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Semantic priming and prosodic structure: At the interface between language redundancy and acoustic salience

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Abstract

The Smooth Signal Redundancy Hypothesis (SSRH) states that there is an inverse relationship between language redundancy and acoustic saliency. Less redundant items, e.g. infrequent or unpredictable ones, become more salient, and vice versa. The SSRH further assumes that prosodic structure, i.e., prosodic boundaries and prominence, mediates the relationship between language redundancy and acoustic saliency. In this paper, we tested whether semantic priming, one of the measures of language redundancy, affects prosodic structure at word boundaries. In a production experiment we presented German sentence pairs with identical target words. These target words were presented either in a context where they were primed by semantically related words or in a context where they were not primed. Results showed an effect of semantic priming on prosodic structure in that primed targets were significantly shorter than non-primed ones. This effect was increased when measures of lexical frequency were taken into account as well.

Index Terms: semantic priming, prosodic boundary strength, Smooth Signal Redundancy Hypothesis, lexical frequency, German

1. Introduction

During conversations, speakers tend to adjust the signal to ease comprehension and to ensure robust and efficient communication. To support the recognition likelihood of linguistic items, the Smooth Signal Redundancy Hypothesis (henceforth SSRH, [1], following [2]) assumes an inverse relationship between acoustic salience and language redundancy, i.e., the likelihood of recognition via lexical, syntactic, pragmatic, and semantic factors. If a linguistic object has high language redundancy, then its corresponding acoustic salience should be low and vice versa [3, 4, 5, 6, 7]. This relationship is assumed to be mediated by prosodic prominence and boundary structure [8, 9].

Previous research into this area mainly focused on the relationship between lexical or syntactic redundancy and acoustic salience [8, 10]. Semantic redundancy factors have received comparably less attention. One of the semantically oriented measures of language redundancy is semantic priming, referring to the phenomenon that a word is processed more quickly, e.g., with shorter reaction time in lexical decision tasks, when it is preceded by a semantically related word [11, 12, 13, 14]. For instance, the subject would recognize the target *pilot* faster, if the previous context contained the prime *plane* compared to a context where the subject is exposed to a semantically unrelated item (e.g., *ship*).

[15] worked on a spreading-activation theory based on [16]'s work, which aimed to explain how the human brain processes semantically related concepts. According to this model, exposure to a linguistic item activates the related concept node of this item as well as its associated semantic network. For the activated linguistic item *plane*, several semantically related nodes such as *pilot*, *flying*, or *stewardess* are likely to be activated as well and are thus more quickly accessible, resulting in shorter reaction times [15, 17].

A line of evidence indicated interactive effects of semantic priming and lexical frequency [18, 19, 20]. On the basis of [21]'s approach, [18] suggested that the processing of semantic context and of lexical frequency for word recognition can be explained with similar models. They assumed that the occurrence of a stimulus entails several word detectors which respond to the sensory features of this stimulus. These word detectors check and count semantic stimulus features that correspond to the features of the presented word. If enough matching features are found, the detector will be activated and the word is recognized. Following this concept, semantic context increases the initial feature count of some word detectors above their normal level. Consequently, primed words need fewer stimulus features than non-primed words in order to be recognized.

[18] further proposed that the process of extracting stimulus features happens in real time. Thus, the longer reaction time for non-primed words could be explained with the time needed for processing additional features that are required for recognizing the word. Arguably, high and low frequency words are recognized in a similar way. Word detectors of high frequency words have a lower initial feature count for matching features than word detectors of low frequency words. By processing fewer features, the word detectors need less time to be activated and the high frequency word is thus recognized faster. [18]'s study on the interaction between semantic priming and lexical frequency revealed that the effect of semantic context was larger for low frequency words.

According to the SSRH, targets that have been primed by a previous semantically related context are predicted to be more redundant than non-primed targets. Furthermore, these primed targets should be less salient, e.g., acoustically shorter, than non-primed targets. Since the SSRH assumes prosodic structure to be mediating between language redundancy and acoustic salience, semantic priming is predicted to affect the stressed syllable and prosodic boundaries of targets. This paper addresses the questions whether semantic priming affects prosodic structure at word boundaries and how lexical frequency effects influence semantic priming effects in German.

2. Experiment

2.1. Methods

2.1.1. Materials

The materials consisted of 22 sentence pairs in Standard German. Each pair included identical target words in a) a context where the target was primed (*priming context*), and b) a context where the target was not primed (*non-priming context*). The tar-

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get words as well as their lexical frequencies were chosen with the help of WebCelex's lexical database [22]. Frequency measures were verified with the targets' number of hits on Google. Words that had more than 60 million Google hits and more than 110 hits in WebCelex were sorted into the *frequent* group (6 in total), words with less than 10 million Google hits and less than 60 hits in WebCelex were sorted into the *infrequent* group (6 in total). Targets with any lexical frequency lying between these thresholds or potential mismatches were sorted as a third group and disregarded for the statistical analysis of the interaction between semantic priming and lexical frequency.

Following the SSRH, differences between primed and non-primed targets should be visible in the boundary-related intervals, i.e., the interval between the previous word and the onset of the target word, and the interval between the target word and onset of the following word. To this end, only target words with plosive onsets were chosen to ensure segmentation reliability and comparability of the boundary-related intervals. The last syllable of the targets was either *-en*, *-er*, *-in* or *-or*. Furthermore, all target words were trisyllabic with the stress on the second syllable. Lexical stress was avoided at the word edges of the targets to better distinguish the possible effects of priming on prosodic boundaries from the effects on prosodic prominence (i.e., of the stressed syllable).

Target words were common nouns that are used to refer to a group of people (e.g., *pilots, pirates*). 18 out of 22 target words appeared in their plural forms to ensure an identical number of syllables across all targets. The target words were preceded by the definite articles *die* (the.FEM/SG,PL) or *der* (the.MASC/SG), followed by the reflexive pronoun *sich* ('herself/himself/themselves') and a verb. The contexts were created with identical sentence structures and controlled to have approximately the same number of syllables. The first part of the sentence included two primes, one noun and one verb, the second part of the sentence included the target word.

Each context pair was used twice with different target words and alternating priming patterns: For the first target word, the first sentence was the priming context and the second one the non-priming context. For the second target word, the order was reversed. Table 1 shows an example of one context pair. *Piloten* is the primed target in the first sentence, and *Piraten* is the primed target in the second sentence. In sentence 1, the target is preceded by the two (non-)primes *Flugzeug* ('plane') and *landen* ('(to) land'), which prime *Piloten*, but not *Piraten*. In the second sentence the target is preceded by the two (non-)primes *Frachtschiff* ('cargo ship') and *kapern* ('(to) hijack'), which in turn prime *Piraten*, but not *Piloten*.

The 22 context pairs were divided into two experimental lists. Each target word only appeared once in each list, either in a priming or a non-priming context, resulting in 11 sentences with primed targets and 11 sentences with non-primed targets in each list. As a consequence, one member of each context pair occurred twice in one list (once as a priming context and once as a non-priming context), while the other member occurred twice in the other list. In each list, the priming context was always presented before the non-priming context to avoid the creation of a context for the non-primed target. The consequence would have been a weakening of the priming context for the primed target. At the same time, this design allowed for the weakening of the non-priming context, which - for this experiment - was a desirable effect to ensure that the context was indeed understood as non-priming by the participant.

Prior to the experiment, the semantic relatedness of the primes and the target words was checked by German native speakers via a questionnaire. The questionnaire featured the 22 primed context sentences, where participants were required to choose the intended target from three options (including the primed target, the non-primed target, and an unrelated third word). 18 participants (mean age: 42, age range: 23-67) completed the questionnaire (and were consequently excluded from participation in the following experiment). Participants chose the intended (primed) target in 98.48% of the cases, which confirmed the semantic relatedness between primes and target words in the materials.

2.1.2. Participants

21 German native speakers (mean age = 27, age range 18-30, 15 female and 6 male) participated in the experiment. They were mostly students or employees recruited at the University of Konstanz. Participants were randomly assigned to one of the two experimental lists.

2.1.3. Procedure

All participants were recorded with a condenser microphone in a soundproof studio at the University of Konstanz (sampling rate 44.1 kHz, 16-Bit, stereo). During the experiment, they were instructed to read out the sentences that appeared on a screen. The instructor clicked manually to display the next sentence each time the speaker finished a sentence. The procedure took approximately 30 minutes and participants received a small compensation after the recording.

2.1.4. Analysis

In total, 462 sentences were extracted and annotated with Praat [23]. We excluded 32 sentences with wrong pronunciation or wrong stress patterns; the remaining 430 sentences were used for the analysis. As a first step, MAUS [24, 25] was used for the automatic segmentation of the sentences, which was then manually checked and corrected according to the standard annotation criteria in [26].

Durations of the following six intervals were annotated and extracted: 1) the rhyme of the last syllable of the preceding word (labelled as *R_prev*); 2) the onset of the target word (*O*);

Table 1: *An example of the target "Piloten" ('pilots') in a priming and non-priming context.*

Sentence 1: *Piloten* in a priming context, *Piraten* in a non-priming context									
Um	das	Flugzeug	zu	landen	muss-t-en	die	Pilot/Pirat-en	sich	beeilen
in.order	the.ART.DEF.N.SG	plane.N.SG	to	land.INF	have.to-PST-PL	the.ART.DEF.PL	pilot/pirate-PL	itself.REFL.3PL	hurry.INF
'In order to land the plane, the pilots/pirates had to hurry.'									
Sentence 2: *Piloten* in a non-priming context, *Piraten* in a priming context									
Um	das	Frachtschiff	zu	kapern	muss-t-en	die	Pilot/Pirat-en	sich	verbünden
in.ordner	the.ART.DEF.N.SG	cargo ship.N.SG	to	hijack.INF	have.to-PST-PL	the.ART.DEF.PL	pilot/pirate-PL	itself.REFL.3PL	team.up.INF
'In order to hijack the cargo ship, the pilots/pirates had to team up.'									

3) the first boundary interval (*B1*) of the target, including the rhyme of the last syllable of the preceding word and the onset of the target; 4) the rhyme of the last syllable of the target (*R*); 5) the second boundary interval (*B2*) of the target word, including the rhyme of the last syllable of the target as well as the onset of the following word, which was the fricative /z/ for all sentences, and 6) the complete target word. Table 2 illustrates a simplified version of the annotation scheme.

Table 2: *Annotation scheme (for the example in Table 1).*

(d)ie	*p*	*ilot*	*en*	*s(ich)*
R_prev	O	–	R	–
B1		–	B2	

2.2. Results

We calculated the duration measures using linear mixed effects regression models with semantic priming and lexical frequency as fixed factors and participants and items as crossed-random factors with the Satterthwaite approximation implemented in the R-library lmerTest [27, 28].

2.2.1. Semantic priming effects for the overall data

A general priming effect could be established. In terms of durations of the whole target words (beginning of onset to end of rhyme), primed targets were significantly shorter than non-primed targets (ß = -0.008, SE = 0.002, t = -3.55, $p < 0.001$). Additionally, significant priming effects for the following intervals were found: 1) The onset (*O*) of primed targets was shorter compared to their non-primed counterparts (ß = -0.003, SE = 0.001, t = -2.19, $p < 0.05$). 2) The rhyme of the last target syllable (*R*) was shorter in the primed condition (ß = -0.006, SE = 0.003, t = -2.00, $p < 0.05$), and 3) The second boundary interval of the targets (*B2*) was shorter in the primed condition as well (ß = -0.005, SE = 0.003, t = -2.14, $p < 0.05$). The first boundary interval *B1* as a whole and the rhyme of the last syllable of the previous word (*R_prev*) showed no significant effect of priming. Figure 1 shows the overall effects of priming for the onsets and the rhymes of the complete data without the lexical frequency factor.

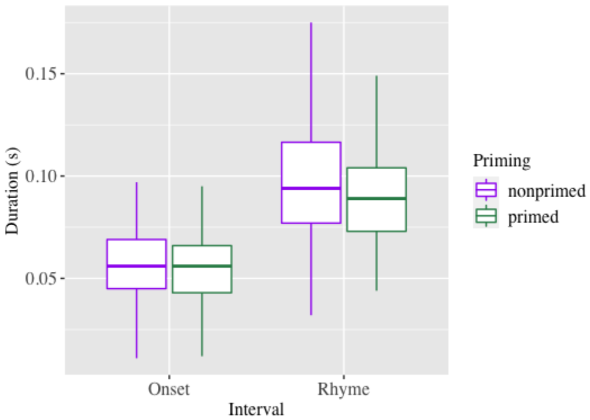

Figure 1: *Box plots for onsets and rhymes of primed and non-primed words for the overall data not divided by lexical frequency.*

Furthermore, results showed a significant interaction between semantic priming and lexical frequency effects. To have a better understanding of the interaction, the data was split into subsets where priming effects were tested for both high and low frequency groups (Section 2.2.2), and lexical frequency effects were tested for both the priming and non-priming condition, respectively (Section 2.2.3).

2.2.2. Semantic priming effects for frequent and infrequent items

For the frequent items, no significant effects of priming were found for *R_prev*, *O*, or *B1*. However, infrequent items showed significant priming effects for these intervals where infrequent items were significantly shorter when they were primed ($p < 0.001$).

Among the frequent items, primed targets had a significantly shorter duration of *B2* compared to the non-primed ones (ß = -0.012, SE = 0.003, t = -3.70, $p < 0.001$). An observation on the sub-interval *R* revealed approaching significance of priming effects (ß = -0.006, SE = 0.003, t = -1.92, p = 0.057). For both intervals, no significant difference by semantic priming was found in infrequent items.

2.2.3. Lexical frequency effects for the primed and the non-primed condition

For the primed targets, the onset interval yielded a significantly shorter duration for infrequent items than for frequent ones (ß = -0.010, SE = 0.004, t = -2.26, $p < 0.05$).

Towards the end of the targets, however, lower lexical frequency led to longer duration irrespective of the priming condition. Contrary to the results of target-initial onset, infrequent targets had longer *B2* in both primed (ß = 0.029, SE = 0.008, t = 3.475, $p < 0.01$) and non-primed condition (ß = 0.02, SE = 0.007, t = 2.782, $p < 0.05$). The same significant results were further attested in the sub-interval *R* (primed: ß = 0.035, SE = 0.01, t = 3.432, $p < 0.01$; non-primed: ß = 0.028, SE = 0.008, t = 3.577, $p < 0.01$).

Figure 2 illustrates the reversed effects of lexical frequency on the onset and the rhyme for primed target words.

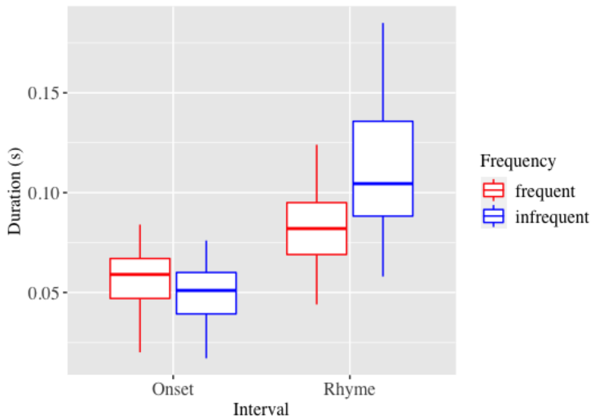

Figure 2: *Box plots of the primed data indicated opposite effects of lexical frequency in the word-initial onset and word-final rhyme.*

Figure 3 extends the illustration to the rhyme of the previous words, suggesting an alternating effect of lexical frequency on primed data depending on word position.

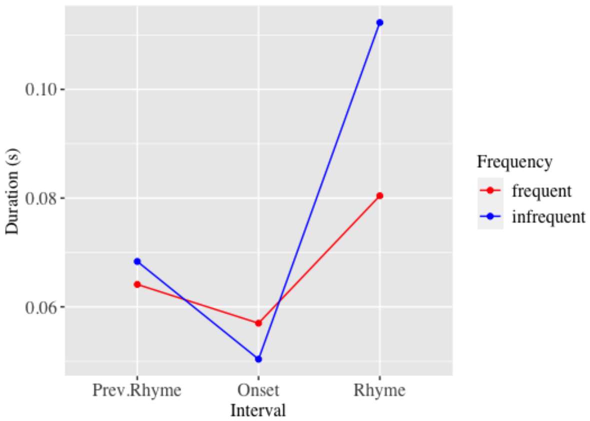

Figure 3: *The duration differences of R_prev, O, and R for frequent and infrequent target words in the primed data.*

3. Discussion

Regardless of the priming condition, infrequent targets constantly yielded longer boundary-related intervals at the end of the words, which is in accordance with previous research and the prediction made by the SSRH in that stronger boundaries (in the form of longer durations) occur at the end of linguistic items with lower language redundancy [7, 8].

With regard to semantic priming, the results are in line with previous findings (see [11, 12, 13, 14, 15, 16] among others) in that primed words are processed more quickly than non-primed ones. The significant differences between primed and non-primed targets in most of the boundary-related intervals including the onset, rhyme and the second boundary intervals speak in favor of the semantic priming effects at the prosodic boundaries. It could be the case that the lack of priming effects in the first boundary-related interval and the rhyme of the previous syllable is due to varying rhymes of the previous syllables (-*er* or -*ie*).

As boundary-related intervals showed higher acoustic salience (in the form of longer duration and stronger word boundaries) when language redundancy was low (i.e., non-primed), the results support the predictions of the SSRH. It is important to note, however, that this does not automatically exclude other theories/hypotheses that can explain the data.

In addition to semantic priming, the current paper investigated the interaction of semantic priming and lexical frequency. This interaction was very significant (as illustrated by the comparison of Figure 1 and Figure 2). For the first boundary-related interval (R_prev, O, B1), infrequent words were significantly reduced in duration when they were primed, whereas no significant difference was found for frequent words. These results suggest that, word-initially, low frequency words become more predictable if primed by related semantic context, which is consistent with findings from e.g., [18] and [19], who, at the word level, found larger priming effects for low frequency words compared to high frequency words.

Surprisingly, the initial and the final intervals showed reversed effects for frequent and infrequent target words: In contrast to the first interval, semantic priming effects were only attested for the second boundary-related interval (R, B2) of frequent, but not of infrequent target words. One possible explanation is that, for infrequent words, semantic priming initially "overrides" lexical frequency, which leads to primed infrequent items (unlike frequent items) to be processed faster at the beginning of words. While the word is processed, lexical frequency comes into play, resulting in longer duration measures for infrequent items towards the end of the target. This suggests that effects of semantic priming and lexical frequency are overlapping during word processing. To better understand the nature of the interaction of lexical frequency and semantic priming and to test the plausibility of this assumption, further empirical research with more intervals throughout the target words is needed.

Although the targets in the current study were partially controlled for their onset type, syllable count and lexical frequency, there were a few limitations. For instance, onsets of the frequent subgroup included almost exclusively voiced plosives, whereas onsets of the infrequent subgroup included both voiced and voiceless plosives. In addition, as indicated by [20] and [19], other factors such as stimulus quality and lexical integrity are also likely to influence the joint effects of semantic priming and lexical frequency. Such factors are beyond the scope of the current study and have to be left for further research.

4. Conclusion

The present paper tested the effects of semantic priming at prosodic word boundaries and its interaction with lexical frequency. Results showed that boundary-related intervals of primed targets were significantly shorter than those of non-primed targets, indicating effects of semantic priming on word boundary strength. These findings support the SSRH by showing that semantic priming, as a measure of language redundancy, inversely correlates with acoustic salience and that this relationship is mediated by prosodic boundary strength. Results further revealed a more complex picture of the varying effects of lexical frequency and semantic priming at the beginning and the end of words as well as their interaction. This finding suggests that semantic priming and lexical frequency influence words to a different extent depending on the position within the word.

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6. References

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