute approach.

Based on these results, we decided to take a relative approach to test the LCPR predictions. But how can this method be applied to triconstituent compounds where we are dealing with three pitch differences and not just one, as in NN compounds? Which of the three pitch differences of left-and right-branching compounds need to be compared to test the LCPR predictions? In order to answer these questions let us recall the predictions of the LCPR.

The LCPR predicts that highest prominence is assigned to N1 in left-branching compounds and to N2 in right-branching compounds. Thus left- and right-branching compounds differ with reference to the prominence relation between constituent N1 and N2. The prominence relation between N1 and N2 is captured in the pitch difference P1P2. From this it follows that left- and right-branching compounds should significantly differ with reference to the P1P2 pitch difference. In particular, the LCPR predicts that the P1P2 pitch difference in right-branching compounds is significantly smaller than in left-branching compounds, indicating that N2 is generally more prominent than N1 in right-branching compounds than in left-branching compounds.[12] For the examples above we would therefore predict that the P1P2 pitch difference of *task force report* should be notably higher than that of *Yale law school*. This is indeed the case: the P1P2 difference is 1.58 ST for *task force report* as against -0.81 ST for *Yale law school.* This first prediction is again illustrated in Figure 4.

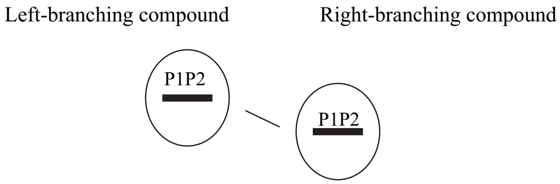


Figure 4. *Across group comparison*

Yet, it is not enough to compare the P1P2 pitch differences of both groups in order to detect whether the LCPR is correct or not. We also need to test if constituent N2 in right-branching compounds, and N1 in left-branching compounds, are each more prominent than the constituent N3 of their respective compounds. How can we detect whether these predictions hold?

Regarding right-branching compounds the prominence relation between constituent N2 and N3 can be tested by comparing the P2P3 pitch difference with the P1P2 pitch difference. As mentioned above, for right-branching compounds we expect a relatively low P1P2 pitch difference indicating higher prominence of N2 in relation to N1, whereas for P2P3 we expect a relatively high pitch difference indicating higher prominence of N2 in relation to N3. If the LCPR is correct and N2 is indeed more prominent than N1 and N3, we predict that the P2P3 pitch difference is significantly higher than the P1P2 pitch difference. Our example *Yale law school* illustrates this nicely, in that its P2P3 difference is 1.50 ST, while the P1P2 value is only -0.81 ST.

Turning to left-branching compounds, we have to compare the pitch differences P1P2 and P1P3. According to the LCPR, N1 is assigned highest prominence in left-branching compounds. This should be clearly marked by assigning high pitch to N1 and lower pitches to constituent N2 and N3. Since the LCPR does not make a prediction for the prominence relation between N2 and N3 in left-branching compounds (none of the two constituents is claimed to be the most prominent one), we assume that constituent N2 is either equal or higher in pitch than constituent N3. Yet, we would not expect N3 to be more prominent than N2 because in that case P1P3 would be smaller than P1P2. Thus when comparing the pitch differences P1P2 and P1P3 of left-branching compounds, we expect P1P3 to be either significantly higher or at least equal to that of P1P2, but never smaller. With regard to our example *task force report*, these predictions are borne out by the facts. For this item the P1P3 difference of 2.63 ST is notably higher than its P1P2 difference of 1.58 ST.

The predictions for the comparisons of the pitch differences within left-branching and within right-branching compounds are illustrated in Figure 5.

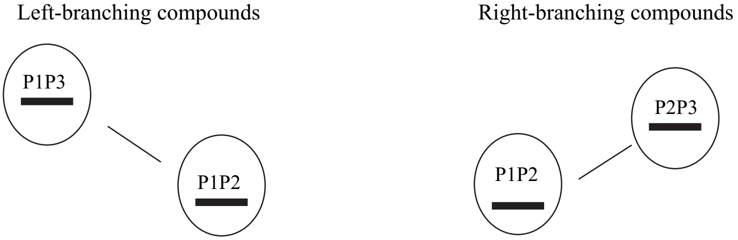


Figure 5. *Within group comparison*

4. Results

4.1. Testing the LCPR predictions: Stress assignment and branching direction

The central aim of the present analysis is to test to what extent the predictions made by the LCPR really hold for NNN compounds. To do so, we will first describe the pitch distributions in our data sets to get a better understanding

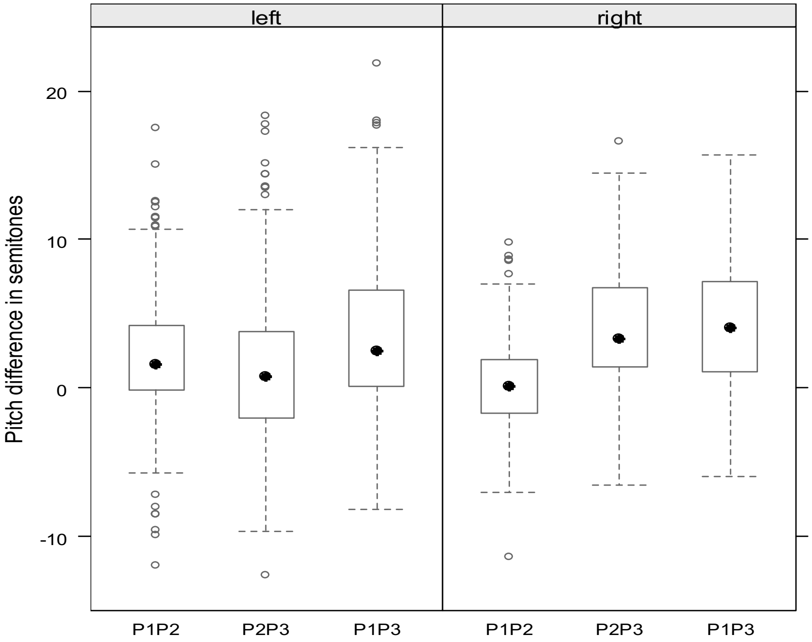


Figure 6. *Pitch differences of left- and right-branching compounds*

of the issues at hand and then test the relevant differences in these data sets statistically.

Figure 6 is a first graphical representation of the calculated pitch differences for left- and right-branching compounds.[13] Each box plot represents one of the three pitch differences P1P2, P2P3 and P1P3 for both groups.

Figure 6 already reveals a difference between left- and right-branching compounds with regard to their median pitch difference P1P2. The median P1P2 pitch difference is smaller in right-branching compounds than in left-branching compounds. Besides, one can observe that the P1P2 and P2P3 pitch differences in right-branching compounds clearly differ from each other, with P1P2 being smaller than P2P3. With reference to the P1P3 and P1P2 pitch differences in left-branching compounds, it seems that the P1P3 median value is slightly greater than that for P1P2. The mean values and standard deviations for all three measurements are summarized in Table 2.

In what follows we will test whether the observed pitch differences P1P2, P2P3 and P1P3 indeed significantly differ in the ways predicted by the LCPR.

A type-III ANOVA with “pitch difference” as dependent variable, and “position” (P1P2, P2P3, P1P3) and “branching direction” (left, right) as predictor variables showed a significant main effect for “position” (F (2, 1320) =

Table 2. *Mean values and standard deviations of pitch differences for left-branching and for right-branching compounds*

	Mean left-branching	Mean right-branching
P1P2	2.06 (SD: 4.07)	0.36 (SD: 3.45)
P2P3	1.21 (SD: 4.72)	3.96 (SD: 4.03)
P1P3	3.26 (SD: 5.03)	4.32 (SD: 4.28

17.325, $p < 0.001$) as well as for “branching direction” (F (1, 1320) = 12.746, $p < 0.001$). Furthermore it revealed a significant interaction between the factors “position” and “branching direction” (F (2, 1320) = 22.208, $p < 0.001$). The interaction of position and branching direction are shown in Figure 7. The dotted line connects the means of the P1P2 values of the left-branching and the right-branching compounds, the solid line does so for the mean P2P3 values, and the broken line connects the P1P3 means of the two sets of compounds.

The significant interaction of position and branching direction is indicated in Figure 7 by the crossing of the lines for P1P2 and P2P3 of left-branching and right-branching compounds.[14] The plot shows that P1P2 is smaller in right-branching compounds than in left-branching compounds whereas P2P3

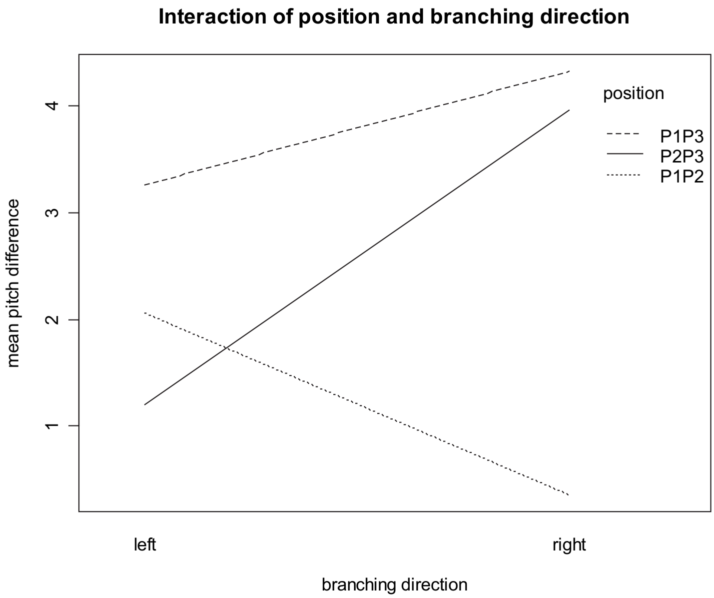


Figure 7. *Interaction of position and branching direction*

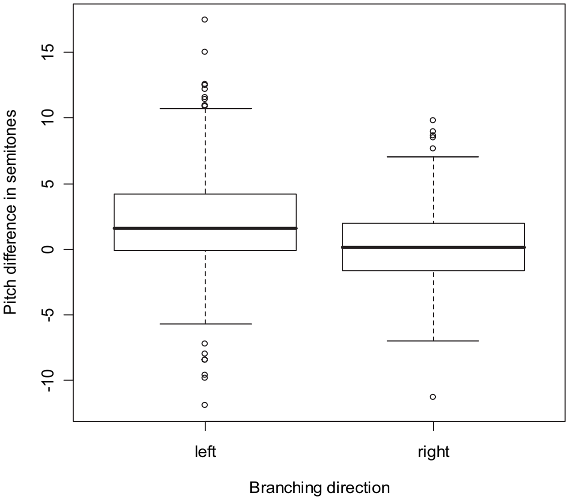


Figure 8. *P1P2 comparison across left- and right-branching compounds*

is smaller in left-branching compounds than in right-branching compounds. For the P1P3 pitch difference we find that left-branching and right-branching compounds behave quite similarly (see below for more details on the P1P3 differences).

Let us turn to the three comparisons described in section 3 in order to find out whether the LCPR is indeed correct or not. Using a Welsh Two sample-t-test to make the comparison between the P1P2 pitch differences of left-branching and right-branching compounds, the difference in means was found to be significant ($t\,(253) = 4.37, p < 0.01$ after Bonferroni-adjustment, Cohen's $d = 0.45$). In particular, we found that P1P2 in right-branching compounds (mean = 0.36 ST) is significantly lower than in left-branching compounds (mean = 2.06 ST). This result is fully in accordance with the LCPR prediction made in section 3, and is illustrated in Figure 8.

As can be seen in Figure 8 the two groups clearly differ in their mean values for P1P2. However it can be also observed that the data overlap to a certain degree. We observe that a number of P1P2 pitch differences of left-branching compounds are quite small, as well as that some P1P2 pitch differences of right-branching compounds are rather clearly positive. This observation must not be left unnoticed here as it indicates possible violations of the LCPR at the N-level for left-branching compounds, and at the IC-level for right-branching compounds (for more discussion see section 4.2).

Let us now inspect in more detail the comparison of the pitch differences within each group in order to detect the prominence relation between N1 and

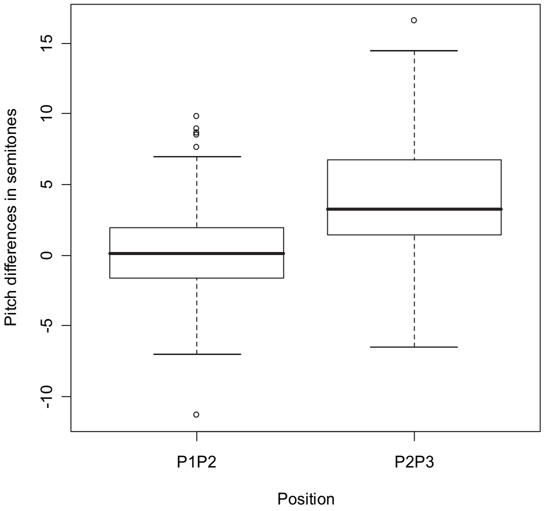


Figure 9. *Comparison of pitch differences in right-branching compounds*

N3 (for left-branching compounds), and the prominence relation between N2 and N3 (for right-branching compounds).

Starting with right-branching compounds, we compared the mean pitch difference for P1P2 and P2P3 of right-branching compounds in a second Welsh Two sample-t-test in order to detect the prominence relation between constituent N2 and N3. The test revealed a significantly higher pitch difference for P2P3 compared to P1P2 ($t(234.39) = 7.42$, $p < 0.01$ after Bonferroni-adjustment). A look at the effect size of the statistical comparison revealed that it was quite large (Cohen's $d = 0.95$) indicating a clear difference between the calculated values of the two groups. Thus, N2 is clearly more prominent than N3, which is once more in accordance with the LCPR prediction from section 3, and illustrated in Figure 9. The large effect size is visible by the rather small overlap of the two boxes.

Based on the comparison of the P1P2 and P2P3 pitch difference, we arrive at the following prominence pattern for right-branching compounds. There is a relatively small P1P2 pitch difference (0.36 ST), which reveals that constituent N1 and N2 hardly differ in their calculated pitch values. What does that mean for the prominence of N1 vis-à-vis N2? As already mentioned in section 3.4, biconstituent compounds that are right-prominent do not necessarily have a higher pitch in the right constituent. Rather, right-prominent compounds are characterized by a more or less level pitch, i.e. by a pitch difference of around 0 ST (e.g. Plag 2006; Kunter and Plag 2007). For illustration, let us briefly look at all left-headed compounds (such as *attorney*

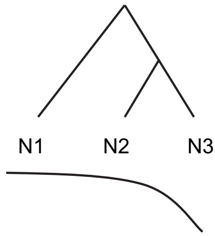


Figure 10. *Schematized pitch curve of right-branching compounds*

general) from the Boston Corpus. This category is uncontroversially taken to be right-stressed, and the mean pitch difference for such compounds in the Boston Corpus is 0.05 ST. Returning to our results from above, we can now say that the very small difference found for P1P2 should be interpreted as a right-prominent pattern. This means that in the right-branching compounds in our data set, N2 is more prominent than constituent N1.

The relatively high mean value of the pitch difference P2P3 (3.95 ST) in Figure 9, which significantly differs from the small P1P2 pitch difference, indicates that N2 in right-branching compounds is much more prominent than constituent N3. Adding up the two mean values for the pitch differences P1P2 and P2P3, we arrive at a mean pitch difference of 4.32 ST for P1P3. Thus pitch decreases more than 4 ST from N1 to N3, which leads to the conclusion that N3 is generally the least prominent constituent in right-branching compounds. Overall, the relatively low pitch difference between N1 and N2 and the high pitch difference between N2 and N3 reveal that N2 is assigned highest prominence in right-branching compounds. For the pitch curve in right-branching compounds this means that the pitch contour is generally level for N1 and N2 of right-branching compounds and decreases towards the third constituent. This is sketched in Figure 10.

For left-branching compounds the situation looks rather different. The comparison of the P1P3 and P1P2 pitch difference revealed that P1P3 is significantly higher than P1P2 (t (613.5) = 3.34, $p < 0.01$ after Bonferroni-adjustment). This is in accordance with the prediction from section 3, namely that P1P3 should not be lower than P1P2. However, in contrast to right-branching compounds, the effect size of the significant effect for this compound group was quite small (Cohen's $d = 0.26$), indicating a relatively strong overlap of the calculated group values. This is clearly shown in Figure 11, which gives the plot for the comparison of the two pitch differences within left-branching compounds.

As can be seen in Figure 11, the two boxes strongly overlap. The distribution of the P1P3 pitch differences is much larger than that of the P1P2 pitch differences, the former ranging from relatively small to clearly large values.

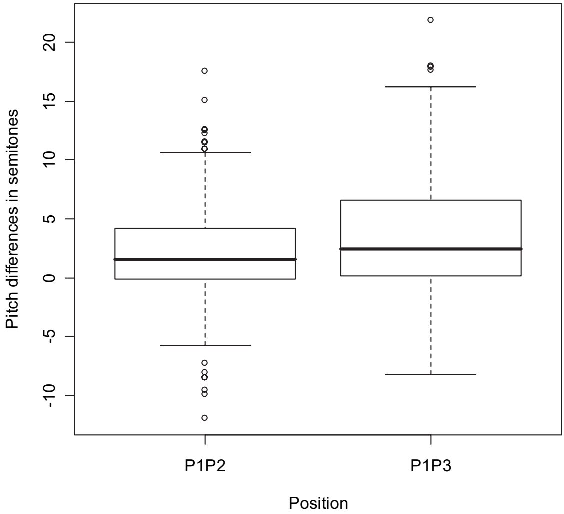


Figure 11. *Comparison of pitch differences in left-branching compounds*

We should note here that relatively small P1P3 pitch differences may be an indication of some violations of the LCPR at the IC-level.

Yet, what does this result mean regarding the prominence pattern of left-branching compounds? Based on the calculated means and the significant effects found in the analysis, we arrive at the following prominence pattern of left-branching compounds. The relatively high mean pitch difference P1P2 of 2.06 ST for left-branching compounds indicates that N1 is generally more prominent than N2 in these compounds. Furthermore, the significantly higher mean pitch difference P1P3 (3.26 ST) vis-à-vis mean P1P2 (2.06 ST) signals that N1 is also for the majority of the compounds more prominent than N3. Finally, due to the fact that P1P3 is significantly higher than P1P2, we may also conclude that N2 is, for the majority of compounds, more prominent than N3. This results in a pitch curve in left-branching compounds for which the mean pitch decreases about 3 ST from N1 to N3, with a greater pitch fall from N1 to N2 than from N2 to N3. A sketch of the pitch curve based on the calculated mean difference is shown in Figure 12.

We finally note that pitch generally decreases from constituent N1 to N3 in both groups of compounds, with a somewhat larger decrease for right-branching compounds (means: 4.32 ST for right-branching vs. 3.26 ST for left-branching). This difference does, however, not reach significance after Bonferroni-adjustment (t (251.195) = 2.171, p = 0.123, Bonferroni-adjusted). Thus, left-branching and right-branching compounds in our corpus do not differ significantly in their overall pitch range.

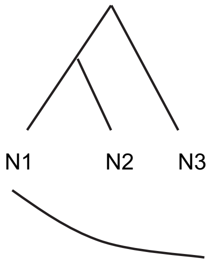


Figure 12. *Pitch curve of left-branching compounds*

To summarize our findings, we can conclude that there is a strong tendency that left-branching and right-branching compounds behave as predicted by the LCPR. The comparison of the P1P2 pitch differences across both groups showed that N2 is more prominent in right-branching compounds than in left-branching compounds in comparison to constituent N1. For left-branching compounds we find that higher prominence is assigned to N1. Furthermore the within-group comparisons revealed that N1 in left-branching compounds, and N2 in right-branching compounds are also more prominent with reference to constituent N3. Thus, the analysis indicates that it is generally N2 that is assigned highest prominence in right-branching compounds and N1 in left-branching compounds.

However, the small effect size calculated for the significant difference in left-branching compounds and the medium effect size calculated for the across group comparison hint towards the possibility that there might also be a number of violations among the group of left-branching and right-branching compounds. This suspicion is also supported by the range of pitch differences, which indicates aberrant stress patterns for quite a few compounds. In order to learn more about potential violators of the LCPR we investigated the two groups of compounds in more detail. This is done in section 4.2 to which we turn now.

4.2. Variation and branching direction

We wanted to address the questions of how many items among the two groups violate the LCPR, and what kinds of violations we find (at the IC-level, or at the N-level). However, using gradient measurements makes this a difficult task, since the only way to make out clear subgroups of compounds that violate the LCPR would be to classify all compounds as either left-stressed or right-stressed. This means that we would need to define a suitable threshold for our pitch differences along which we could clearly separate cases of violations from cases that conform to the rule. But which threshold is appropriate? At which point can we more or less clearly say that the relation between two constituents reveals left stress or right stress, respectively?

As argued in section 3, one can generally assume that whenever a constituent to the right has a higher pitch than a constituent to the left, the constituent to the right is more prominent. Thus, we can assume that negative pitch differences clearly indicate right stress between two constituents. What would be a suitable threshold for left stress? Under the assumption that the more positive the pitch difference, the clearer the left stress, we should choose a pitch difference that is not too close to 0 ST. A look at the means in Table 2 shows us that the mean of the P1P2 difference for left-branching compounds is 2.06 ST. Recall that according to the assumptions of the Compound Stress Rule and the LCPR the P1P2 difference should reflect left stress. We therefore decided to take 2 ST as the threshold for left stress, i.e. we assume that values equal or above 2 ST indicate left stress. This entails that we choose not to say anything about the prominence relationship for all those constituent pairs whose pitch difference is between 0 and 2 ST. While we are losing data under this approach, we try to minimize the risk of making wrong generalizations. In other words, by using this methodology, we try to be conservative and rather underestimate the number of exceptions to the LCPR.

Let us first turn to the stress patterns we found for left-branching compounds. According to the LCPR highest prominence in left-branching compounds is assigned to constituent N1. Thus, the LCPR is violated as soon as highest prominence is assigned to constituent N2 or constituent N3. Highest prominence on N2 violates the LCPR at the N-level but not at the IC-level since in that case highest prominence remains within the complex constituent, with node B being weak and node A being strong. Highest prominence on N3 violates the LCPR at the IC-level, since it causes node B to be strong, in spite of its being non-branching. The patterns that violate the LCPR are listed in the following table, in which ‘positive’ means ST > 2 (indicating left stress), and ‘negative’ means ST < 0 (indicating right stress).

Table 3. *Violations of the LCPR, left-branching compounds*

Pattern	P1P2	P2P3	P1P3	Most prominent	# of items	Violation at level
1	positive	negative	negative	N3	40	IC
2	negative	negative	negative	N3	24	IC
3	negative	positive	irrelevant	N2	7	N
4	negative	positive	irrelevant	N2	42	N

In pattern 1 we find N1 to be more prominent than N2, but the negative differences of P2P3 and, especially, P1P3 indicate that N3 is most prominent. Analogous arguments hold for pattern 2. Patterns 3 and 4 are exhibited by compounds in which N2 is most prominent, due to a negative P1P2 difference, indicating the prominence of N2 vis-à-vis N1, and a positive P2P3 difference, indicating the prominence of N2 vis-à-vis N3. We can see from the figures, that a non-negligible proportion of 35.2 % of our left-branching compounds (113 of 321) clearly violate the LCPR, 15.2 % at the N-level, 19.9 % at the IC-level.

Let us now turn to the group of right-branching compounds in more detail in order to find out more about the violations among that group. The analysis in section 4.1 indicated that right-branching compounds behave more uniformly according to the LCPR than left-branching compounds as the effect size of the statistical comparison was much stronger for this compound group. Nonetheless, we might also find violations of the LCPR among this group. As violations of the rule we consider all right-branching compounds with highest prominence assigned to N1 or to N3. Whereas highest prominence on N3 would indicate a violation of the LCPR at the N-level, a right-branching compound with highest prominence on N1 would be a violation of the LCPR at the IC-level. Again, we assume that a negative pitch difference indicates right prominence, a positive pitch difference of more than 2 ST indicates left prominence. Table 4 lists the violating patterns for right-branching compounds.

Compounds with negative P2P3 and P1P3 pitch differences exemplify exceptions to the rule at the N-level, since for them N3 is most prominent. Compounds with positive pitch differences throughout violate the LCPR at the IC-level. We find a total of 29.8 % (i.e. 36 out of 121) right-branching compounds that violate the LCPR, with 9.9 % violations at the N-level and 19.8 % at the IC-level.

Is there a difference between left- and right-branching compounds with regard to their conformity to the LCPR? A Chi-squared test revealed that left- and right-branching compounds do not significantly differ in the proportion of violations found for both groups (Yates' Chi-square = 0.94, $p = 0.33$). What is also interesting is the fact that in both groups of compounds we find the same distribution of violations over the two levels. One third of the violations are found at the N-level, while two thirds are found at the IC-level. It is presently unclear why such a distribution would occur.

In sum, our exploration of potential violations of the LCPR has revealed that there seems to be a substantial number of compounds that violate the

Table 4. *Violations of the LCPR, right-branching compounds*

Pattern	P1P2	P2P3	P1P3	Most prominent	# of items	Violation at level
1	positive	negative	negative	N3	7	N
2	negative	negative	negative	N3	5	N
5	positive	positive	positive	N1	24	IC

LCPR, and these violations occur at both IC- and N-levels, and in both left- and right-branching compounds.

5. Discussion

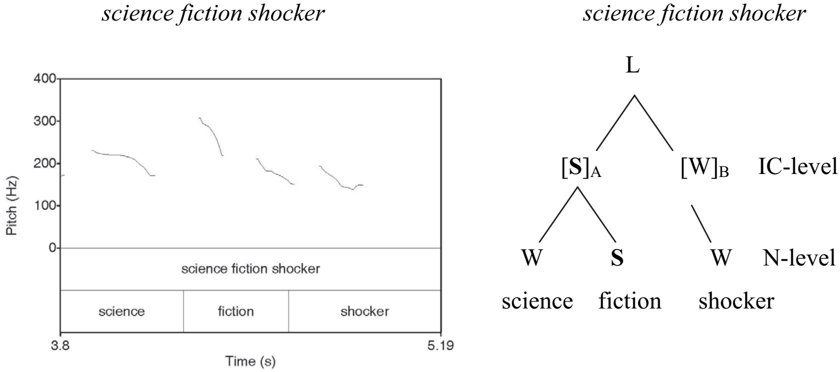
Our analysis of the prominence patterns of triconstituent compounds has provided empirical support for Liberman and Prince's LCPR. Testing the predictions made by the LCPR, we found that left-branching compounds tend to be stressed on N1 whereas right-branching compounds tend to be stressed on constituent N2.

However, as shown in particular in section 4.2, we also found a considerable number of compounds that do not behave in accordance with the LCPR. About one third of both left- and right-branching compounds belong to this ill-behaved group. The result that some left-branching compounds are stressed on N2 is in line with previous findings, for example, by Berg (2008), Kvam (1994) and Giegerich (2008). Left-branching compounds with primary stress on N3 have also been mentioned by some linguists before (e.g. Hayes 1995; Sproat 1994) although these authors classified these structures as phrases. The exceptions found for right-branching compounds also match findings by Berg (2008) and Giegerich (2008) and illustrate that even in the case of a complex head, stress is quite variable. Yet, the question is what causes the violation of the LCPR at the N-level and the IC-level, respectively? Let us first look at the N-level.

5.1. Violations of the LCPR at the N-level

Figure 13 gives the pitch track and the metrical tree for the left-branching compound *science fiction shocker*, which violates the LCPR at the N-level, i.e. it is stressed on constituent N2.[15]

In the example *science fiction shocker*, the violation of the LCPR takes place only within the complex constituent of the compound. Instead of a left-stressed complex constituent, we find a right-stressed NN compound embedded in a larger compound. Thus, in *science fiction shocker* the prominence pattern of the right-stressed NN compound *science fiction* is preserved under embedding, which causes highest prominence on N2. Yet, this violation does not affect the immediate constituent-level of NNN compounds because highest prominence remains within the complex constituent. However, it indicates that the existence of right-stressed NN compounds seems indeed to have an effect on the overall prominence patterns of left-branching compounds, in that those compounds trigger highest prominence on N2. Other examples of this kind from our corpus are *Thanksgíving day*, *grass roóts advocates*, *capital gáins tax* and *home impróvement loans*. According to our



science fiction shocker *science fiction shocker*

Figure 13. *Pitch track and tree diagram for* science fiction shocker

acoustic analysis all of these compounds are clearly stressed on constituent N2, and their complex constituent is also attested as right-stressed in dictionaries. Furthermore, among this subset of violations we find compounds such as *governor-sérgeant appointee, Mattapan-Róxbury area* and *felony-sódomy charges*, whose complex constituents belong to the class of copulative compounds. This class is uncontroversially considered to be right-stressed (e.g. Fudge 1984; Olsen 2000; Plag 2003), and, like in the other cases, their stress pattern is preserved under embedding. The same kind of stress preservation can be found for right-branching compounds with N-level violations (e.g. *state health prógrams, school drug úse, Operation desert stórm*).

In general, it appears to be the case that a large portion of the data can be explained by the fact that, contra the LCPR, a considerable number of the embedded compounds are right-stressed, and that this rightward prominence is preserved under embedding, just like leftward prominence is preserved under embedding according to the LCPR. This finding merits further empirical testing with more carefully controlled data. Let us now turn to the violations at the IC-level.

5.2. *Violations of the LCPR at the IC-level*

We begin with the left-branching compounds. Figure 14 shows the pitch track and metrical tree of the left-branching compound *child care crisis*.[16]

The violation found in *child care crisis* affects the IC-level. Highest prominence is assigned to N3, which is the constituent outside the complex constituent. In this case B is strong at the IC-level although it is not branching. Note that the observed prominence of *crisis* is not due to contrastive stress. For verification, consider the pertinent text, which runs as follows:

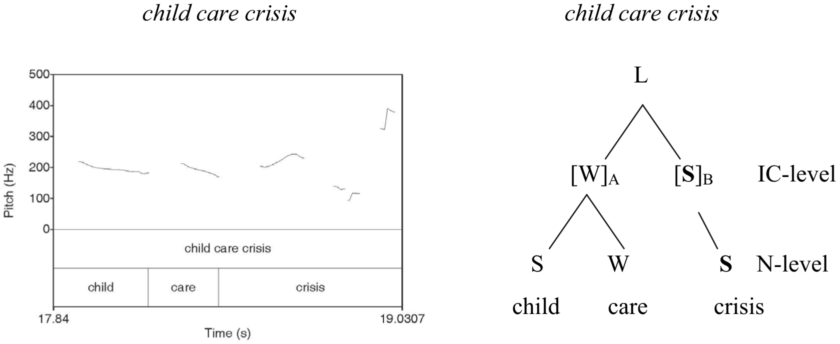


Figure 14. *Pitch track and tree diagram for* child care crisis

> The legislature's Human Services Committee is debating a bill that would require developers to set aside day care space or child care money brth[17] in new buildings in Massachusetts larger than fifty thousand square feet. brth The measure's co-sponsor, Newton representative, David Cohen, says brth with the state on the brink of a *child care crísis* this first step is needed.
>
> (F1AS15P4.txt, our emphasis and stress notation).

An explanation for the violation at the IC-level seems less clear than the one we offered for the N-level violations. Yet, one possible assumption could be that the same factors which are claimed to trigger rightward stress in NN compounds are also operating at the IC-level. What are these factors? The recent literature on this problem discusses three kinds of factor, namely structure, semantics and analogy, of which the latter two seem to be the most significant (Plag et al. 2008; Lappe and Plag 2007, 2008).

In the most recent formulation of an approach referring to structure, Giegerich (2004) proposes that, due to the order of elements, complement-head structures like *trúck driver* cannot be syntactic phrases, hence must be compounds, hence are left-stressed. Modifier-head structures such as *steel brídge* display the same word order as corresponding modifier-head phrases (cf. *wooden brídge*), hence are syntactic structures and regularly right-stressed. The aberrant behaviour of many modifier-head compounds (cf. *ópera glasses*, *táble cloth*) is, according to Giegerich, the result of lexicalization.

The second approach to account for the variability of compound stress assignment makes use of the semantic characteristics of compounds. It has been argued that words with rightward stress such as *Boston márathon, morning páper* or *silk tíe* are systematic exceptions to the compound stress rule (e.g. Sampson 1980; Fudge 1984; Ladd 1984; Liberman and Sproat 1992; Sproat 1994; Olsen 2000, 2001). Although these authors differ slightly in the details of their respective approaches, they all argue that rightward prominence is restricted to only a limited number of more or less well-defined types of meaning categories and relationships (see, for example, Plag et al. 2007, 2008 for empirical evidence). Pertinent examples are the above-mentioned copulative compounds, temporal or locative ones (e.g. *summer níght, Boston márathon*), or causative compounds, whose constituents form a semantic relation that is usually paraphrased as 'made of' (as in *aluminum fóil, silk tíe*) or 'created by' (as in *Shakespeare sónnet*, *Mahler sýmphony*).

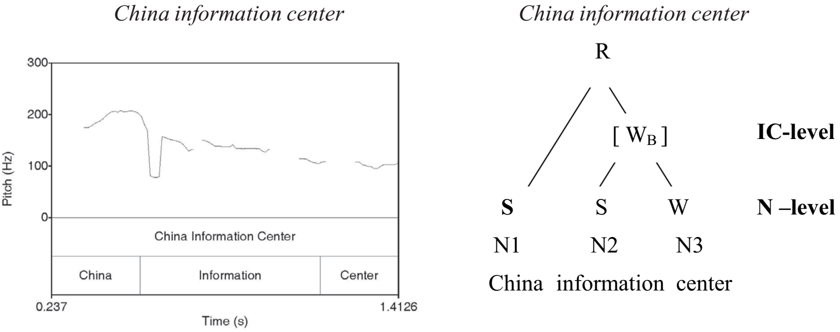
Under the analogical approach (e.g. Schmerling 1971; Liberman and Sproat 1992; Plag 2006; Lappe and Plag 2007, 2008) stress assignment is generally based on analogy to existing NN constructions in the mental lexicon. Plag (2003) mentions the textbook examples of *street* vs. *avenue* compounds as a clear case of analogy. All street names involving *street* as their right-hand constituent, pattern alike in having leftward stress (e.g. *Óxford Street, Máin Street, Fóurth Street*), while all combinations with, for example, *avenue* as right-hand member pattern alike in having rightward stress (e.g. *Fifth Ávenue, Madison Ávenue*).

Among the aberrant cases in our corpus we find indeed a number of triconstituent compounds which show one of the semantic relations assumed to trigger rightward stress in NN compounds. For instance, the compounds *Bay state vóters, Boston area commúnities, Beacon Hill démocrats, nursing home pátient* and *weekend séries* reveal a locative and temporal relationship, respectively, at the IC-level. Furthermore, we detected compounds with the semantic relation IC1 HAS IC2 (e.g. *waste company offícials*, *state lottery offícials*, *oil company exécutive*, *Beacon Hill ínsiders*), which is also one of the semantic relations that was found to trigger rightward stress in NN compounds in the study by Plag et al. (2008).[18] However, as we did not code our data for semantic categories and relations, or for constituent families, a more detailed study is called for to substantiate the hypothesis that the LCPR violations at both IC-level and N-level result from the same mechanisms that trigger rightward stress in biconstituent compounds.

We finally turn to the right-branching compounds that violate the LCPR at the IC-level. Figure 15 shows the pitch track and the metrical tree of the right-branching compound *China information center* which is stressed on constituent N1. In this case the compound has main stress on IC1 although we would have expected rightward stress at the IC-level, i.e. stress on the complex head.

The pertinent transcript runs as follows (the text is given in full):

> At the *Chína Information Center* in Newton, Massachusetts, the big question is what impact forty thousand U.S. educated students will have on China if and when they return. brth The center serves as a home base for exiled students leaders, young leaders who believe they will play a role in a post-Communist Chinese government. [. . .]
>
> (M1BS02P6.txt, our emphasis and stress notation).


China information center

China information center

Figure 15. *Pitch track and tree diagram for* China information center

Again, as for left-branching compounds, the question arises of which factors cause the violation at the IC-level, in this particular example, as well as in general. One possible explanation for some violations might be the influence of "pragmatic interpretive strategies" (Ladd: 1984) on the prominence patterns of compounds. Ladd argues that the head of a compound may be deaccented if it is semantically not very specific. With reference to the complex head *information center* this might indeed be the case, if we assume that the crucial information is conveyed by the constituent on the left, i.e. *China*. The same explanation might be valid for a number of other compounds found among the violations (e.g. *Washington law professor, Superman comic book)*. Although Ladd does not explicitly refer to triconstituent compounds in his discussion, there is no reason why this assumption should not also hold for more complex compounds.

Among the ill-behaved group are also a few compounds whose heads are strongly lexicalized with a high token frequency (e.g. *Fóx network, tráffic headaches, Tíffany network, Mássachusetts congressman, Lógan airport*). Given that items with a higher token frequency are more expectable, hence less informative, than items with lower token frequency, these constructs could also be explained in terms of Ladd's deaccentuation account. Obviously, an account based on informativeness is not easy to test, since the relevant categories are hard to operationalize. Future research is necessary to investigate the potential effect of informativeness using information-theoretically valid measures.

One could of course also argue again that semantic factors play a role. There might be semantic relations or categories that trigger left stress at the IC-level, which would override the potential effect of branching and lead to highest prominence of N1. For instance, Plag et al. (2007) found a particulary strong statistically significant tendency towards left stress for the semantic relation N2 for N1. Support for the idea that this effect may be responsible for some of the LCPR violations comes from Giegerich (2008). He provides some examples of right-branching compounds that are stressed on constituent IC1, namely *tómato green-house*, *gráin store-room, stéel ware-house, ówl nest-box*. All of them can be interpreted as N2 for N1, the semantic relation which triggers leftward stress. With regard to our corpus, this explanation may hold for the compounds *cómmunity meeting hall (* a meeting hall for the community) and *credit scoring system* (a scoring system for credit).

Bringing in semantics may also lead to a complete abandonment of branching direction as a factor in prominence assignment. Thus, one could argue that if the semantic relation at the IC level triggers rightward stress, main prominence on IC2 is not due to branching, but due to the semantics at the IC level. This is in the spirit of Selkirk (1984), who claims that right-branching compounds are right-stressed because the relation between the complex and single constituent is always that of a modifier-head relation (which is taken to trigger rightward stress) but never that of an argument-head relation (which would trigger leftward stress). From recent research (as referenced above) we know, however, that it is only certain semantic relations and categories that favor rightward stress, and not all modifier-head relationships.

Now, among our right-branching compounds we find that a majority of compounds stressed on IC2 exhibit those semantic relations which are claimed to trigger rightward stress in biconstituent NN compounds. Hence, in these compounds, both branching and semantics would favor rightward prominence at the IC level. A list of a few examples is given in Table 5.

Table 5. *Semantic relations at the IC-level for some compounds with prominence on IC2*

Compound	Semantic relation
brick townhouses	IC2 is made of IC1
Iowa cornfield	IC2 is located at/in IC1
corner drug store	IC2 is located at/in IC1
Rockingham horse track	IC2 is located at/in IC1 IC1 has IC2
Yale law school	IC1 has IC2
School drug use	IC2 located at/in IC1
State taxpayers	IC1 has IC2
Roxbury housing project	IC1 has IC2
Hynes convention center	IC2 is named after IC1

To summarize, we find two kinds of violations of the LPCR with left- and right-branching triconstituent compounds. There are left-branching compounds with right-stressed first ICs, which lead to highest prominence on N2, and there are also left-branching compounds with highest prominence on N3. In addition, we find right-branching compounds with right-stressed IC2s and right-branching compounds with highest prominence on N1. These violations strongly indicate that it is not solely branching direction that governs prominence assignment in triconstituent compounds but that other factors seem to play a role as well, in particular semantics and information structure.

6. Conclusion

In this paper we investigated the prominence patterns of triconstituent compounds. We found that the hypothesis we tested turned out to make correct predictions for the majority of the data. Thus right-branching and left-branching compounds generally behave as predicted by the Lexical Category Prominence Rule. However, the investigation of left- and right-branching compounds clearly showed that a considerable amount of compounds cannot be explained by the LCPR. This result is fully in accordance with some previous studies (e.g. Kvam 1990; Berg 2008), which leads to the assumption that prominence assignment must be (also) governed by factors other than branching. Such factors might be the same as those claimed to be responsible for variation in NN compounds.

The crucial task for future research is to devise an account of the stress behaviour of triconstituent compounds that factors in these influences. For example, based on the present findings one could devise experiments in which the factors triggering rightward stress are carefully controlled at both the IC-level and at the N-level. Such experiments could shed light on the question of whether the same factors that trigger right stress in NN compounds also trigger formerly unexpected stress patterns in NNN compounds.

Another important question is of course why one should find a correlation between stress assignment and branching direction in the first place (even if this correlation is not perfect), and a few rather speculative remarks may be in order. Berg (2008), for instance, argues that branching direction is indicative of lexical structure and that stress assignment according to branching direction would be functional for lexical access. This position hinges on research by Cutler and Norris (1988), who found that listeners detected words embedded in nonsense bisyllables more slowly when the bisyllable had two strong syllables than when it had a strong and a weak syllable. In other words, a strong syllable followed by a weak syllable can be used as a cue for a lexical boundary, and hence facilitates lexical access. Berg applies these findings directly to triconstituent compounds and argues that the stress position in such constructions serves as cue in lexical access.

We feel that an explanation along the lines of Cutler and Norris cannot readily account for the correlation of branching direction and stress assignment. First, Cutler and Norris investigated nonsense words and not real speech. While stress may well be used as strong cue to word boundaries in the absence of any other information (semantics in particular), it is unclear how strong such an effect still is if additional information (phonological, morphological, syntactic, semantic, contextual) is available to the listener. Second, although many English words are stressed on the first syllable, there are a great many words that are not stressed on the first syllable, and speakers are therefore well trained to attend to other, more reliable cues. Third, Berg's discussion ignores crucial theoretical insights, especially from metrical phonology. Thus, in compound stress, we are not faced with a distinction between stressed versus unstressed syllables (as in Cutler and Norris's experiment), but with a prominence relation between two or more stressed syllables. It is completely unclear how his explanation would work if this problem was taken into account. Fourth, lexical access to compounds goes hand in hand with lexical access to the constituents that make up the compound (e.g. Libben 2006), and both storage and computation have a say in this process. Viewed from this angle, it is unclear to us how the complexities of lexical access could be facilited by the recognition of the stress pattern, which, in any case, can only be picked up after the last constituent has been phonologically, and perhaps even lexically, processed. Fifth, it is unclear how a perception-based account à la Cutler and Norris (1988) translates to production. What is the role of stress assignment for the speaker?

The only functionality we can see for a correlation of branching direction and stress is not an advantage for lexical access, but (for the listener) an advantage with regard to the computation of the meaning of the whole structure after lexical access, and (for the speaker) an advantage with regard to the mapping of meaning and morphological/syntactic structure. Under such an explanation, apparent mismatches of branching and stress pattern[19] could turn out to be quite functional, because the apparent mismatch may in fact be the straightforward result of, for example, the specific semantics of the embedded complex constituents which influences the stress pattern of that constituent, and thus of the whole compound. At the present stage, however, with our understanding of the different possible stress patterns and the processing mechanisms of triconstituent compounds being rather limited, the proposal of simple functional explanations seems to be premature.

Bionotes

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Notes

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1. The LCPR has found its way also into pertinent phonology and morphology textbooks, such as Giegerich (1992), Spencer (1996), Plag (2003).
2. In the literature on compound stress, there is no unanimity concerning the terminology that is used to refer to the phenomenon at hand. While one group of scholars speaks of 'stress', another group prefers the term 'prominence'. The choice of terms by different authors seems sometimes arbitrary, sometimes dependent on their theoretical assumptions about the place of the phenomenon under discussion in an overall theory of prosodic organization. For the purposes of the present paper such considerations are not at issue and we therefore use both terms more or less interchangeably.
3. See also Giegerich (2004) for an analysis of compound stress along these lines.
4. Selkirk does not explicitly refer to stress in left-branching compounds but from her argumentation regarding right-branching compounds this prediction for modifier-head compounds follows straightforwardly.
5. The discrepancy in the prediction follows from the assumed distinction between compounds and phrases. The LCPR only predicts stress in compounds, and structures with stress on N3 are automatically treated as phrases by Liberman and Prince.
6. See also Plag (2006), and Plag et al. (2008) for recent discussions of this distinction, with similar methodological consequences.
7. Thus it could be argued that *U.S.* is actually a compound itself, which would turn *U.S. district judge* into a four-constituent compound. Although we would not subscribe to such an analysis we wanted to restrict our analysis to items that are as uncontroversial as possible in their status.
8. It is well-known, though not well researched (but see Bauer 1983:103, Kunter 2009), that there is sometimes variation in stress across tokens of the same compound. Taking just the first instance of each compound therefore runs the risk of losing interesting data, as well as losing an opportunity to assess this type of variation. However, we wanted to test the LCPR under its own assumptions, in particular under the assumption that we abstract away from within-type variability. Taking only one token per type has the additional advantage that many variant tokens of a limited number of compounds do not unduly influence the overall distributions. A larger study is certainly called for that tests within-type variablity of compounds.
9. See Plag et al. (2007, 2008) and Sepp (2006) for more discussion and evidence.
10. Although the meaning difference between two interpretations may in fact be rather subtle, the LCPR would nevertheless predict different stress patterns for the two differently branching structures.
11. Difference in semitones = 12*log (left pitch/right pitch)/log2 (cf. e.g. Henton 1989:302)
12. This comparison is analogous to Plag's comparison of left-stressed argument-head compounds vs. right-stressed modifier-head compounds. For triconstituent compounds we

predict leftward stress between constituent N1 and N2 in left-branching compounds and rightward stress between the same constituents in right-branching compounds. Therefore both groups should differ in their P1P2 pitch difference.

13. In these boxplots, the median is indicated by the black dots within the boxes, the boxes show the interquantile range, and the whiskers give 1.5 times the interquantile range in each direction. Dots indicate individual outliers.
14. Note that the plot does not want to suggest that branching-direction is a gradient phenomenon. Rather, the lines that combine the means for the two categories convey a better visual impression of the interaction than different kinds of dot representing the six different means would.
15. In the left panel of Figure 13, there is no pitch curve for the final syllable of *shocker* due to creaky voice on that syllable.
16. In the left panel of Figure 14, the high pitch on the final syllable of *crisis* is an artefact of creaky voice phonation. The first syllable of *crisis* is the most prominent one.
17. The Boston Corpus transcripts use 'brth' to indicate breathing pauses.
18. It should be noted here that for some compounds there is more than one interpretation, as for instance, the compound *nursing home patient* may be interpreted as IC1 HAS IC2 as well as IC2 IS LOCATED IN IC1.
19. These are 'mismatches' only under the assumption that branching and stress generally match in a certain way, an assumption that has turned out to be quite problematic.

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