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The time course of lexical access in morphologically complex words

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Abstract

Compounding, that is the concatenation of words (e.g., dishwasher), is an important mechanism across many languages. The present study investigated whether access of initial compound constituents occurs immediately or, alternatively, whether it is delayed until the last constituent (i.e., the head). EEG was measured as participants listened to German two-constituent compounds. Both the initial as well as the following head constituent could consist of either a word or nonword, resulting in four experimental conditions. Results showed a larger N400 for initial nonword constituents, suggesting that lexical access was attempted before the head. Thus, the present study provides direct evidence that lexical access of transparent compound constituents in German occurs immediately, and is not delayed until the compound head is encountered.

Keywords: Auditory language comprehension, N400, ERP, compound word, lexicon, morphology

Introduction

Auditory language comprehension is essentially the conversion of acoustic input into meaning. This involves segmenting continuous speech into its component parts, word recognition, utterance interpretation and integration into a discourse model. Regarding the relative timing of these processes, it has been suggested that the interpretation proceeds incrementally and is as immediate as possible [c.f. 1]. In this context, Hagoort and Van Berkum [2] discussed a one-step model of language comprehension, where every source of information that can constrain the interpretation of an utterance (e.g. prosody, syntax, prior discourse, gestures) can in principle do so immediately.

However, whereas this immediacy assumption is discussed with regard to the processing of sentences (which have propositional content), it seems to be partially contradicted for the comprehension of morphologically complex words (which do not have propositional content). For instance, some aspects of compound words, which are words that result from the concatenation of simple words [so called morphemes, see 3, e.g. book+shop], are not processed immediately. The initial constituent of a spoken German compound carries prosodic cues [i.e., reduced duration, increased pitch, see 4,5] that signal to the listener that this constituent is part of a compound and not a simple word. Koester et al. [5] showed that listeners process the morphosyntactic number information of initial constituents when spoken with a single word prosody, but not when constituents carry a compound prosody. Thus, comprehension of morphologically complex words seems to differ partly from the immediate processing of all available information as described for the sentence level [1,2].

Another unresolved question is whether *semantic* access of initial compound constituents is also delayed or immediate. In a series of cross-modal priming experiments, Isel et al. [4] found no priming effects for initial constituents at their acoustic offset. This result led to the suggestion that semantic access of initial constituents is delayed until the last constituent becomes available (in languages with right-headed compounds, e.g. German

or English [4]). This is plausible as the last constituent (the head) defines the semantic category and morphosyntactic features (e.g. number and gender) of the whole compound.

Possibly, Isel et al. found no priming effects because they used rather short, monosyllabic initial constituents. It is well known that longer words produce stronger priming effects than shorter ones [6]. Therefore, in the present study, we decided to use compounds containing longer tri-syllabic initial constituents, to maximize the probability of detecting evidence for immediate semantic access of initial constituents. We manipulated the lexical status of individual constituents in two-constituent compounds. Both the first and the second constituent could consist of a word or a nonword, resulting in four experimental conditions (word+word (WW), nonword+word (NW), word+nonword (WN) and nonword+nonword (NN)). Stimuli were produced with natural prosody, thereby providing natural prosodic marking of the compound structure [7,8]. We recorded the Electroencephalogram (EEG) while participants listened to compounds and judged the semantic relation of the compound with subsequently presented test words.

The N400, a component of the Event-Related Potential (ERP), is sensitive to lexical access [9] and nonwords are known to elicit a larger N400 than words [10,11], reflecting the more difficult and eventually unsuccessful access of nonwords. Thus, if compound constituents are incrementally accessed, a larger N400 for initial nonword as compared to initial word constituents is expected. In contrast, the delayed access account [4] holds that access of initial constituents is delayed; hence this view predicts no N400 effect at initial constituents.

Materials and Methods

20 native German-speaking students (11 female; 20-30 years; mean 24.7) participated after giving written informed consent following the guidelines of the Ethics committee of the Leipzig University. They were right-handed and none reported any hearing deficit.

120 nominative compounds were selected from the CELEX database [12]. All compounds were semantically transparent, i.e. both constituents were related to the

compound's meaning (e.g., both *dish* and *washer* are related to the meaning of *dishwasher*). All first constituents (C1) consisted of three syllables; second constituents (C2) had either one or two syllables. For multi syllabic constituents, nonword constituents were created by randomly interchanging the syllables of the word constituents. All nonword constituents were phonologically legal. Next, nonword constituents were randomly combined with word constituents which resulted in 120 stimuli per condition. No constituent was repeated. For stimulus examples and properties see Table 1. The stimuli were recorded using a female professionally trained speaker and were equalized for loudness. C1s were matched for constituent length and fundamental frequency (F0). F0 contour was analyzed in subsequent 100 ms time slots [c.f. 5]. Duration, uniqueness point [13] and F0 did not differ significantly between conditions (duration: $F(3,476) < 1$; uniqueness point: $F(1,238) < 1$; F0: all Fs < 2.26 , all $p > .08$).

Subjects were seated in a dimly lit, sound-attenuated and electrically shielded room facing a computer screen. They had to listen carefully to the stimuli and to judge afterwards by pressing a button which of the two visually presented words was semantically related to the compound (or the word constituent's meaning for conditions WN and NW). The relation of the test words was tested in a prior rating study using 10 different German native speakers. A trial started with a fixation cross presentation for 2000 ms followed by an auditory stimulus. After the compound, the fixation cross was visible for another 500 ms. Next, the two test words were presented to the left and right of the fixation cross.

The session lasted about 60 min and consisted of 6 blocks. Subjects received 16 training trials and 2 filler items at the start of each block. Two pseudo-randomized lists were used with no more than two repetitions of any condition. Switching the presentation side of the related word resulted in four experimental lists which were randomly assigned to subjects. All lists were used equally often.

The EEG was recorded from 56 Ag/AgCl electrodes with impedance being kept below 5 k Ω . It was amplified and digitized online at 500 Hz and was referenced to the left mastoid. Vertical and horizontal EOG were also measured.

Single-subject ERPs (-200..1200 ms) were calculated for each experimental condition, time-locked either to the onset of C1 or C2. A 200 ms pre-stimulus baseline was used. Four Regions of Interest (ROI) were defined: anterior-left (AL): AF7, AF3, F7, F5, F3, FT7, FC5, FC3; anterior-right (AR): AF4, AF8, F4, F6, F8, FC4, FC6, FT8; posterior-left (PL): TP7, CP5, CP3, P7, P5, P3, PO7, PO3; posterior-right (PR): CP4, CP6, TP8, P4, P6, P8, PO4, PO8.

An automatic artifact rejection using a 200 ms sliding window was performed on the EOG channels ($\pm 30 \mu\text{V}$) and the EEG channels ($\pm 40 \mu\text{V}$) and was double-checked by a visual inspection. Overall, about 13% of the trials were excluded due to artifacts or incorrect responses. A repeated-measure ANOVA with the within-subject factors Lexical Status of C1 (word vs. nonword) and ROI (AL, AR, PL, PR) was performed to analyze the statistical reliability of the N400 effects of the C1s. To analyze the N400 effects at the C2, a repeated measure ANOVA with the factors Lexical Status of C1 (2), Lexical Status of C2 (2) and ROI (4) was performed.

Only effects that involve the crucial factor of Lexical Status are reported. Greenhouse-Geisser correction [14] was applied where necessary. In that case, the uncorrected degrees of freedom (df), the corrected p-values and the correction factor ϵ are reported.

Results

Accuracy was high for the three conditions involving a word constituent (WW: 96.62%; WN: 95.53%; NW: 93.83%) and at chance level for the NN condition (49.85%). All pairwise comparisons were statistically significant (all $t(19) > 2.4$, all $p < 0.05$).

ERPs time-locked to the onset of the C1 revealed a more pronounced, broadly distributed negativity for nonword as compared to word constituents, starting about 400 ms after constituent onset. Based on the experimental manipulation and its polarity, this component is suggested to be an N400.

To test the N400 effect, the mean amplitude from 500 to 700 ms after the onset of the C1 was computed for all conditions. The corresponding ANOVA with the factors Lexical Status (2) and ROI (4) yielded a significant main effect of Lexical Status ($F(1,19) = 11.69, p < 0.005$), indicating that the N400 was more pronounced for nonword than for word constituents. The interaction of Lexical Status and ROI was not significant ($F(3,57) = 1.3, p = 0.28, \epsilon = .53$), suggesting a broadly distributed N400 effect.

Compared with regular compounds (i.e., WW), compounds with one or two nonword constituents elicited a stronger negativity peaking around 500 ms after the onset of the C2. This component is identified as an N400 based on its latency, topography and the experimental manipulation. The N400 is largest for condition WN, intermediate for condition NW and smallest for condition NN (see Figure 1).

To test these N400 effects at the C2, the mean amplitudes from 400 to 600 ms after the onset of the C2 were computed for all conditions. The ANOVA with the factors Lexical Status of C1 (2), Lexical Status of C2 (2) and ROI (4) yielded a main effect of Lexical Status of C2 ($F(1,19) = 15.78, p < 0.001$), a two-way interaction between Lexical Status of C1 and C2 ($F(1,19) = 41.91, p < 0.0001$) and a three-way interaction between the Lexical Status of C1 and C2 and the topographic factor ROI ($F(3,57) = 6.59, p < 0.01, \epsilon = .48$). The two-way interaction indicated that the effect of the lexical status of the C2 was modulated by the lexical status of the preceding C1. Specifically, the N400 elicited by nonword head constituents compared with word head constituents was larger if preceded by word constituents ($t(19) = 6.65, p < 0.0001$), and smaller if preceded by nonword constituents ($t(19) = -2.06, p = 0.05$).

Bonferoni-corrected post-hoc tests carried out to clarify the origin of the three-way interaction, separately for each ROI, revealed the following significant differences:

AL: WN>NW>NN>WW ($p < .05$ for all differences)

AR: WN>NW \approx NN>WW (all $p < .0001$)

PL: WN>NW>NN>WW (all $p < .0001$)

PR: WN>NW>NN \approx WW (all $p < .0001$)

Thus, the smallest N400 at head constituents was elicited by regular compounds (WW) and the amplitude increased for condition NW and further for WN. For Condition NN, the N400 tended to be larger than for WW but smaller than for NW, at least in the left hemisphere.

Discussion

This study investigated the time course of lexical access during spoken compound comprehension. We found a larger N400 for initial nonword as compared to initial word constituents, suggesting immediate lexical access. Thus, the present study provides direct evidence for the incremental nature of lexical access in compound comprehension.

Behaviorally, we observed very accurate semantic relatedness judgments when at least one constituent was a word, while performance was at chance level for condition NN. This suggests that although the study contained partly meaningless constituents, participants engaged in a semantic-conceptual processing of the stimuli.

In the ERP data, compounds with initial nonword constituents elicited a larger N400 than compounds with initial word constituents. This N400 effect is in line with previous findings that suggest a specific sensitivity of the N400 to lexical-semantic processing within compound words [15,16]. The N400 was already fully established during the initial constituent (average length 700ms), with the onset occurring on average after the uniqueness point of the C1. This suggests that the N400 is driven by the C1 and temporarily linked to the point when word meaning is likely available. Whereas N400 effects are usually observed to begin around 300 ms after stimulus onset [for review, see 9,17], we detected a slightly delayed N400 effect starting at 400 ms. We attribute this to the long, tri-syllabic initial constituents we used, whereas previous research often investigated words with fewer syllables. Longer words presumably have later uniqueness points than short words, and it has been shown that late uniqueness points delay the onset of the N400 [11].

Given the sensitivity of the N400 to lexical access [9-11], the present N400 effect is taken to reflect the more difficult process of lexical access for initial nonword constituents. Thus, lexical access seems to be attempted before the head constituent is available. The effects at C1 therefore do not support the delayed account of lexical access [4], but rather provide direct evidence for incremental lexical-semantic access of semantically transparent compound constituents. This result is in accordance with the immediacy assumption discussed for the sentence level [1,2] and suggests that the immediacy assumption also holds for auditory comprehension of morphologically complex words which are not integrated into a proposition [c.f. 18].

We also explored the compound processing at the position of the head. The ERP effect observed at the first constituent suggests that constituents were accessed separately, before the compound meaning could be derived by integrating the meaning of both constituents [15,16]. Thus, at the head, at least two processes seem to take place: lexical access of the head and semantic integration of both constituents.

Nonwords at the head position (condition WN) elicited a larger N400 compared to regular compounds (condition WW). This N400 effect is suggested to reflect primarily the more difficult and eventually unsuccessful lexical access of nonword constituents because the nonword constituents do not have lexical entries. In contrast, the larger N400 for word preceded by nonword constituents (condition NW compared to WW) cannot be explained by differences in lexical access because the head constituents have been matched to one another. Instead, since previous research has shown that the N400 is also sensitive to the difficulty of integrating a word into a preceding context [i.e., the postlexical view, 19], this latter N400 effect is suggested to reflect the increased integration difficulty for NW compared to WW. A word constituent at the head position can easily be integrated with a preceding word constituent (WW), but it is difficult to integrate a word constituent into the context of a nonword constituent. Hence a larger N400 was observed for condition NW than for condition WW.

Notably, the N400 was larger when the nonword constituent occurred at the head position (condition WN) than when it occurred at the initial position (NW) even though in both cases only one constituent was a nonword. This result suggests that a nonword in the head position is more disturbing for the comprehension process than a nonword in initial constituent position. This observation is in accordance with the semantic primacy of head constituents (at least in German) as they determine the compound's semantic category. Although speculative, an attempt of constituent integration in parallel to the lexical search for the head constituent might increase the processing load [20] in condition WN as compared to when the first constituent was already detected as a nonword (NW).

Interestingly, the N400 for nonword compounds (NN) was larger than for regular compounds (WW), but significantly smaller than the N400 in conditions NW and WN. Apparently, when the comprehension system realizes that no constituent actually carries meaning, no further attempts towards integration are made and the system exits the compounding process, especially as no further processing seemed to be required for the given task. The larger N400 for condition NN than for regular compounds (WW) suggests that lexical access of the head was attempted and is more difficult for condition NN than for WW. Future work should clarify whether this reduction in N400 amplitude is related to the task, to further examine the adequacy of the immediacy assumption for morphosyntactic information.

Conclusion

Our results suggest that lexical access proceeds incrementally in auditory compound comprehension. Initial nonword constituents elicited an increased N400 compared with word constituents. This N400 effect occurred during the presentation of the initial constituents and led to the conclusion that lexical access proceeds incrementally during the comprehension of transparent morphologically complex words.

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Figure captions

Figure 1:

Left panel: ERPs time-locked to the onset of the first constituent ($n=20$). Negativity is plotted up. The solid black line represents conditions with an initial word constituent (conditions WW and WN), the dashed red line represents conditions with an initial nonword constituent (conditions NW and NN). *Right panel:* ERPs for the four experimental conditions, time-locked to the onset of the second constituent. Data were filtered with a 10 Hz low-pass filter for presentation purposes only.

Figure 1 in separate file (as pdf)

Table 1: Stimulus examples, duration and frequency

Condition	Example	C1 duration	C2 duration	Compound duration	C1 frequency	C2 frequency	Compound frequency	C1 uniqueness point
WW	Ameisen haufen	0.701 (0.054)	0.636 (0.099)	1.338 (0.110)	29.83 (53.67)	107.02 (241.62)	0.86 (1.96)	0.349
	ant hill							(0.098)
WN	Maschinen bönf	0.698 (0.048)	0.654 (0.084)	1.353 (0.094)	17.64 (43.79)			0.339
	machine bönf							(0.101)
NW	Patose schlot	0.703 (0.050)	0.644 (0.085)	1.347 (0.097)		95.27 (165.58)		
	patose chimney							
NN	Kronube josche	0.702 (0.051)	0.662 (0.082)	1.364 (0.098)				
	kronube josche							

Mean length in seconds, mean frequency in occurrences / million according to the CELEX database [11]. Uniqueness point was determined based on all CELEX-listed monomorphemic nouns. Standard deviation in parenthesis. 120 items per condition.