Speech segmentation is modulated by peak alignment: Evidence from German 10-month-olds

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Abstract

In two headturn preference experiments, we tested whether German infants' speech segmentation skills are sensitive to the position of the pitch peak relative to the stressed syllable. Specifically, we compared target words with medial-peak accents (where the pitch peak is aligned with the stressed syllable, i.e. H* accents) and early-peak accents (where the pitch peak is early with respect to the stressed syllable, i.e. H+L* accents). Such differences in accent type signal mostly pragmatic distinctions in German, such as the difference between contextually new and recoverable information. We familiarized infants with target words produced with one of the two intonation conditions; target words were embedded in sentences. We measured looking times to lists of trochaic part-words that were either embedded in the target words or were novel to them. Results showed a novelty effect only in the medial-peak condition, suggesting that German infants at 10 months of age are very sensitive to pitch information for segmenting running speech.

Index Terms: speech segmentation, pitch, metrical prominence, headturn preference procedure, German

1. Introduction

The ability to segment units from continuous speech is a vital skill for infants to build up their mental lexicon. Research has shown that the segmentation skills in the second half of the first year of life correlate positively with later vocabulary size [1, 2]. The focus of our investigation is on infants' use of metrical stress for segmentation. Previous findings suggest that stressed syllables are preferred word onsets for infants whose mother tongue is a stress-timed language (English [3, 4], German [5], Dutch [6]), but not for infants who are exposed to syllable-timed languages such as French [7]. Although the exact timeline has not been determined yet, it seems that infants shift their attention from statistical to prosodic cues and that by 9 months of age stress cues outweigh distributional cues in segmentation [8]. In stress-timed languages, metrical prominence is generally signaled by a wide variety of acoustic cues: Stressed syllables are longer and louder than unstressed syllables [9, 10], they are produced with increased vocal effort [11] [see 12 for an overview] and often have more peripheral vowel qualities [13]. When stressed syllables additionally receive phrase-level prominence (pitch accents), they are additionally produced with audible pitch movement. However, in intonation languages, the actual type of pitch accent (and hence the alignment of the pitch peak with regard to the stressed syllable) can vary. For instance, the pitch peak can be early, medial or late with respect to the stressed syllable, resulting in distinct accent types [14, 15]. These are described as H+L*, H* or L*+H in the framework of autosegmental metrical phonology [16, 17]. Factors that determine the realization of pitch accents are, among others, utterance position (prenuclear accents are realized with later peaks than nuclear accents, cf. [18]) as well as the information status of the accented referent (non-identifiable referents are preferably associated with medial-peak accents and identifiable referents with early-peak accents, cf. [19]) and information structure (new information is associated with medial-peak accents, inferable information with early-peak accents, cf. [14]). Hence, while a prominence-lending pitch movement in general is a salient cue for metrical stress, the exact position of the pitch *peak* is not a reliable indicator for the position of the stressed syllable in a given word. It must be pointed out that the distinction between early, medial and late pitch peaks is not only signaled by the position of the pitch peak but also in the duration and intensity distribution over the stressed and neighboring unstressed syllables [20]. Specifically, in early-peak accents, the contrast in duration and intensity between the pre-accented (high-toned) syllable and the accented (low-toned) syllable was reduced compared to medial-peak accents. [21] further showed that listeners also use duration and intensity for pitch accent type interpretation. These changes in the intensity and duration distribution suggest that it is more difficult to identify the stressed syllable in early-peak accents than in medial-peak accents. In the present study we investigate if peak alignment affects German 10-month-old infants' segmentation of trochaic part-words (which are salient to young infants) as a function of peak position (early vs. medial peak accents).

High pitch may play a crucial role in segmentation as infants are highly sensitive to pitch information. Specifically, they show a strong listening preference for f0-patterns in infant-directed speech over amplitude and duration patterns [22] and the preference for high pitch and expanded melodic contours is present very early in infancy [23-25]. [26] suggest that this early sensitivity to pitch information might be caused by its phonetic salience and by its distribution across languages. Regarding salience, [27] hypothesize that acoustic salience affects speech perception and infants indeed seem to be especially salient to pitch contrasts, even earlier than to other acoustic features, such as duration [28]. Regarding the distribution of pitch contrasts, [29] claims that melodic contours are present in all languages, either in form of lexical tone, lexical pitch accent or intonation. It has been shown that such common and salient acoustic distinctions as falling vs. rising pitch contours are discriminated early in infancy [26].

Previous segmentation studies have not manipulated peak alignment when familiarizing infants with test words. It can be assumed that the infant-directed speech samples used in these studies have a high proportion of medial-peak accents [30], but there is not enough information in the literature to know whether peak alignment modulates infants' ability to segment words or part-words that start with metrically strong syllables. In the present study, we used the headturn preference procedure [3] with a familiarization phase, in which infants hear two out of four possible passages containing the target words. In the test phase, infants listen to lists of isolated words, half of which already occurred in the familiarization

phase and half of which were novel to the infants. The crucial manipulation was the intonational realization of the target words in the familiarization phase: In Experiment 1, the target words were presented with a medial-peak accent, in Experiment 2, they were presented with an early-peak accent. We hypothesize that infants associate high pitch with metrical prominence and hence show different looking times to familiar and unfamiliar test lists only in the medial-peak condition and not in the early-peak condition.

2. Experiment 1

Experiment 1 investigated whether infants are able to segment embedded trochees from continuous speech when the stressed syllable carries the pitch peak. The target words were presented with a medial-peak accent in the familiarization phase. This is the intonational realization that was most likely used in earlier segmentation studies [3] and we expect to see differences in looking times to familiar and unfamiliar part-words. The target words were all trisyllabic with penultimate stress. This word-prosodic structure was chosen as it allowed us to present the pitch accent on the target word in both intonation conditions (in disyllabic trochaic words, the pitch peak would have been placed on different other words in the early-peak condition, as the target words were presented within whole sentences in the familiarization phase). The trochaic part of the target words (i.e., the last two syllables) served as test words, since infants are very good at segmenting trochees from running speech (see Introduction). Thus, compared to other segmentation studies in which infants were tested on their ability to detect trochees in fluent speech (e.g., [2]), the task demands are more challenging here: Since infants have to extract *embedded* trochees, they cannot rely on acoustic cues to word onsets, and statistical co-occurrences are not helpful either in that they would suggest to extract the complete trisyllabic target word. While the lexical activation of embedded words in adult listeners (e.g., *date* from *sedate* or *bone* in *trombone*) is often disputed [31], the task is different for young infants who are not affected by lexical competition (and inhibition) in the same way as adults are.

2.1. Methods

We conducted a headturn preference study, in which infants were familiarized with target words that were embedded in sentences (see [3]). In the test phase, infants heard word lists consisting of isolated disyllabic trochees that were either part-words of the target words in the familiarization phase or not.

2.1.1. Participants

We tested 21 infants between 37 and 41 weeks from monolingual German-speaking homes and who had not been exposed to languages other than German. All infants were born full-term. For the analysis, we could only include those 16 infants (7 male, 9 female) who finished the familiarization phase and all 12 test trials. They had an average age of 38.9 weeks (SD = 1.26 weeks). Parents were reimbursed for public transport fees and received a small present for the child.

2.1.2. Materials

We chose four low-frequency trisyllabic words (less than 0.1 occurrences per million in the CELEX word form dictionary, cf. [32]) with open syllables as target words (*Kanone* [kaˈnoːnə], 'cannon'; *Lagune* [laˈguːnə], 'lagoon'; *Kasino* [kaˈsiːno], 'casino'; *Tirade* [tiˈʁaːdə], 'tirade'). All were stressed on the second syllable. Note that in all these target words, the unstressed initial syllable is not reduced to [ə] but produced with a full vowel. For each target word we constructed six carrier sentences, such that the target word appeared in different lexical contexts and different sentence positions (twice each in sentence-final position, four times early in the sentence following an article or prenominal adjective). We used naturally produced auditory stimuli in our experiments since the perception of stress is influenced by a variety of acoustic cues that are distributed over the stressed and neighboring unstressed syllables [e.g., 33]. A native female speaker of German recorded the 24 target sentences with a medial-peak accent on the target words. To achieve equally salient f0-movements across target words, the average f0-excursion was matched across the four sets of target words (average f0-excursion was 9.34st, SD = 1.51st). The pitch contour of an example sentence is provided in Figure 1.

The four test words consisted of the second and third syllable of the target words: [ˈguːnə] (taken from *Lagune*), [ˈsiːno] (taken from *Kasino*), [ˈnoːnə] (taken from *Kanone*) and [ˈʁaːdə] (taken from *Tirade*). These disyllabic trochees were recorded approximately 30 times. For the experiment we chose 15 items of each disyllable, such that the average f0-excursion of the pitch fall and the average duration did not differ across test words (average f0-excursion = 10.0st, SD = 1.8st, average duration = 791ms, SD = 72ms). Two consecutive tokens in the test lists were separated by 800ms silence.

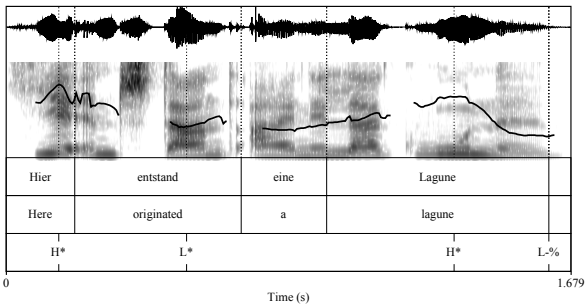

Figure 1: *Example pitch track of a target sentence in the medial-peak condition (f0-range is shown between 100 and 300Hz).*

2.1.3. Procedure

Half of the infants were assigned to the *Kanone* and *Tirade* familiarization trials and the other half to the *Kasino* and *Lagune* familiarization trials. All infants listened to three randomized repetitions of the four test lists (twelve test trials in total). Infants were tested in a three-sided experimental booth at the University of Konstanz. The infants sat on a caregiver's lap. The caregivers wore headphones and did not hear the auditory stimuli the infants were exposed to. Each trial started with a green blinking light at the center of the screen. As soon as the infant oriented towards the center light, a red light to the right or left of the child started blinking. When the infant turned his/her head towards the sidelight, an auditory word list started playing. It played as long as the infant oriented towards this side. If the child looked away for more than 2 seconds, the next trial started. In the familiarization phase, the two passages were presented randomly from the left or the right side until the child had

listened to each of the two paragraphs for at least 45 seconds. In the test phase also, the word lists played randomly from the left or the right side. Looking times were coded online by an experimenter who monitored the child via a video camera and controlled the experiment. The experimenter wore headphones and was not aware of the condition that was played (familiar or novel word list). Prior to testing, parents filled in a questionnaire regarding the infant's language background. The experimental session lasted approximately 5 minutes.

2.2. Results

Looking times in seconds were averaged by familiarity condition for each infant. Log-normalized looking times were analyzed using linear-mixed effects regression models with *familiarity* (familiar vs. novel) as fixed factor and *participants* and *lexicalization* as crossed random factors, allowing for random adjustments of intercepts and slopes for within-group factors [34, 35]. Data points with residuals beyond 2.5 SD of the mean were removed and the model was refitted. p-values were calculated on the basis of model comparisons, using the anova()-function in R [34]. In other words, only when a model with a given main effect improved compared to a simpler model without that effect, the main effect was considered to be significant. Results showed a significant effect of *familiarity* (ß = 1.13, SE = 0.05, t = 2.3, $p < 0.05$), see left-hand bars in Figure 3. Participants fixated on average 1.1 seconds longer to novel test lists (9.3 sec) than to familiar ones (8.2 sec).

2.3. Discussion

Participants looked significantly longer to the novel than to the familiar word lists, suggesting that they were able to segment the trochaic part-words from the trisyllabic words that were used in the familiarization phase. German 10-month-olds can hence segment trochaic syllable sequences from fluent speech even if they are embedded in trisyllabic carrier words, and thus contain neither probabilistic nor acoustic cues to word onsets. Our findings replicate earlier studies on the metrical segmentation strategy in German and English [3-5]. Importantly, we found evidence for segmentation with familiarization and test stimuli that had comparatively small f0-excursions. This suggests that infants are able to segment strings from fluent speech even when exposed to adult-directed speech.

3. Experiment 2

Experiment 2 examined whether a misaligned pitch peak affects infants' segmentation of embedded trochees.

3.1. Methods

3.1.1. Participants

Another group of 19 infants took part in Experiment 2. They fulfilled the same criteria as the infants in Experiment 1. The data of 16 infants could be analyzed (9 male, 7 female, mean age = 38.7 weeks, SD = 1.18). There was no significant difference in age across experiments ($t(30) = 0.3$, $p > 0.7$).

3.1.2. Materials

The four test words were identical to Experiment 1. The same speaker as in in Experiment 1 recorded the 24 sentences again, this time with an early-peak accent on the target word (Fig. 2).

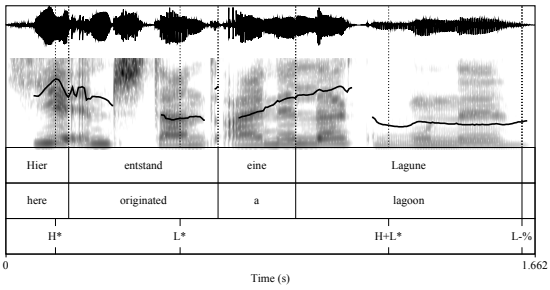

Figure 2: *Example pitch track of a target sentence in the early-peak condition (f0-range is shown between 100 and 300Hz).*

The target sentences were recorded until the productions did not differ from the recordings in the medial-peak condition for Experiment 1 in terms of f0-excursion of the pitch fall, total duration of the target word, the duration of the stressed syllable and the onset consonant of the stressed syllable (mean values are shown in Table 1). Also, the intonation conditions did not differ with respect to the spectral realization of the vowels in the first and second syllable (measured in terms of the Euclidian distance in the F1/F2 space between a particular vowel and the average over all 15 [ə]s in the target words, see (1)).

$$(1)\ \sqrt{(F1_{vowel} - F1_{[ə]})^2 + (F2_{vowel} - F2_{[ə]})^2}\ ).$$

Yet, since the target words were all naturally produced, there are some differences in the materials of the two experiments, mirroring the effects of early- and medial-peak accents described in [20].

3.1.3. Procedure

The procedure was the same as in Experiment 1.

3.2. Results

Looking times were analyzed in the same way as for Experiment 1. Results showed no effect of familiarity ($p > 0.8$), see right-hand graphs in Figure 3.

To statistically corroborate the differences across experiments, we calculated a single linear mixed effects regression model with *intonation condition* (early vs. medial) and *familiarity* as fixed factors and *participants* and *lexicalization* as crossed random factors. The results of this model showed no main effects, but a significant interaction between *intonation condition* and *familiarity* (ß = 0.16, SE = 0.08, t = 2.2, $p < 0.05$).

3.3. Discussion

Looking times did not differ significantly for familiar and unfamiliar disyllables in Experiment 2, in which high pitch was misaligned with the stressed syllable. This suggests that in this intonation condition infants were not able to segment the part-words starting with a stressed syllable. Taken together, the results of the two experiments indicate that trochees could only be successfully extracted from the speech stream when the pitch peak was aligned with the stressed syllable but not when the peak preceded the stressed syllable.

Table 1. *Acoustic realization of target words in the familiarization phase for both intonation conditions.*

Acoustic variable	medial-peak condition	early-peak condition	p-value (paired t-test, df =23)
F0-excursion of the pitch fall	9.3st	9.6st	n.s.
Duration of 1st, unstressed syllable	182ms	193ms	$p < 0.005$
Duration of 2nd, stressed syllable	253ms	256ms	n.s.
Duration of onset consonant of 2nd, stressed syllable	81.3ms	80.6ms	n.s.
Intensity in middle of initial vowel	67dB	66dB	n.s.
Intensity in middle of stressed vowel	71dB	64dB	$p < 0.001$
Euclidean distance of 1st vowel from [ə]	293.3Hz	307.8Hz	n.s.
Euclidean distance of 2nd vowel from [ə]	837.9Hz	737.7Hz	n.s.

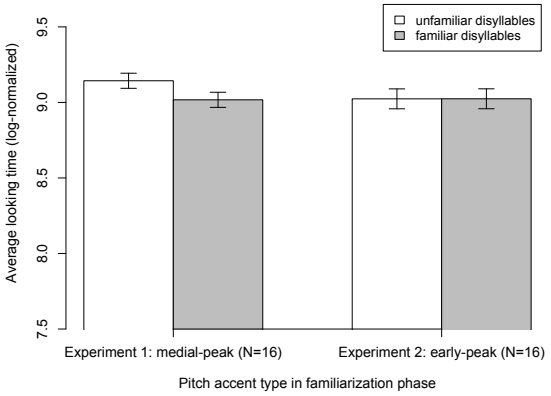

Figure 3: *Average looking time in the medial- and early-peak condition split by familiarity. Whiskers represent standard errors*

4. Discussion and Conclusion

The present study shows that German infants at 10 months of age are able to segment trochaic part-words from trisyllabic target words. However, this is only possible when the familiarization phase provides target words in which the pitch peak is aligned with the stressed syllable (medial-peak condition in Experiment 1) and not when the peak precedes the stressed syllable (early-peak condition in Experiment 2). We see four possible explanations for this finding. First, under the assumption that German 10-month-olds treat stressed syllables as preferred word onsets [36], stress perception appears to be partly linked to high pitch. When the stressed syllable carried a low tone, the segmentation of the trochaic part-words failed. This may be interpreted as an effect of cue strength, in analogy to findings showing that infants are able to distinguish different phrasings only when the prosodic phrase boundary is signaled by phrase-final lengthening and pitch movement, but not, when one of these cues is missing [37]. Second, recent research within the framework of the iambic/trochaic law [38, 39] showed that Italian infants at 7 months group high-low sequences as trochaic patterns while ignoring information on duration [28], suggesting that intonation may be a stronger cue to metrical stress than other stress cues. Third, high-pitched syllables may be likely word-onset markers per se, irrespective of their perceived metrical prominence. Fourth, our effects may not be related to the acoustic salience of pitch at all but may be explained in terms of frequency of occurrence. In infant-directed speech medial peaks are more frequent than early peaks [30]. Thus, infants' segmentation abilities displayed in the medial peak condition might correlate with the relative frequencies in the input.

To investigate the role of pitch on the perception of metrical stress more closely, we test infants' attention to the first two syllables of the target words, produced with a trochaic stress pattern (e.g., [ˈlaːgu] for *Lagune*, [ˈkaːno] for *Kanone*). If high pitch is the most salient cue to metrical prominence, an effect of familiarity is expected only in the early-peak condition, but not in the medial-peak condition. Furthermore, we plan to use resynthesized stimuli to be able to focus on the role of f0-information in speech segmentation.

5. Acknowledgements

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