ACQUISITION OF WORD STRESS IN GERMAN: VOWEL DURATION AND INCOMPLETENESS OF CLOSURE

Katrin Schneider

Institute of Natural Language Processing, University of Stuttgart, Germany
katrin.schneider@ims.uni-stuttgart.de

ABSTRACT

This paper presents the results of a study concerning the acoustic correlates of contrastive word stress in bisyllabic and trisyllabic German words, produced by four children aged 2;3 to 7;3 and their mothers. We found that German children of that age are certainly able to produce contrastive word stress and that vowel duration is the most reliable correlate of word stress in the target words, independent of the position of the vowel within the word. Furthermore, we found the voice quality parameter *incompleteness of closure* most uniformly used by the mothers to mark word stress while the children are on different acquisition stages for this parameter.

Keywords: language acquisition, prosody, word stress, acoustics, voice quality

1. INTRODUCTION

Research in the area of prosody perception and prosody production has received more and more attention, for both adult and child language. Infants not only have to be sensitive to their native language's sound organization, its phonotactic structure, and its word structure in order to segment words in fluent speech [11], but they also rely on the prosodic characteristics of their native language to infer its syntactic properties [3]. By 9 months of age, infants show a selective preference for stress patterns of their native language [4]. Many speech perception studies found that infants store specific information about voices and the words which they are exposed to. By using the input from their surroundings, especially from their parents, children establish expectations about the typical patterns of prosodic variations of utterances and words in the ambient language. They obtain sufficient exemplar variance to develop language specific generalizations about the distribution of values in the auditory dimensions of the phonetic space [2]. The relationship of the phonetic cues to the hierarchical prosodic and intonational representation must be learned for each individual language [6].

In this study, we analyzed spontaneous target word productions of four children and their mothers while they performed a special playing task. By the use of artificially constructed names for animal toys that are geared to the typical phoneme sequences in the production of German infants we guarantee that the input for the stress patterns of these target words only comes from their mothers. We therefore analyzed only these target words for both, mothers and children, and compared the obtained results with respect to the use of word stress parameters. The productions were recorded during several sessions over the course of at least one year. Our hypothesis is that children adopt the features that their parents use to indicate word stress, and that they probably start with the most saliently presented parameter they can find. Parameters that need a closer analysis of the speech sample will be noticed later and then also used to indicate word stress.

2. METHOD

2.1. Participants

The data reported here are part of a larger investigation of children's acquisition of stress. We present the data produced by four children (Table 1) and their respective mothers during a period of at least one year. All children live in monolingual German speaking families and had no prenatal, sensory, developmental, or hearing problems. The recordings were made at their homes. As the boys are brothers there are only recordings of three mothers.

Table 1: Participant information (children only).

child	age range	# sessions	total length
girl 1	2;3 to 3;2	5	225 min
girl 2	4;11 to 6;8	5	65 min
boy 1	4;1 to 7;3	14	110 min
boy 2	2;5 to 5;1	13	105 min

2.2. Stimuli

According to the TAKI task design proposed by Allen [1], we created five pairs of animal toys, and the names within each pair differ only in the position of word stress. These names were the target

words in our study and the participants should use them to refer to the animal toys during the recordings. The target words (Table 2) are bisyllabic or trisyllabic words that consist of consonant-vowel (CV) syllables and contain only speech sounds that are acquired as the first ones by German children: the vowels /a i o/ and the consonants /b d m n/. The CV syllables are phonetically similar to the reduplicated babbling and to a child's first words.

Table 2: Animal toy pairs and their names with contrastive stress used in the TAKI task.

Animal toy 1		Animal toy 2	
brown bear	['bimo]	polar bear	[bi'mo]
big zebra	['nami]	small zebra	[na'mi]
otter	['doba]	badger	[do'ba]
big tiger	['midano]	small tiger	[mida'no]
flying eagle	['badoni]	standing eagle	[bado'ni]

In this contrastive stress condition, stressed and unstressed vowels can be compared in identical segmental contexts. Both stress positions in the target words are possible stress patterns in German, although stress on the second or third syllable is much less common than stress on the first syllable.

2.3. Acoustic measurements

All recorded utterances were annotated on the segmental and word levels by two trained labellers. The absolute duration, F_0 contour, the first four formants, and root mean square (RMS) intensity of each stressed and unstressed target vowel were measured. Voice quality parameters were estimated from their acoustic correlates based on amplitude and frequency measurements at harmonic spectral peaks [10]. The following voice quality parameters were extracted: *open quotient*, *glottal opening*, *skewness*, *rate of closure*, *completeness of closure* and *incompleteness of closure*. All measurements were made at five relative temporal positions within each target vowel (at 10%, 30%, 50%, 70% and 90% of the total vowel duration) to capture parameter changes over the duration of the speech sound.

2.4. Data preparation

2.4.1. Restrictions

A closer inspection of the recorded data showed that most of the vowels in medial position in the trisyllabic words, which are always unstressed, were reduced to [ə]-like productions of the target vowel. We therefore decided to restrict our analyses to the vowels appearing in the first and in the last syllable of the target words. Thus, only full vowels produced in stressed positions were compared to full vowels produced in unstressed positions.

2.4.2. Relative stress parameters

In previous analyses we compared unstressed vowels with stressed vowels over all target words. But stress is relative, it only emerges in polysyllabic structures. In the present study, we additionally considered parameter differences between the stressed and the unstressed (full) vowel of each word. The results of these analyses are taken as parameters indicating word-internal stress.

2.4.3. Statistical analysis

The SPSS program version 12.0 was used for statistical analysis. An univariate ANOVA analysis was carried out for each parameter and each participant separately, with the parameter as the dependent and *word stress* as the independent variable, followed by a posthoc test (Waller-Duncan).

3. RESULTS

Most of the analyzed parameters turned out to be vowel-specific as well as speaker-dependent. We therefore analyzed both raw and z-transformed parameter values. For each parameter, the z-transformation eliminates vowel-specific effects by replacing raw values by their difference to the vowel-specific mean and dividing this difference by the vowel-specific standard deviation of this parameter.

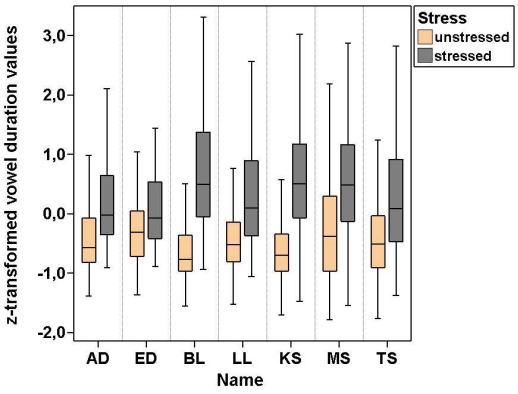
In this paper we only report and discuss the results for the parameters vowel duration and *incompleteness of closure*.

3.1. Vowel duration

Vowel duration has been shown to be the most reliable cue for word stress in German adults [5]. In our data, there were slight vowel-specific duration differences between the three analyzed vowel qualities. However, all children and all mothers produced stressed vowels significantly longer ($p < 0.001$) than unstressed vowels (Figure 1). This effect is observed for all vowels pooled, for each vowel phoneme separately, and also for the position of the vowel phoneme in the word. We also found evidence for the lengthening of word-final syllables, but the strength of this final lengthening differs between speakers.

Our results show strong evidence that vowel duration is a reliable correlate of word stress in German adults and in children as young as 2;3 years of age. We also found that the total duration of vowels decreases with increasing age of the children, but the older the children are, the lower is the decrease of the vowel length. This supports the hypothesis that

Figure 1: Z-transformed vowel duration values of stressed and unstressed vowels for children (ED, LL, MS, TS) and their mothers (AD, BL, KS).



children converge to adult-like usage of the vowel duration parameter.

3.2. Incompleteness of closure

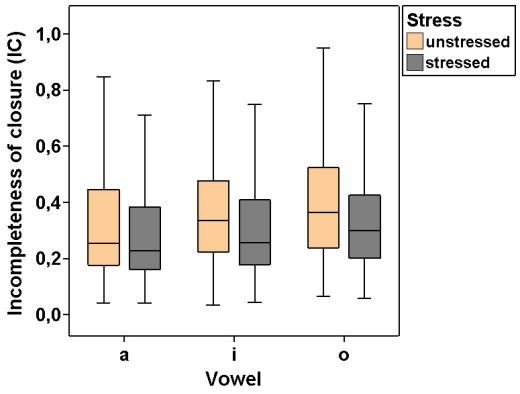
Sluijter found that stressed vowels show higher values of the voice quality parameter *completeness of closure (CC)* corresponding to a greater F1 bandwidth *(B1)*, suggesting that they have a greater glottal leakage than unstressed vowels [9]. In our data we found that *CC* was not correlated with word stress and it seemed to be vowel dependent. Therefore, we used a normalized version of this parameter, *incompleteness of closure (IC)* [8], in which the influence of the first formant on the *CC* values is minimized (Equation 1).

$$(1) \quad IC = CC/F1 = B1/F1$$

Our results indicate that the parameter *IC* is a good indicator for word stress in German, at least for adults. All mothers demonstrate higher z-transformed *IC* values for unstressed vowels compared to stressed ones, indicating that unstressed vowels are produced with a greater glottal leakage than stressed vowels. However, their raw data for this parameter show slight individual differences. While AD always produces higher *IC* values for unstressed vowels compared to stressed ones, BL displays almost no difference for /i/ vowels, and KS displays almost no difference for /i/ and /a/ vowels. Furthermore, BL produces higher *IC* values for stressed /o/ vowels compared to unstressed ones.

The children seem to be on different stages of acquiring this stress parameter. The oldest child MS already uses *IC* to mark stress, additionally to the parameter vowel duration. His data show adult-like behavior for the z-transformed well as for the raw *IC* data, with higher values for unstressed vowels compared to stressed ones (Figure 2).

Figure 2: IC parameter values for all target vowels produced by child MS.



The youngest child has acquired the use of this parameter only for the vowel /i/. The two other children produce adult-like *IC* values for one or two vowels correctly, but they do not yet show this tendency in the z-transformed *IC* values.

4. DISCUSSION

The speech production data analyzed in this study provide clear evidence that children at the age of 2;3 are able to produce contrastive word stress. Vowel duration seems to be the first and most robust correlate of word stress in German. All subjects in our study used vowel duration to differenciate between stressed and unstressed vowels. In the absence of strong reduction effects as a function of stress in full vowels, vowel duration is one of the most salient cues for syllabic stress in German and may thus be implemented and used consistently even by young children. The analysis of the difference between the first and the last vowel in a word revealed the same results. Here we found that stressed vowels in the last position in a word are additionally lengthened which corresponds to the well-attested word final lengthening effect.

We also found strong evidence that vowel duration is not the only acoustic correlate to mark word stress in German, as already proposed by other researchers. The parameter *incompleteness of closure*, a F1-normalized version of the well-established *CC* parameter, turned out to be a good cue for word stress in German adults. All three mothers demonstrate higher z-transformed *IC* values for unstressed vowels compared to stressed ones, while the children were at different acquisition stages for this stress-related parameter, depending on their age. *IC*

expresses the degree of glottal leakage. The higher the *IC* value, the greater the glottal leakage, and according to our results, unstressed vowels show a greater glottal leakage than stressed ones. This corresponds to the original hypothesis of Sluijter [9], even though her results did not confirm it. We assume that the effect we found may be caused by the increased subglottal pressure with which stressed vowels are produced. Due to higher subglottal pressure the air flows faster through the vocal folds, which results in a greater Bernoulli force. This is responsible for the glottis being more completely closed during the production of stressed compared to the production of unstressed vowels. However, the differences in the behavior of the raw *IC* values between the mothers and vowel qualities have to be further analyzed. Our hypothesis is that the age differences between the children might explain these discrepancies. The child of AD was the youngest one in this study, and therefore, AD might have used a higher degree of child-directed speech when talking to her daughter than BL and KS when talking to their children. Child-directed speech is known to be more accurately produced than adult-directed speech. In child-directed speech, the *IC* parameter might be used to mark stress additionally to other parameters. This redundancy in marking stress might simplify the recognition of stressed syllables in words for young children, and this might influence the word stress acquisition process. By contrast, the older children of BL and KS should have learned already how to produce word stress correctly. Therefore, their mothers have possibly already reduced the degree of child-directed speech, i.e. the redundancy in marking words stress, and this might result in a more speaker-specific use of the *IC* parameter as a stress marker. This has to be analyzed further in additionally child data as well as in adult-directed speech.

5. CONCLUSION

Vowel duration is the main correlate of word stress in German, with stressed vowels having longer durations than unstressed vowels. It seems to be the first correlate children rely on, because human hearing is sensitive for time differences. This most salient correlate of word stress is already adopted by the children in this study to mark stress.

Incompleteness of closure appeared to be a good cue for word stress in adults with higher z-transformed *IC* values for unstressed vowels compared to stressed ones. This parameter has already acquired by the oldest child in our study while the others still seem to try to find out its appropriate use.

As our data show, there are stress marking differences between adult speakers. However, our results also indicate that when z-transformed values are used for duration and *IC*, a consistent separation between stressed and unstressed vowels is found. The parameters that mark stress may change during language acquisition, especially when the children are exposed to more speakers.

These results support our hypothesis that children adopt the parameters that their parents use, applying the most saliently presented parameter first.

6. Acknowledgements

This study was carried out as part of the project *An exemplar-theoretic model of the acquisition of acoustic correlates of stress* funded by the German Research Foundation (DFG Grant MO 597/1).

7. REFERENCES

[1] Allen, G. D. 1981. Development of prosodic phonology in children's speech: Further evidence from the TAKI task. In: Dressler, W. U., Pfeiffer, O. E., Rennison, J. R. (eds) *Phonologica 1980, Insbrucker Beiträge zur Sprachwissenschaft* 36, 9–14.

[2] Beckman, M. E. 2003. Input representations (Inside the mind and out). In: Garding, G., Tsujimura, M. (eds), *WCCFL 22 Proceedings*. Somerville, MA: Cascadilla Press, 70–94.

[3] Christophe, A., Gout, A., Peperkamp, S., Morgan, J. 2003. Discovering words in the continuous speech stream: the role of prosody. *J. Phonetics* 31, 585–598.

[4] Curtin, S., Mintz, T. H., Christiansen, M. H. 2005. Stress changes the representational landscape: evidence from word segmentation. *Cognition* 96, 233–262.

[5] Jessen, M., Marasek, K., Schneider, K., Claßen, K. 1995. Acoustic correlates of word stress and the tense/lax opposition in the vowel system of German. *Proc. 13th ICPhS* Stockholm, 4, 428–431.

[6] Pierrehumbert, J. B. 2003. Probabilistic Phonology: Discrimination and Robustness. In: Bod, R., Hay, J., Jannedy, S. (eds), *Probabilistic Linguistics*. Cambridge, MA: MIT Press.

[7] Pierrehumbert, J. B. 2003 Phonetic diversity, statistical learning and acquisition of phonology. *Language and Speech* 46 (2–3), 115–154.

[8] Pützer, M., Wokurek, W. 2006 Multiparametrische Stimmprofildifferenzierung zu männlichen und weiblichen Normalstimmen auf der Grundlage akustischer Analysen. *Laryngol Rhino Otol* 85, 1–8.

[9] Sluijter, A. M. C. 1995 *Phonetic correlates of stress and accent*. PhD Thesis, University of Leiden.

[10] Wokurek, W., Pützer, M. 2003. Automated corpus based spectral measurements of voice quality parameters. *Proc. 15th ICPhS* Barcelona, 2173–2176.

[11] Zamuner, T. S., Gerken, L., Hammond, M. 2004. Phonotactic probabilities in young children's speech production. *J. Child Language* 31, 515–536.