

Stress Patterns of Complex German Cardinal Numbers

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Abstract

German cardinal numbers show variable stress patterns on the phonetic surface. Former studies showed that these cannot be explained by stress shift. In a combined production and perception study, the hypothesis is tested that German cardinal numbers are of a hybrid phonological nature: sentence medially, they behave like compounds following the CSR, while they behave like phonological phrases following the NSR when occurring phrase finally. The hypotheses were tested and for the majority of cases confirmed.

1. Introduction

German cardinal numbers show variable phonetic surface realisations with regard to their stress patterns. Note that unlike most languages, the phonological structure of cardinal numbers does not follow the order of its numerical representation. This leads to a number realisation for “29” as *neun-und-zwanzig* (= ‘nine-and-twenty’ instead of ‘twenty-nine’ or ‘vingt-neuf’). According to [1], the additive connecting expression *und* is never stressed and rather tends to be reduced in German cardinal numbers. [2] claim that the multiplicative expressions ‘*zig*’ (= ‘times 10’), *hundert* (= ‘times hundred’), *tausend* (= ‘times thousand’) etc. are never stressed. Of course, these descriptions do not account for all stress variations in German cardinal numbers: Even if we deaccent “und”, “zig” etc., there remain several landing sites for stresses, and there exist alternative placements for primary and secondary stresses. These are apparently created by contextual variations. This phenomenon is illustrated in the examples 1-4 (Increased prominence is indicated by capitals and boldcase):

- (1) Ich kaufe **NEUN-und-zwanzig** Eier. (‘I buy nine-and-twenty eggs.’)
- (2) Das macht zwei Euro **neun-und-ZWANZIG**. (‘That makes two Euro nine-and-twenty.’)
- (3) ...Ich zähle **SIEBEN-und-zwanzig**, **ACHT-und-zwanzig**, **NEUN-und-zwanzig**... (‘...I count seven-and-twenty, eight-and-twenty, nine-and-twenty...’)
- (4) Wolltest du **neun-und-ZWANZIG** oder **neun-und-DREISSIG** Rosen? (‘Did you want nine-and-twenty or nine-and-thirty roses?’)

While the stress patterns in (3) and (4) are explicable by an implicit (cf. 3) or explicit (cf. 4) contrastive stress on specific numerical lexemes, (1) and (2) appear to be true phonological alternations.

The possible stress patterns become more variable with increasing complexity of the cardinal number involved

(Possible landing sites for primary and secondary and tertiary stresses are indicated in italics.):

- (5) Wir haben *zwei-hundert-vier-und-dreißig* Erstsemester. (‘We have two-hundred-four-and-twenty first year students’.)

It therefore is expected that there exist alternative possible realizations for the more complex numbers as well.

With the help of our study, we want to explain and predict the various surface realisations as closely as possible. In a first step, some hypotheses predicting the stress alternations are formulated. In a second step, a combined production and perception study is presented evaluating the conditions for the different surface realisations. In a last step, results are discussed and conclusions are drawn for the development of a prediction model.

2. Previous studies

In an earlier study, [3] examined the hypothesis that the alternating surface realisations are the result of phonological stress shift rules. They proposed that the default realization of cardinal numbers can be heard when the numbers are produced in isolation. In this context, lexical stress falls on the final number (*vier-und-VIERzig*). In a context such as (6) a stress shift towards the left edge of the word is expected, because the lexical stress on the number “VIERzig” clashes with the lexical stress of the first syllable “ROsen”. In (7), no such shift is necessary, as there are two intervening syllables between the two syllables carrying lexical stress.

- (6) *vier-und-VIERzig* ROsen → **VIER-und-vierzig** ROsen (‘four-and-fourty roses’)
- (7) *vier-und-VIERzig* VerGISSmeinicht (‘four-and-fourty forgetments’)

However, [3] could not find empirical support for the alternations they predicted. Final stress was constrained to sentence final and focused positions in their data. This is in accordance with other studies on German stress shift: [4] could show stress shift to be an exception rather than a rule in German. We conclude from their study that the alternating surface realisations in numbers are the result of a hybrid morphosyntactic nature of German cardinal numbers. They behave like compounds in a sentence medial position, when they act as quantifiers within an NP. Here, lexical stress falls on the initial element based on the Compound Stress Rule (henceforth: CSR, [5]). In phrase final position, the Nuclear Stress Rule (henceforth: NSR, [5]) places stress on the compound and overrides the compound stress. In these environments, the last number lexeme (the decade) receives

both lexical and phrasal stress. Such a view would lead to stress placements illustrated in Figure 1:

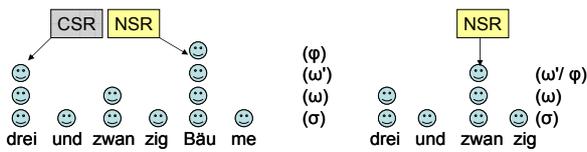


Figure 1: The left metrical grid shows the predicted stress pattern for non-final two-digit numbers (CSR and NSR place their stresses independently), the right grid shows the phrase final stress pattern, where the NSR eliminates the influence of the CSR.

Unlike [3], we believe the CSR-realizations to be the default ones. This additional hypothesis will be tested in the subsequent empirical study as well. For three-digit words, a wide variety of stress patterns are possible in German (cf. example 5)). Our hypothesis for such complex numerals is that they largely mirror the tendencies for two-digit numerals. We therefore expect that in phrase medial position, such numbers receive lexical stress on the leftmost lexeme according to the CSR and secondary stress on the number lexeme in the middle, also based on the CSR. However, in phrase final conditions, the lexical stress should fall on the final — or rightmost — lexeme based on the NSR. Here, secondary stress falls on the first syllable, caused by the CSR, the CSR-effect on the middle lexeme is again overridden. The predicted stress patterns for three-digit numbers are illustrated in Figure 2:

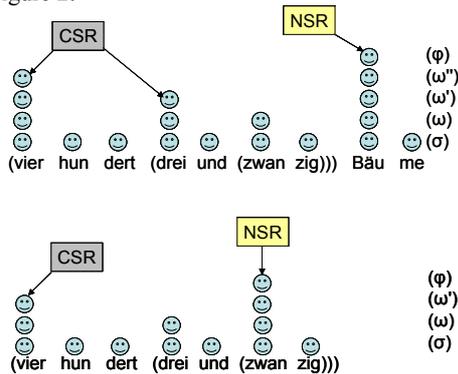


Figure 2: Predicted interactions of CSR and NSR in three-digit cardinal numbers in phrase medial and phrase final position.

3. Production study

The original hypotheses by [3] were tested in a combined production and perception study. The surface realizations of more complex numbers were examined as well. For the study, 26 two-digit and 26 three-digit numbers were selected randomly¹. Each number was then embedded in a longer, semantically meaningful text passage once in each of the following conditions:

¹ The numbers 100-199 were excluded, because there exist different pronunciation variants for them, e.g., "100" can be pronounced as "einhundert" or simply "hundert".

- **Condition 1** (phrase medial position, unfocussed):
Das Jahr hat 52 Wochen und nicht 52 Tage.
(,The year has 52 weeks and not 52 days.)
- **Condition 2a** (phrase final position, progredient):
Merke dir zuerst die Zahl 66,...
(,First keep in mind the number 66,...')
- **Condition 2b** (phrase final position, sentence final):
...und addiere anschließend 526.
(,and then add 526.)

Condition 2 was split in order to examine possible realisation differences between progredient and sentence final phrase boundaries. Condition 1 was introduced in order to find out more about a realisation of numerals that is not influenced by phrase boundaries and thus the NSR. Such a "neutral" (= unfocussed) realisation cannot be studied if the numbers are produced in isolation or in lists, because an interaction with the sentence prosody (including phrasal stress placement or contrastive stresses) can hardly be avoided. The contrast between "Wochen" and "Tage" in our example above attracts strong focal accents on these words and may result in a rather deaccented realisation of the numerals. We expect that despite the lack of pitch accents due to deaccentuation, the relative weighting of primary and secondary lexical stress should remain perceivable.

The text passage consisted of a several stories about a young teacher who is presenting math and spelling problems to her students. In a pretest with two speakers, it was verified that the text passages were not too long or complicated to read out aloud. Numbers were represented as digits in the text – due to their length an orthographical representation would have caused too many reading mistakes. Subjects were instructed that in case of reading mistakes, they should restart the sentence. The text was read by 5 male and 5 female subjects, most of them graduate students of computational linguistics or phonetics. None of the subjects guessed the real purpose of the study. The subjects were recorded in an anechoic chamber. Each session took 15-20 minutes. In order to minimize reading mistakes due to fatigue, the text was split into four passages. In between these passages, different distraction tasks were given (a math problem, a memorization task and a brainstorming task).

4. Perception study

The realizations from the 6 most fluent speakers of the production study were used as stimuli in a perception study. In order to keep the perception experiment within the limits of the listener's ability to concentrate, 6 two-digit and 6 three-digit numbers were selected, for which there existed useful (no hesitations, no pronunciation mistakes) realizations by all six speakers and for each of the three conditions. This resulted in 108 two-digit and 108 three-digit stimuli. The numbers were presented out of context to 15 subjects, all of them advanced students of phonetics or trained phoneticians. The minimum requirement to qualify as a subject was the successful completion of a class of phonetic transcription. This requirement was introduced because earlier studies [4] had shown that phoneticians produce more reliable results in the rating of stress patterns. Due to the preliminary nature of our study, we believed this to be a useful first approach.

Follow-up experiments should definitely be carried out with naïve listeners as well. Due to the large number of stimuli, the perception task was split into two subtests: Subtest 1 contained all of the two-digit numbers, subtest 2 all of the three-digit numbers. Each subtest took 30-45 minutes to be completed. Stimuli were randomized and presented via headphones. The subjects were asked to mark the perceived relative prominence of the different number lexeme on a free grid with the help of a slider in a simple GUI. Subjects were allowed to perceive all syllables as equally stressed or equally unstressed if they were unable to make a decision concerning the stress placement. The slider positions were mapped on a scale of perceived prominence in between 0 and 30 according to [6] but this scale was not visible to the subjects.

5. Results

The perception study resulted in 1512 listener responses for each subtest.¹ In some rare cases, listeners perceived number lexemes as equally prominent. Then, both were counted as carrying lexical stress.

For two-digit numbers, the results show a particular significantly preferred (χ^2 , $df=1$, $p<0.001$) stress pattern for all conditions. In a medial position (= condition 1), lexical stress falls on the left lexeme in accordance with the CSR, in both phrase final conditions (progredient and final, conditions 2a and 2b), perceived stress falls preferably on the right lexeme (decade). It is interesting that this pattern is much more evident before progredient phrase boundaries: Here, 93% of all subjects have a significant (χ^2 , $df=1$, $p<0.001$) preference for the stress pattern in accordance with the NSR, while in sentence final position, only 50% of all subjects showed a significant preference. Figure 3 shows the frequencies for the preferred stress patterns.

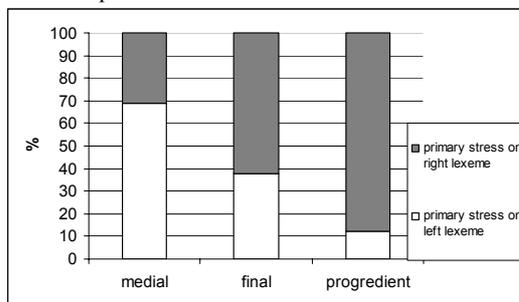


Figure 3: Frequency distribution of different stress assignments for two-digit numbers (percentages) in different contextual conditions.

In addition to the relative stress placements, the median prominence values were compared for the different conditions. The median ratings were then compared for the different conditions (cf. Figure 4) and the result of the frequency analyses could be replicated (Wilcoxon-T, $n=504$; $p<0.001$).

A look at speaker specific patterns showed little variation as well: most speakers agreed in their accent realizations in all conditions.

Summing up the results for the two-digits, the predictions derived from our hypotheses were largely confirmed.

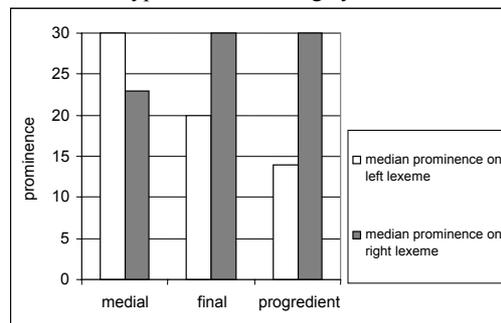


Figure 4: Median prominence ratings for two-digit numbers in the different contextual conditions.

For three-digit numbers, the results show a significantly preferred (χ^2 , $df=1$, $p<0.001$) stress pattern each condition as well. If the first part of the numbers is ignored (the hundreds column) and the remaining two-digit word is looked at in isolation, the results for the two-digit numbers are mirrored as expected: In the phrase final conditions, primary stress falls on the rightmost lexeme, the decade ((vier-hundert-)neun-und-DREISSIG) while in neutral condition, stress falls on the medial position, the unit ((vier-hundert-)NEUN-und-dreißig)). These results match our hypotheses very well. But an interesting alternation occurs on the first number lexeme, the hundreds column: Sentence medially, the majority of the listeners (79%) has a significant (χ^2 , $df=1$, $p<0.001$) preference to perceive lexical stress on the hundreds column as predicted (VIER-hundert-neun-und-vier-zig), while only a small minority perceives lexical stress on the final number. Some of these, however, do not perceive a difference between the accent on the hundreds column and the units column ('VIER-hundert-NEUN-und-vier-zig'). The first element shows further variation between the progredient and the sentence final condition: sentence finally, a majority significantly prefers an accent on the hundreds column (VIER-hundert-neun-und-vierzig) like in the medial condition. At the end of a progredient phrase, a similar majority significantly perceives lexical stress on the last number, the decade (vier-hundert-neun-und-VIER-zig). This result contradicts our hypothesis at least for the sentence final condition: According to the strong influence of the NSR, we did expect lexical stress on the last element. The frequency distributions for primary stress assignment are illustrated in Figure 5.

¹ Two listener's responses were ignored, because immediately after the experiment they claimed to have followed a listening strategy trying to ignore the final lengthening effect during perceptual stress placement.

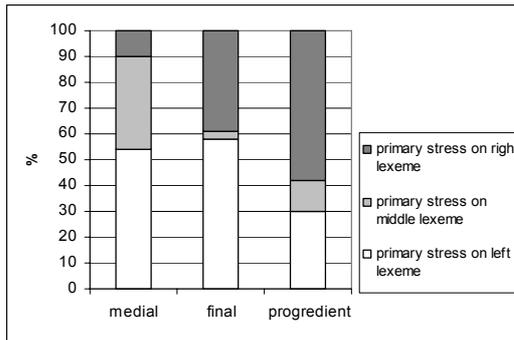


Figure 5: Frequency distribution of different stress assignments for three-digit numbers (percentages) in different contextual conditions.

When comparing median prominence ratings for the three-digit numbers, the results of the frequency analysis are again mirrored. Figure 5 shows the different (Wilcoxon-T, $n=504$, $p<0.001$) prominence patterns. The median of the lexeme that preferably received lexical stress lies at the maximal value of 30 for all conditions. It can be shown quite clearly, that sentence finally the NSR does *not* override the CSR, while it appears to do so at the end of a progredient phrase (cf. Figure 6).

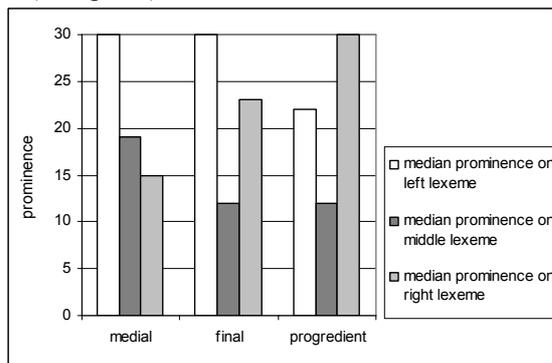


Figure 6: Median prominence ratings for three-digit numbers in the different contextual conditions.

The fact that the median prominence value for the lexeme that was assigned primary stress is maximal in all conditions provides additional support for the validity of our results: subjects were quite sure what they were doing.

6. Discussion

Our hypothesis was that German cardinal numbers show a hybrid stress pattern in phrase medial and phrase final position. This hypothesis could be confirmed. In phrase final positions, the NSR apparently overrides the influence of the CSR, at least for two-digit numbers. Maybe, the CSR influence is lost due to deaccentuation in a stress clash environment. [4] could show that unlike stress shift, deaccentuation is a frequent strategy in German to avoid stress clashes. Here, the NSR assigns both phrasal and lexical stress at the final number lexeme. In three-digit numbers, there exists a very similar tendency: in phrase medial positions, the CSR has no competitor and assigns primary stress on the first lexeme. In phrase final conditions, the NSR tries to assign stress on the last number lexeme, but it has to

compete with the CSR, which has an additional landing site on the first lexeme without causing a stress clash condition. Thus, no deaccentuation needs to take place. The competition is won by the CSR at sentence final phrase boundaries, but the NSR wins at progredient phrase boundaries. Both conditions show a clear influence of both stress assignment rules but it is unclear how this phenomenon can be explained.

7. Conclusions

Both NSR and CSR must be taken into account in order to explain the stress pattern realizations of German cardinal numbers. The NSR treats numbers as phrases and assigns its stress onto the last lexeme of a complex number. The CSR treats numbers as compounds and chooses the first element while placing stress. Obviously, in phrase medial positions, the NSR is not applied. Therefore, we believe that the default, unmarked realisation of numbers can be regarded as governed primarily by the CSR. The CSR can be overridden, if other than the first lexical elements are focused. The true hybrid nature of cardinal numbers occurs in phrase final positions only, where CSR and NSR compete. In two-digit numbers, the NSR overrides the influence of the CSR as expected. In more complex numbers, CSR and NSR can both show their influence in terms of higher prominence ratings. Here, no deaccentuation is evident but the rules have to compete for primary stress assignment. At progredient phrase boundaries, three-digit numbers tend to let the NSR win, while sentence finally, the CSR causes lexical stress in the majority of cases. Before drawing further conclusions concerning this last issue, the experiment ought to be replicated with naïve listeners in order to avoid the postulation of a phenomenon which only exists in the ears of phoneticians.

8. References

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