Speech Prosody 2024
2-5 July 2024, Leiden, The Netherlands

Prosody can provide subtle disambiguating cues for local ambiguity resolution

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Abstract

The present study investigated the effects of prosodic cues for local ambiguity resolution in German SVO and OVS sentences. Thirty-two healthy participants were tested in a web-based two-alternative forced choice task to examine whether listeners are sensitive to two different prosody conditions for distinguishing SVO and OVS structures as quickly and accurately as possible. We examined a syntactically marked prosody condition (i.e., naturally produced f0 cues differentiating between SVO and OVS structures) and an enhanced prosody condition (i.e., marked prosody with naturally increased f0 maximum). Response accuracy and reaction times were assessed following signal detection theory and by running linear mixed models. We found only moderate discriminability of both word order structures with higher sensitivity levels for enhanced compared to marked prosody. This is in line with the mixed results of previous studies suggesting that prosodic cues constitute more subtle information for structural disambiguation of German SVO and OVS sentences. However, we add to those results by demonstrating a more facilitative role of enhanced prosody. Research on variability of prosodic word order cues in sentence comprehension still remains open to further investigation.

Index Terms: prosody-syntax-interface, prosodic contrasts, structural prediction, sentence comprehension, local ambiguity resolution, word order

1. Introduction

Sentence comprehension involves rapid integration of lexical, semantic, morpho-syntactic or prosodic information to generate predictions about the upcoming input [1]. Thematic role assignment is one important aspect of sentence comprehension to determine “who did what to whom”. In German, transitive sentences typically include a subject as the agent and an object as the patient of an action. However, German word order is flexible and allows for both subject-verb-object (SVO) as well as object-verb-subject (OVS) structures. Therefore, listeners frequently need to make use of cues like morpho-syntactic case markers to determine the thematic roles of the constituents [2], [3]. The determiner of a masculine sentence-initial noun phrase (NP1) in SVO structures has nominative case and thus marks the constituent as the subject (agent), the determiner of the post-verbal noun phrase (NP2) appears in accusative case and hence marks it as the object (patient) of the sentence. However, since there is a form-function ambiguity (syncretism) among neuter and feminine articles in German, ambiguous case-marking results in locally ambiguous structures as exemplified in (1) for SVO and (2) for OVS sentences:

Das Kamel tritt nun [den Tiger.] (1)
the$_{\text{NOM/ACC-n.}}$ camel kicks currently the$_{\text{ACC-m.}}$ tiger
“The camel is currently kicking the tiger.”

Das Kamel tritt nun [der Tiger.] (2)
the$_{\text{ACC/NOM-n.}}$ camel kicks currently the$_{\text{NOM-m.}}$ tiger
“The camel is currently kicked by the tiger.”

Listeners initially interpret an ambiguous NP1 as the subject, because of a subject-first bias in German [4]. However, in OVS sentences, this initial interpretation is incorrect and a re-analysis is required at the morpho-syntactic point of disambiguation at NP2 [5]. This re-analysis is costly because of a complete re-assignment of thematic roles leading to higher processing demands [6].

To overcome the functional gap arising from syncretism and flexible word order in German, prosodic cues might provide additional information to facilitate sentence comprehension [7]. Previous studies demonstrated that listeners rapidly integrate prosodic cues for syntactic disambiguation and thematic role assignment [7], [8]. However, research on the role of prosody for local ambiguity resolution has provided mixed results suggesting a facilitative effect of prosodic cues on the comprehension of SVO, but no reliable effects for OVS sentences [7], [9]. Variations in study design and differences among the examined prosodic contours might have contributed to the mixed results observed so far. Moreover, inter-individual differences among speakers and listeners could lead to variations in the reliability of prosodic cue use, their detectability and strength [10], [11]. On the one hand, variability among listeners can, for example, lead to differences in reliably decoding prosodic contrasts across speakers [10]. Therefore, an increased prosodic cue strength could lead to beneficial effects of prosody on sentence comprehension [12], [13]. On the other hand, in a production study on prosodic cue use in locally ambiguous sentences, a speaker-specific strategy for distinguishing SVO and OVS structures was observed demonstrating variability among speakers [14]. In this study, participants were asked to utter the sentences in a referential communication task in such a way that listeners would be able to identify the picture matching the correct sentence interpretation as quickly and accurately as possible. Overall, speakers demonstrated only minor use of prosody to differentiate between SVO and OVS sentences with a high degree of variability between them. Only one speaker (out of 16) naturally and consistently used fundamental frequency (f0) cues to syntactically mark and distinguish both word order structures.

However, it has not been tested yet whether listeners are (i) sensitive to this speaker-specific prosodic contrast and (ii) capable of reliably decoding prosodic cues for local ambiguity

 10.21437/SpeechProsody.2024-242

resolution in German SVO and OVS sentences. In the present study, we examined the effects of a marked prosody condition (i.e., naturally produced f0 cues differentiating between SVO and OVS structures) and an enhanced prosody condition (i.e., marked prosody with naturally increased f0 maximum) for differentiating German SVO and OVS structures by means of a web-based two-alternative forced choice task.

We expected marked and enhanced prosody to provide disambiguating cues for local ambiguity resolution because of the rapid integration of prosodic cues for syntactic disambiguation [7]. If participants were (i) sensitive to the prosodic contrasts, we expected a high sensitivity to discriminate SVO and OVS structures in our analysis following signal detection theory. Because of increased prosodic cue strength, we further hypothesised a higher sensitivity for enhanced compared to marked prosody. Moreover, if participants were (ii) capable of reliably decoding these prosodic contrasts, we expected response accuracy to show performances above chance level. In addition, we hypothesised overall higher response accuracy and faster reaction times for SVO compared to OVS structures because of a subject-first bias in German [4] and higher processing demands for OVS structures [6]. We further expected higher response accuracy and faster reaction times for enhanced compared to marked prosody, because of increased prosodic cue strength and previously demonstrated beneficial effects of enhanced f0 cues for listeners with hearing impairments [13] and in infant-directed speech [12]. As a result, we expected main effects of word order (SVO > OVS) and prosody (enhanced > marked) in our (generalised) linear mixed models on response accuracy and reaction times.

2. Methods

2.1. Participants

Thirty-two healthy native German participants (29 females, 3 males) with a mean age of 21.9 years (*SD* = 3.1 years) were included. All participants reported normal hearing, normal or corrected-to-normal vision and no history of neurological or psychiatric impairments. Participants were compensated by course credits and gave informed consent. The study was approved by the ethics committee of the University of Potsdam adhered to the Declaration of Helsinki [15].

2.2. Materials

Stimuli were taken from [14] and consisted of locally ambiguous German sentences with the following structure: NP1, verb, adverb, NP2. The sentences were constructed in two word order conditions: SVO and OVS. Animate nouns of the categories humans, animals and fairy tale characters were used in subject and object position. Case-ambiguous (neuter) nouns were used in NP1, unambiguous (masculine) nouns were used in NP2. The case-marked determiner in NP2 (den_{ACC} vs. der_{NOM}) constituted the point of structural disambiguation. All verbs described reversible depictable actions. Auditory stimuli were spoken by a trained female native speaker of German in marked and enhanced prosody and differed in their prosodic contours of NP1, respectively. The marked condition was recorded with reference to the speaker-specific prosodic contrast that differentiated between SVO and OVS sentences found in [14]. The prosodic SVO contours showed an f0 rise and a prolonged f0 peak at the end of the last syllable of NP1 around 15-20 ms from word onset resembling an L*+H accent following the GToBI annotation system [16]. In contrast, the prosodic OVS contours showed an f0 peak at the centre of NP1 around 10-15 ms from word onset resembling an L+H* accent, and a smaller f0 rise from minimum to maximum in Hz (SVO-OVS (marked): t = 8.41, df = 165.53, $p < .001$; SVO-OVS (enhanced): t = 3.81, df = 165.53, $p < .001$; Welch's two-sample t-test, two-sided). The enhanced condition differed from the marked condition by showing an increased f0 maximum in Hz within NP1 (marked-enhanced (SVO): t = -22.01, df = 149.41, $p < .001$; marked-enhanced (OVS): t = -29.11, df = 158.71, $p < .001$), as well as a larger f0 rise (marked-enhanced (SVO): t = -19.19, df = 156.33, $p < .001$; marked-enhanced (OVS): t = -25.219, df = 162.52, $p < .001$) in both word order conditions (see Figure 1). Please note that no formal GToBI analysis was run here. The prosodic contours resembled the pitch accents of the GToBI system and were described in reference to previous studies to make it easier to compare the auditory stimuli.

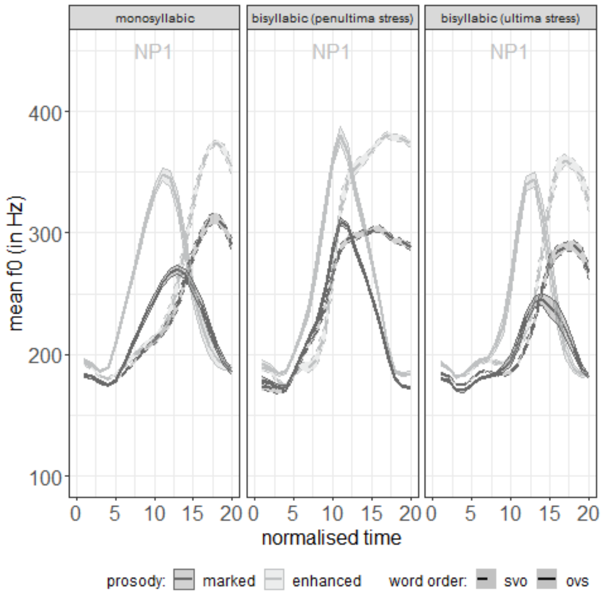

Figure 1: *Time-normalised marked and enhanced f0 contours in Hz for NP1 in SVO and OVS; separated by stress patterns.*

Prosodic contours were post-processed using Praat [17] in reference to procedures of Mausmooth [18] and ProsodyPro [19] to select four tokens of each sentence. The auditory stimuli were cut such that participants listened to them only up to the disambiguating determiner in NP2. They were scaled at an intensity level of 70 dB. Stimuli consisted of 336 experimental items (21 verbs * 2 word orders * 2 prosody conditions * 4 tokens of each sentence). Four pseudorandomised lists were tested in a between-participant design. The experiment was divided into two prosodic blocks with block order varying across participants.

2.3. Procedure

Participants gained access to the web-based experimental tool LabVanced [20]. They answered demographic questions and performed an adapted version of the implemented headphone screening test to check their audio settings. Instructions and auditory examples were presented on the screen and via headphones. After a central fixation cross was shown for a variable time window of 500 to 2000 ms to ensure participants' attention, the auditory stimulus was played up to NP2 (for example: *Das Kamel tritt nun*). Two written options (for example: *den Tiger* vs. *der Tiger*) were shown one above the other on the screen representing the SVO and OVS condition, respectively. Participants performed a two-alternative forced choice task by clicking with the mouse on the respective text box which they thought would complete the sentence as quickly and accurately as possible. A timeout was set after 8000 ms. The whole experiment took sixty minutes and there were short breaks within and between blocks to keep participants' attention.

2.4. Data analysis

Data analysis was performed on response accuracy and reaction times using RStudio, version 4.1.2 [21]. For response accuracy, binomial tests served to determine chance levels. Reaction times (RTs) were measured from the onset of NP1. Results from the box-cox transformation test ($\lambda = 0.59$) suggested no need for data transformation of RTs.

Following signal detection theory, we carried out *d'*-analyses [22], for which responses were transformed to *a'*-scores as a non-parametric estimate of discriminability. An *a'*-score of 1.0 indicates very good discriminability of SVO and OVS structures based on their prosodic contours, an *a'*-score of 0.5 represents chance performance [21]. We defined sensitivity levels to facilitate the interpretation of the *a'*-scores (see Table 1).

Table 1: *Sensitivity levels for discriminability (a'-scores).*

discriminability					
0.5	0.6	0.7	0.8	0.9	1.0
none	poor	moderate	fair	good	very good

In addition, *b"d*-scores served as non-parametric estimates of response bias. Positive values represent a tendency towards OVS responses, negative values indicate a tendency towards SVO responses. A value of 0 indicates no bias [23].

For further statistical analyses, we fitted a generalised linear mixed model with a binomial link function on response accuracy and linear mixed models with a Gaussian link function on RTs of correct responses including word order, prosody and their interaction as predictors. Block order was included as a covariate. All contrasts were effect coded. Models further comprised random effects of word order and prosody with correlated varying intercepts and slopes by participant and item. The random effects structure was reduced following the concept of parsimony in mixed models [24]. Model comparisons were performed and residuals were checked for their distributional properties. All data and code are available on OSF: https://osf.io/5mr9z/.

3. Results

3.1. Response accuracy

3.1.1. Descriptive statistics

Overall, response accuracy was above chance level (CL) in both word order conditions with higher response accuracy for SVO (*M* = 68.4%, *SD* = 11.6%, CL = 57.2%) compared to OVS structures (*M* = 60.2%, *SD* = 18.0%, CL = 57.2%).

In the marked condition, mean response accuracy was above chance for SVO structures (*M* = 65.6%, *SD* = 10.9%, CL = 60.6%), and below chance for OVS structures (*M* = 55.9%, *SD* = 18.3%, CL = 60.7%) (see Figure/Table 2).

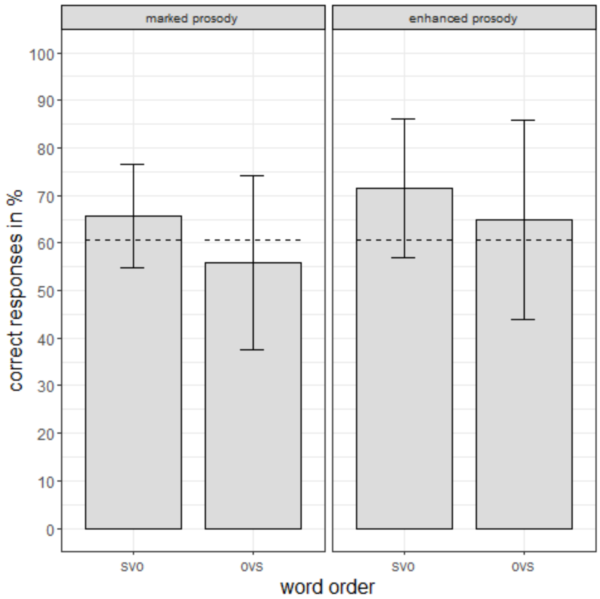

Figure 2: *Mean percentage of correct responses in SVO and OVS for marked and enhanced prosody; whiskers show +/- 1 standard deviation; dashed lines indicate chance level.*

In contrast, mean response accuracy in the enhanced condition was overall higher and above chance in both word order conditions. The SVO condition (*M* = 71.4%, *SD* = 14.6%, CL = 60.7%) showed again higher response accuracy compared to the OVS condition (*M* = 65.0%, *SD* = 21.0%, CL = 60.7%).

Table 2: *Mean signal detection theory measures.*

		correct condition			
		marked prosody		enhanced prosody	
		SVO	OVS	SVO	OVS
participants' response	SVO	**65.6%** hits	44.1% false alarms	**71.4%** hits	35% false alarms
	OVS	34.4% misses	**55.9%** correct rejections	28.6% misses	**65.0%** correct rejections

3.1.2. Signal detection theory

An *a'*-score of 0.69 (*b"d* = -0.01) indicated an overall moderate sensitivity to discriminate SVO and OVS structures. In the marked condition, an *a'*-score of 0.64 (*b"d* = -0.02) represented a lower sensitivity compared to the enhanced condition with an *a'*-score of 0.72 (*b"d* = 0.02). The respective *b"d*-scores indicated no response bias.

3.1.3. Generalised linear mixed modelling

The generalised linear mixed model on response accuracy showed a significant main effect of word order ($p < .01$) indicating higher response accuracy for SVO vs. OVS structures with an estimated difference of 7.3%. In addition, there was a significant main effect of prosody ($p < .001$) indicating higher response accuracy in the enhanced vs. marked condition with an estimated difference of 10.2% (see Table 3).

Table 3: *Fixed effects of the generalised linear mixed model on response accuracy.*

predictor	estimate	standard error	z-value	p-value
intercept	0.74	0.14	5.27	< .001 ***
word order	0.33	0.11	3.04	< .01 **
prosody	-0.47	0.12	-3.93	< .001 ***
block order	0.03	0.18	0.18	0.86
word order*prosody	0.19	0.17	1.13	0.26

3.2. Reaction times

3.2.1. Descriptive statistics

Participants generally responded faster in the OVS (M = 2039 ms, SD = 408 ms) compared to the SVO condition (M = 2084 ms, SD = 429 ms). In the marked condition, RTs for OVS structures (M = 2102 ms, SD = 495 ms) were faster than for SVO structures (M = 2178 ms, SD = 525 ms). In the enhanced condition, RTs for OVS structures (M = 2034 ms, SD = 460 ms) and SVO structures (M = 2020 ms, SD = 478 ms) were more comparable.

3.2.2. Linear mixed modelling

The maximal linear mixed model on RTs showed a singular fit and was thus reduced stepwise in its random effects structure following [24]. The final model explained variance equally well in comparison to the maximal model ($\chi^2(13) = 2.01$, $p = 1.0$) and showed a better model fit (smaller AIC), such that it was preferred as the less complex one. There was a significant interaction between word order and prosody ($p < .01$) indicating faster RTs for OVS structures only in the marked condition (see Table 4).

Table 4: *Fixed effects of the final linear mixed model on reaction times.*

predictor	estimate	standard error	df	t-value	p-value
intercept	2082.41	75.87	29.81	27.45	< .001 ***
word order	30.68	20.92	28.38	1.47	0.15
prosody	106.13	73.57	31.10	1.44	0.16
block order	237.89	141.89	30.11	1.68	0.10
word order*prosody	77.50	27.52	6239.17	2.82	< .01 **

4. Discussion

Our results on the effects of prosodic cues for local ambiguity resolution showed overall moderate sensitivity levels to discriminate SVO and OVS structures. Thus, listeners were sensitive to the presented prosodic contrasts only to some extent. Responses were not characterised by any bias in choosing one of the two presented options in the two-alternative forced choice task.

Overall, response accuracy was above chance level in both word order conditions indicating that participants were capable of decoding these prosodic contrasts in line with our predictions. A statistically significant main effect of word order supported an overall higher response accuracy for SVO structures. Because of a subject-first bias in German [4], participants might have been more familiar with SVO structures and their prosodic contours or just generally biased towards them. This is also reflected in previous findings demonstrating facilitative effects of prosodic cues only in the comprehension of SVO sentences [7], [9]. A statistically significant interaction of word order and prosody suggested faster RTs for OVS structures in the marked prosody condition, which was against our predictions. A possible interpretation could be a speed-accuracy trade-off effect, where slower decisions are associated with higher response accuracy and faster decisions with more errors [25]. Thus, participants showed faster reaction times but lower response accuracy for OVS structures especially in the marked prosody condition.

For marked prosody, results showed a response accuracy above chance for SVO, but chance performance for OVS structures. Hence, the present findings were only partially in line with our hypotheses. However, they reflected results of previous studies that did not find reliable effects of prosodic cues for OVS sentences [7], [9]. Moreover, an *a'*-score of 0.64 could be interpreted as a rather poor sensitivity to discriminate SVO and OVS structures. As a result, listeners showed a poor discriminability of the presented prosodic contrasts and were only capable of decoding them in SVO structures. We would therefore argue that syntactically marked prosody as it was produced with this speaker-specific prosodic contrast indeed plays a role in the comprehension of SVO structures potentially facilitating the disambiguation of local ambiguities. However, our findings did not suggest a facilitative effect for OVS structures in the marked prosody condition, since listeners showed chance performance and thus did not benefit from prosodic cues in OVS structures. Since inter-individual differences among speakers and listeners could lead to variations in reliably decoding prosodic contrasts [10], the underlying speaker-specific strategy, which was only produced by one speaker in [14], might have not facilitated comprehension for all listeners. Our findings also add to the debate if there are prototypical prosodic contours for OVS structures at all [26].

For enhanced prosody, both SVO and OVS structures were discriminated above chance, with again higher response accuracy for SVO structures. An *a'*-score of 0.72 and a significant main effect of prosody suggested that participants were more sensitive to discriminate SVO and OVS structures in enhanced compared to marked prosody. Listeners were thus more capable of reliably decoding the presented prosodic contrasts. These results are in line with our hypotheses and the previously demonstrated beneficial effects of enhanced prosody [12], [13]. However, sensitivity levels were still only moderate and we would therefore argue that prosodic cues provide rather subtle information for structural disambiguation of German SVO and OVS sentences. Notably, sentence comprehension involves an interplay of multiple linguistic cues, which listeners in the present study might have attended to.

5. Conclusions

We examined the effects of prosody as disambiguating cues in the resolution of locally ambiguous German SVO and OVS sentences. Our results demonstrate only moderate discriminability of both word order conditions and are in line with the mixed results of previous studies. We further extend those findings to an enhanced prosody condition providing subtle cues for structural disambiguation and demonstrating a more facilitative role for local ambiguity resolution.

6. Acknowledgements

We would like to thank C. Huttenlauch for stimuli recording and experimental set up. This research was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation, Project ID 317 633 480 - SFB 1287).

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