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Differences in brain potentials to open and closed class words: class and frequency effects

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Abstract

Closed class (determiners, pronouns, conjunctions, prepositions etc.) and open class (nouns, verbs, adjectives, adverbs) words have different linguistic functions and have been proposed to be processed by different neural systems. Here, event-related potentials (ERPs) were recorded in young German-speaking subjects while they read closed class and open class words flashed upon a video-screen. In the first experiment closed class words were sorted into four different frequency categories and open class words into three categories. The words were presented in a list with the subjects' task to detect occasional non-words. A centroparietal negativity (N400) with a peak latency of about 400 ms varied in amplitude as a function of frequency in both classes. The N400 in closed class items, however, was considerably smaller than that in open class words of similar frequency. A left anterior negativity (N280/LPN) showed some degree of frequency-sensitivity regardless of word class. Only for the very high frequency closed class words a frontal negativity with an onset of about 400 ms was obtained (N400–700). This N400–700 effect was replicated in the second study, in which medium frequency closed and open class words and very high frequency closed class words were presented at the fifth position of simple German sentences. It is suggested that neither N400 nor the left anterior negativity (N280/LPN) distinguish qualitatively between the two word classes and thus claims about different brain systems involved in the processing of open and closed class words are not substantiated electrophysiologically. The N400–700 effect is possibly related to specific grammatical functions of some closed class items, such as determiners.

Keywords: Event-related potentials; Language; Closed class words; Open class words; Function words; Content words; N400; Lexical processing negativity

1. Introduction

Traditionally, words are grouped into two basic types of words: open and closed class or content and function words, respectively. Open class words include nouns, verbs, adjectives and most adverbs, and the characteristic of the open class is that new words can be added as the language changes (e.g. computer, fax, rocket). Open class words carry the bulk of the semantic meaning of an utterance, hence their second label content words. The closed class (function) words on the other hand comprise determiners, pronouns, conjunctions, prepositions and a number of particles that serve the purpose of syntactically structuring a sentence. This class of words tends to be conserved over time, which led to the term closed class. Implicitly, the different word classes differ on a variety of other dimensions as well. For example, open class words, on average, are less frequent, have more letters, are more concrete, have higher ratings for imageability etc. The actual differentiation between open and closed class words, however, at times proves difficult. This can be attributed partially to the fact that some closed class words historically

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have been derived from open class words. Examples are the English preposition *while* and its German counterpart *während*. Some authors (e.g. [14]) have therefore advanced the view that the differentiation into open and closed class words is not clear-cut but rather that the two word classes represent a continuum. A clear-cut classification of words as belonging to the closed or open class by this view is possible only for those words that are placed on the outer edges of this continuum.

This view can be contrasted with findings from neuropsychology that have been taken to suggest that the processing of open and closed class words is subserved by separable brain systems. Evidence for this view has come primarily from observations on patients that showed a differential impairment for open or closed class words. For example, agrammatism is a symptom often observed in Broca's aphasia characterized by the omission of closed class words and morphological features of content words [10]. Friederici [8,9] found a selective slowing in lexical decision times for closed class items in Broca's but not Wernicke's aphasics, thus suggesting a separate mechanism responsible for the processing of these words. On the other hand, there are patients that appear to have a selective impairment for the retrieval of open class words from the lexicon, a syndrome which is called anomic aphasia [1].

In normal subjects, evidence for a different processing of the two word classes comes from lexical decision data. While initial claims of a frequency dependency of lexical decision times in open but not in closed class words [2] have not been confirmed [11,12,25], a robust finding seems to be a stronger right visual field advantage for closed class compared with open class words on tachistoscopic half-field presentation [3,6,19]. Taken together, these neuropsychological and behavioral studies are anything but conclusive with regard to the question as to how the processing of closed and open class words is implemented in the brain. Not surprisingly, a number of researchers have turned to the recording of event-related brain potentials (ERPs) to address this issue. ERPs are voltage fluctuations that can be recorded from the intact scalp synchronous to cognitive events [13]. They can be recorded in a wide variety of psychological tasks including the language domain. In a seminal paper, Kutas and Hillyard [16] reported a negative wave with an onset of approximately 250 ms and a peak latency of about 400 ms in response to written words that semantically did not fit the preceding context. This component, the N400, has been the most robust finding with regard to ERPs and language (for reviews see [7,18]).

With regard to the differences between function words and content words, a number of papers using different designs have appeared. Van Petten and Kutas [28] visually presented sentences, syntactic prose (i.e. sentences that had a preserved grammatical structure but no meaning) and random sequences of words. A major difference between closed and open class words was an anterior negativity for the former. Because of its waveshape and the fact that the closed class words often serve to introduce a new phrase, Van Petten and Kutas compared this ERP phenomenon to the contingent negative variation (CNV) and tentatively interpreted it in terms of expectancy.

Neville et al. [21] similarly presented sentences and found a variety of effects that appeared to differentiate closed and open class words: (1) a negativity with a left anterior temporal maximum at 280 ms for the closed but not the open class words; (2) a posterior, slightly right preponderant negativity peaking at 350 ms for the open class words; (3) a left late negativity (called N400–700) for closed class items. This was described to be the largest over left frontal regions, but in fact was seen with almost equally large amplitude over parietal areas. Neville et al. [21] included all words of the presented sentences except the first and the last words in the averages. Frequency was only assessed for the open class. From their description most of their closed class items must have had very high frequencies (articles, conjunctions, pronouns). No attempt was made to match the two word classes for frequency.

In a recent study, King and Kutas [15] (see also [17]) visually presented sentences with open and closed class words coded for both frequency and length. They presented evidence that the left anterior negativity (N280 of Neville et al. [21]) is in fact present for open *and* closed class items and that this negativity varied in latency as a function of frequency and length (with more frequent and shorter items having shorter latencies). They therefore coined the term LPN (lexical processing negativity) for this component. In addition, they also found that the later posterior negativity (N400) did not distinguish qualitatively between the two word classes but was also dependent on word frequency. A similar approach was taken by Brown et al. [4]. These authors, working with the Dutch language, found an anterior negativity to vary in latency as a function of word class but not as a function of word frequency, a finding interpreted as the earliest sign of the availability of categorical information from the mental lexicon. In an additional study [27], this group found that Broca aphasics lacked the differentiation of the early component as a function of word class. Finally, Osterhout and colleagues [23] visually presented normal or scrambled prose. These authors reported a correlation of the latency of an early negativity and the mean normative frequency and mean length of the words regardless of word class. Osterhout et al. [23] did not distinguish between the N280/LPN and the N400 component and — although they found differences in scalp distribution of the negativities to the two word classes — found their results inconsistent with the claim that qualitatively distinct negativities are elicited by open and closed class items.

While it is the advantage of the aforementioned studies using sentences or prose that they assess the electrophysiological concomitants of word processing in a quasi-natural setting, the fact that closed class items tend to be repeated quite often in the course of a study is potentially troublesome. This is illustrated by the point that King and Kutas actually obtained averages of multiple presentation of one word (e.g. *a*, *the*, etc.). Similarly, 120 articles and 130 prepositions were entered in the averages of Osterhout et al. [23]. As repetitions are known to have quite strong effects on ERPs (see, e.g., [20]) any differences between closed and open class items might have been partially due to repetitions for the former but not for the latter class in the aforementioned studies.

A somewhat different approach was taken by Nobre and McCarthy [22], who visually presented word lists (one at a time) with the subjects' task being to press for synonyms within this list. They did not systematically manipulate word frequency. In contrast to King and Kutas [15], Nobre and McCarthy [22] did not observe an N400–700 component. Closed and open class words were also distinguished in terms of the amplitude of the elicited N400 response, which was larger for the open class words. No systematic assessment of the N280/LPN was reported by these authors.

In a study using a lexical decision task, Pulvermüller et al. [24] presented high frequency (1000–10,000 per 9.5 million words) German closed and open class words. They reported differences for an early component (N160) between the two word classes. Differences for the N280/LPN, N400, and N400–700 were not explicitly analyzed and reported.

A possible criticism that can be put forward regarding the use of word lists is that differences in processing between open and closed class words might occur only when these words are encountered in sentence context. Thus, both approaches taken so far in the analysis of electrophysiological differences of open and closed class words have short-comings, word-repetition in the case of the sentence-based studies and the possibility of natural processing not being engaged in the case of the word-list studies.

Table 1
Information on word stimuli

Class	Category	Frequency	Length	No. of words
Closed	Very high	21,946	3.17	35
	High	2892	5.68	108
	Medium	689	6.66	65
	Low	42	7.18	32
Open	High	1760	6.56	75
	Medium	549	6.85	66
	Low	9.4	4.71	76

In the present communication we therefore report a word-list and a sentence-reading experiment using German closed and open class words covering a wide range of frequencies. As it is the main characteristic of most closed class words to have a very high frequency, we did not try to equate closed and open class words for frequency as this would inevitably lead to the overrepresentation of odd words (like *henceforth* in English or *obgleich* in German). Rather, we grouped the words of both classes into several categories of frequency. The first experiment used a lexical decision task and the words were presented visually in the form of a list. The following questions were asked:

1. Is the N400 response for closed and open class words frequency dependent and is the amplitude for a given frequency equivalent for the two classes?
2. Is the N280/LPN present for both word classes?
3. Is the N400–700 confined to sentence contexts or can it be observed in word lists as well?

The second experiment was a sentence-reading experiment and followed up several questions raised by the first experiment.

2. Experiment 1

2.1. Methods

2.1.1. Subjects

Sixteen young healthy subjects (11 women, mean age 25.6 years, range 22–32), with normal or corrected to normal vision, participated in the experiment. All were native speakers of German and right-handed by self-report. The data of one subject was lost for analysis due to technical failure.

2.1.2. Stimuli

The stimuli were prepared using the CELEX database [5], which consists of 6 million German word-tokens and 359,611 different word forms. A total of 227 function and 211 content words were selected and classified according to word frequency and word length, as detailed in Table 1. In addition, 47 pronounceable non-words were constructed by changing one or two letters in existing German words. Non-words had a mean length of 4.8 letters. These stimuli were arranged in a list in pseudo-random order. The words were presented in small letters (eight subjects) or all capital letters (eight subjects) in yellow against a dark-blue background in the middle of a videomonitor. The duration of the words was 300 ms, the interstimulus interval was fixed at 1800 ms.

The subjects had to read the stimuli and press a button held in the right hand whenever they detected a

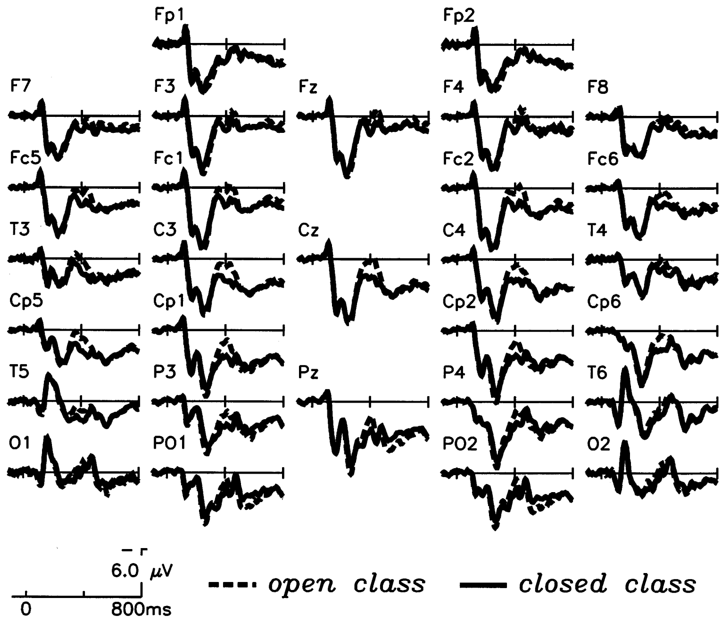

Fig. 1. Experiment 1: grand average ERPs for all open and closed class words averaged across all frequencies. Word classes are distinguished by a negativity with centro-parietal maximum being larger for the open class words (N400).

non-word. At the viewing distance of 80 cm, the words subtended 1.2° of visual angle in height and five letter words subtended 3.8° of visual angle in width. The list was presented in three blocks of 6-min duration.

2.1.3. Recording and analysis

EEG was recorded from 29 scalp electrodes including all standard sites of the 10/20 system (Fp1/2, F3/4, C3/4, P3/4, O1/2, F7/8, T3/4, T5/6, Fz, Cz, Pz, Fc1/2, Fc5/6, Cp1/2, Cp5/6, Po1/2) using tin electrodes mounted in an electrode cap (Electro-Cap), with reference electrodes placed at the mastoid processes. Biosignals were collected using one of the mastoid electrodes as a reference. Off-line the data were algebraically re-referenced to the mean of the activity at the mastoid processes. Additional electrodes were affixed at the right external canthus and at the right lower orbital ridge to monitor eye movements for later off-line rejection.

The biosignals were amplified with a bandpass from 0.01 to 100 Hz, digitized at 250 points per second and stored on a magnetic disk. After artifact rejection by an automated procedure, ERPs were averaged for 1024 epochs with a 100-ms prestimulus interval.

The waveforms were quantified by mean amplitude and latency measures in time windows indicated in Section 2.2. Measures were taken without further filtering the data with the exception of the LPN component, for which in some cases, indicated in the Section 2.2 (following previous authors [15]), a digital bandpass filter (4–13 Hz) was used. These measures were subjected to repeated measures analyses of variance. Since effects were differentially distributed over the scalp, separate analyses were done for the midline (ml; Fz, Cz, Pz), parasagittal (ps; Fp1/2, F3/4, C3/4, P3/4, O1/2), and temporal (te; F7/8, T3/4, T5/6) electrodes, with the latter two sets split into an electrode site and a hemisphere factor. The Greenhouse–Geisser correction for inhomogeneities of covariance was applied whenever applicable. Reported p-values are corrected.

2.2. Results

Performance in the non-word detection task was virtually perfect (92.8% non-words detected, 1.5% false alarms). The false alarms were not differentially distributed across the different word classes. The mean reaction time was 749 ms (SD 83).

2.2.1. Open vs. closed class words, general differences

The grand average waveforms for all open and all closed class words are given in Fig. 1. As these averages are confounded by the different overall frequency; we will consider them only briefly before examining the effects of frequency on the two classes in more detail. The ERPs are characterized by an initial negativity followed by a steep positivity peaking at about 230 ms. No difference was seen in the time window 160–200 ms, i.e. for a component termed N160 by Pulvermüller et al. [24] (main effect of word-type: ml: $F(1,14) = 0.55$, n.s.; ps: $F(1,14) = 0.35$, n.s.; te: $F(1,14) = 0.17$, n.s.). Open and closed class words differ from approximately 300 ms post stimulus in that the former give rise to a typical monophasic negativity (N400) that was seen only to a lesser degree in the closed class words peaking at about 400 ms. For the posterior electrodes, a late

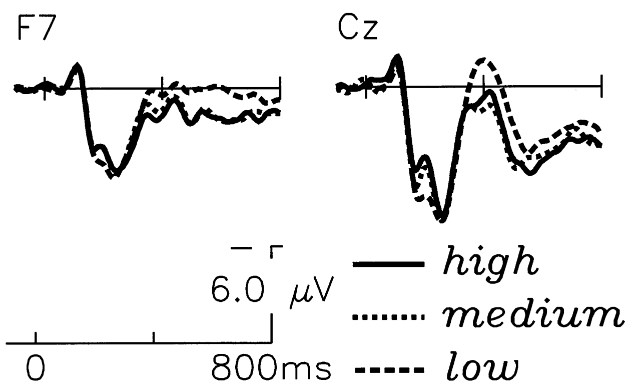

Fig. 2. Experiment 1: grand average ERPs for the open class words at selected scalp sites. The N400 component is most prominent for the low frequency words.

positivity is present for the open class words. At the left frontolateral site, no clear difference of the so-called LPN was seen.[1] Statistically, the difference between open and closed class words was reflected in a main effect of word-type in the 350–420 ms window (ml: $F(1,14) = 17.32$, $p < 0.001$; ps: $F(1,14) = 10.41$, $p < 0.007$; te: $F(1,14) = 29.63$, $p < 0.0001$) and the differential distribution of the N400 gave rise to a word type by electrode site interaction (ml: $F(2,28) = 3.81$, $\varepsilon = 0.959$, $p < 0.04$; ps: $F(3,42) = 8.96$, $\varepsilon = 0.433$, $p < 0.008$; te: $F(2,28) = 1.48$, n.s.).

2.2.2. Word frequency effects, open class words

Fig. 2 depicts the grand average ERPs for the three different frequency classes of open class words. Clearly, low frequency words were associated with a larger N400 amplitude than the medium and high frequency words, with this negativity displaying the typical centroparietal N400 distribution (see Fig. 3, left side). This was reflected in a main effect of frequency in the 350–420 ms time window (ml: $F(2,28) = 7.37$, $\varepsilon = 0.609$, $p < 0.015$; ps: $F(2,28) = 7.17$, $\varepsilon = 0.692$, $p < 0.015$; te: $F(2,28) = 16.63$, $\varepsilon = 0.837$, $p < 0.0001$). Pairwise post hoc analyses indicated that the N400 amplitude in the low frequency items was significantly different from that of the high and medium frequency words for all electrode sets (all $p < 0.05$). The medium and high frequency words did not differ significantly. This effect was differentially distributed over the scalp, thus leading to a frequency × electrode site interaction (ml: $F(4,56) = 2.91$, $\varepsilon = 0.684$, $p < 0.05$; ps: $F(6,84) = 6.93$, $\varepsilon = 0.388$, $p < 0.003$; te: $F(4,56) = 2.94$, $\varepsilon = 0.534$, n.s.).

The late positivity following the N400 appeared to vary in latency as a function of frequency, but an ANOVA on a P3 peak latency measure at the Pz site (maximum effect) did not reveal a significant effect (high 537 ms, SD 33; medium 548 ms, SD 33; low 550 ms, SD 32; $F(2,28) = 1.20$, $\varepsilon = 0.979$, n.s.).

In the grand average ERPs shown in Fig. 2 no clear-cut anterior left negativity (N280/LPN) in the 280–350 ms latency range was observed. This might have been due to overlap with later components. We therefore employed a digital filter (4–13 Hz). Fig. 4 (lower panel) shows the result of this procedure for the electrodes previously reported to show the maximal effect (F7, Fc5, F3). In fact, their appeared to be a monotonic, albeit non-significant, relationship between word frequency and peak latency of the emerging nega-

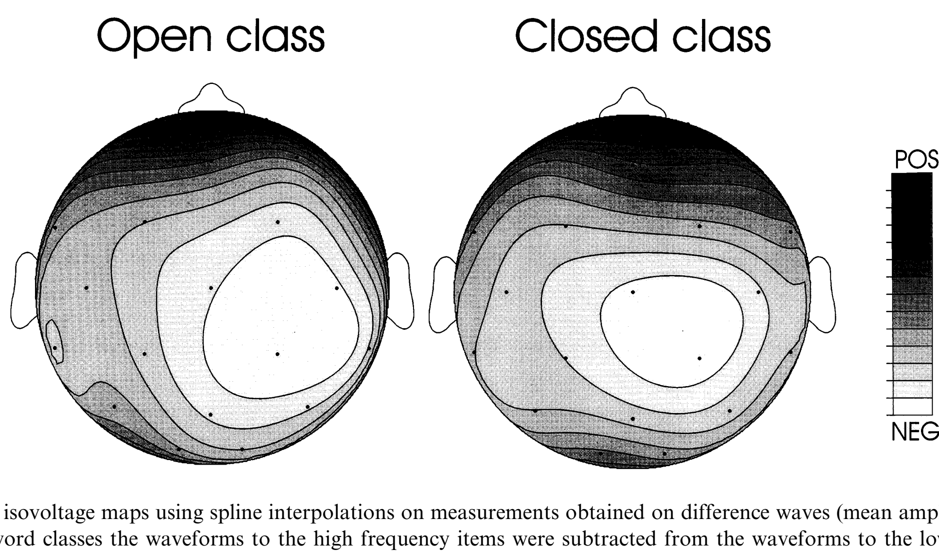

Fig. 3. Topographical isovoltage maps using spline interpolations on measurements obtained on difference waves (mean amplitude in time window 350–420). For both word classes the waveforms to the high frequency items were subtracted from the waveforms to the low frequency items. In both cases a typical N400 distribution with a right centro-parietal maximum emerged.

[1] An ANOVA on mean amplitude within the 280–370 ms time window (electrodes F7, F3, Fc5) did not reveal a main effect of word-class; $F(1,14) = 0.13$, n.s. (measured after digital filtering as described by King and Kutas [15] with 4–13 Hz).

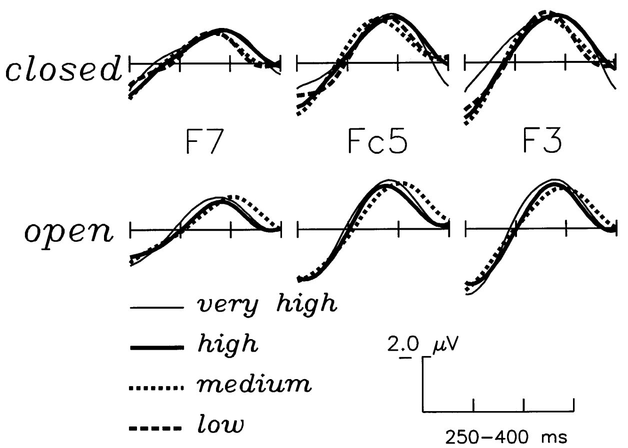

Fig. 4. Experiment 1: lexical processing negativity. After bandpass filtering (4–13 Hz), a negativity at left fronto-temporal sites is visible that shows some latency variability as a function of frequency (see text).

tive peak (high 340 ms, SD 30; medium 352 ms, SD 30; low 356 ms, SD 21; $F(2,28) = 1.41$, $\varepsilon = 0.774$, n.s.). To illustrate the constant location of the N280/LPN component across frequency bins and word classes the scalp topography for high and low frequency words is illustrated in Fig. 5.

With regard to the N160 effect described by Pulvermüller et al. [24], no systematic difference was seen for the three different frequency bins (main effect of frequency, mean amplitude 160–200 ms, ml: $F(2,28) = 0.56$, n.s.; ps: $F(2,28) = 2.91$, n.s.; te: $F(2,28) = 1.6$, n.s.).

2.2.3. Word frequency effects, closed class words

The grand average for the closed class words is depicted in Fig. 6. Several effects can be observed as a function of word frequency. At centro-parietal sites an N400 modulation is present in that the medium and low frequency words are associated with an N400 while those of high and very high frequency gave rise to only a rudimentary negativity (see also Fig. 3, right side). While the ANOVA on the 350–420 ms mean amplitude measure failed to reveal a main effect of frequency (ml: $F(3,42) = 1.50$, $\varepsilon = 0.748$, n.s.; ps: $F(3,42) = 1.10$, $\varepsilon = 0.746$, n.s.; te: $F(3,42) = 1.36$, $\varepsilon = 0.82$, n.s.), the differential distribution of the frequency effect was reflected in a frequency × electrode site interaction only for the parasagittal rows ($F(9,126) = 2.87$, $\varepsilon = 0.291$, $p < 0.05$). Again, no clear LPN was visible on inspection of the grand-average. The bandpass-filtered (4.0–13.0 Hz) ERPs in the LPN latency range for the F7 electrode are shown in Fig. 4 (upper panel; see also Fig. 5 for distribution). When measured on the individual subjects, no significant differences emerged for the latency of this negativity (very high: 339 ms, SD 27; high: 337 ms, SD 18; medium: 337 ms, SD 30; low: 342 ms, SD 29; $F(3,42) = 0.17$, n.s.).

With regard to the N160, again no significant differences were found for the frequency factor (ml: $F(3,42) = 0.69$, n.s.; ps: $F(3,42) = 0.61$, n.s; te: $F(3,42) = 1.64$, n.s.). Beginning approximately 400 ms after the word onset, a pronounced effect was seen for the very high frequency words only in that these were associated with a long stretched (relative) negativity lasting for the rest of the recording epoch. This effect was more pronounced at anterior recording sites, yet extended as far back as parietally. It did not show a marked asymmetry. Visual inspection suggests that the effect might be a composite of actually two phenomena: (1) a more negative ERP at frontal sites for the very high frequency closed class words; and (2) a late positivity present for all word classes except for the very high frequency closed class words. An ANOVA on the mean amplitude in the 400–700 ms time window revealed a highly significant main effect for word frequency (ml: $F(3,42) = 8.94$, $p < 0.001$; ps: $F(3,42) = 8.81$, $p < 0.001$; te: $F(3,42) = 3.79$, $p < 0.04$) and the differential distribution led to a frequency by electrode site interaction (ml: $F(6,84) = 0.46$, n.s.; ps: $F(9,126) = 4.51$, $p < 0.008$; te: $F(6,84) = 6.24$, $p < 0.002$). The post hoc pairwise comparisons revealed that this effect was entirely due to the very high frequency items being different from all other frequency bins (all $p < 0.05$, except te comparison of very high vs. high, $p = 0.08$). All main and interaction effects regarding the hemisphere factor were non-significant.

2.2.4. N400 in open and closed class words

In Fig. 7 the mean N400 amplitude (window 350–420 ms) is plotted against the log-frequency of the different word classes. A frequency dependent amplitude modulation becomes apparent for both word types, but there appears to be a contribution of word type as well. In fact, the N400 amplitude values of the high frequency content words and the low frequency function words appear to be very similar. Conversely, the N400 amplitude for medium frequency closed and medium frequency open class words, which have very similar frequencies, differed markedly (interaction effect of word class × electrode site, 350–420 ms mean amplitude: ps, $F(4,56) = 5.95$, $\varepsilon = 0.442$, $p < 0.008$).

2.3. Discussion

The present set of data varies in several important respects from previous ERP experiments addressing differences of open and closed class words. We will consider these effects in the order of their occurrence using the labels established by other authors:

2.3.1. N160

Pulvermüller et al. [24] found a difference between closed and open class words for an early component (termed N160). This finding was not replicated by the

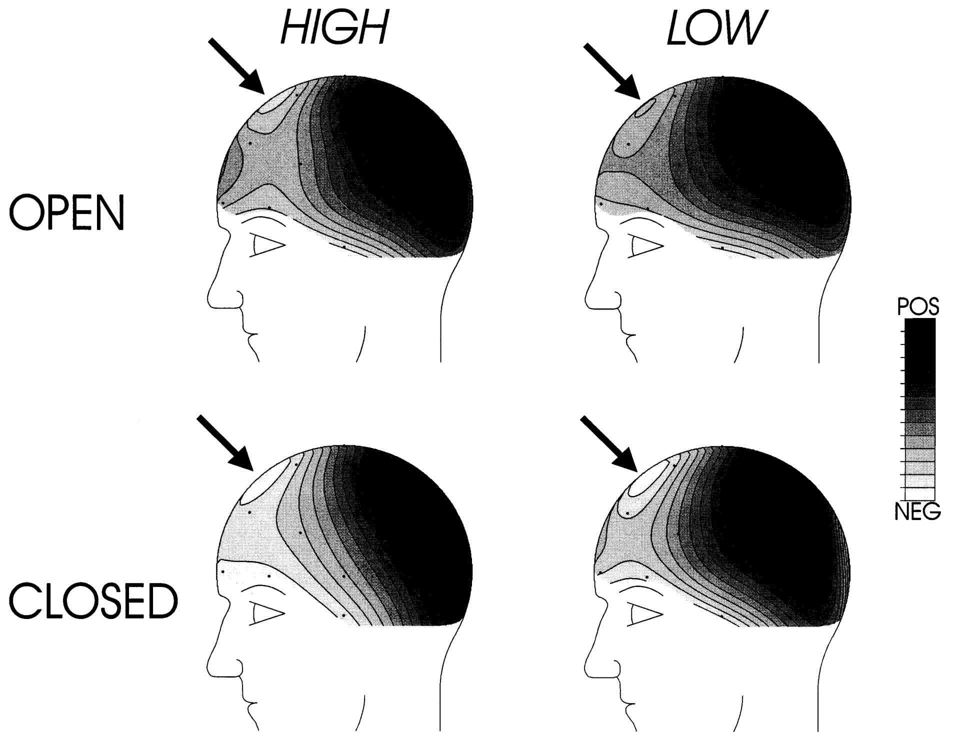

Fig. 5. Experiment 1: scalp maps showing a uniform distribution of the N280/LPN. Depicted are interpolated mean amplitude measurements taken on the bandpass filtered (4–13 Hz) ERPs in 40 ms time windows centered upon the peak in the grand average.

present study. There was no difference in N160 for the overall comparison between function and content words, nor were there differences found as a function of frequency in both word classes. At present it is unclear why Pulvermüller et al. [24] appears to be the only study, in which a difference for the N160 was found.

2.3.2. N280/LPN

The LPN was barely visible in the grand averages, possibly due to the overlap with the adjacent N400 component. After digital filtering (4–13 Hz), a left anterior negativity could be observed. Except for the very high frequency closed class words, there was a (non-significant) tendency of the latency of this negativity to be slightly later for less frequent words, thus partially confirming the results reported by King and Kutas [15]. The amplitude of the LPN did not differ significantly for open and closed class words and did not show a significant effect of frequency in either of the word classes. This finding is at odds with Neville et al., who interpreted their N280 response in terms of a class specific electrophysiological trait confined to closed class words, an interpretation that is inconsistent with the current data as well as the data of King and Kutas [15] and Osterhout et al. [23]. A number of differences between the Neville et al. [21] and the current study might account for these discrepancies.

A salient possibility is that the LPN effect reported by Neville et al. [21] might be coupled to the presentation of words within sentences, whatever the exact nature of the underlying process might be. Another possibility is that repetitions of closed class words in that study might have contributed to their effect.

2.3.3. N400

In accordance with previous work [15,28] an N400 effect was present for both classes of words. Thus, the N400 cannot be viewed as being elicited by open class words only. However, while the N400 amplitude showed some orderly relation to word frequency within both classes, the absolute size for open class and closed

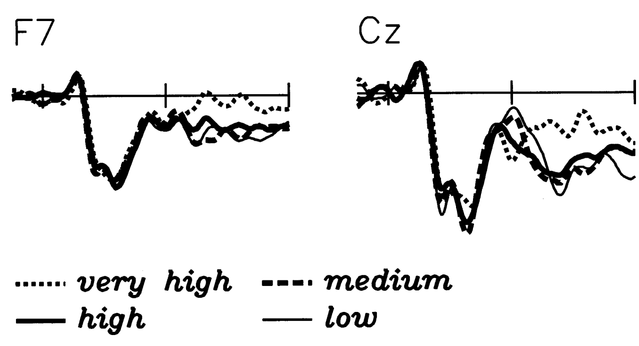

Fig. 6. Experiment 1: grand average ERPs to the closed class words. There is some modulation of the N400 (centro-parietal sites) as a function of frequency with the low frequency words having the largest relative negativity. Only very high frequency closed class words are associated with an extended negativity starting at about 400 ms (N400–700).

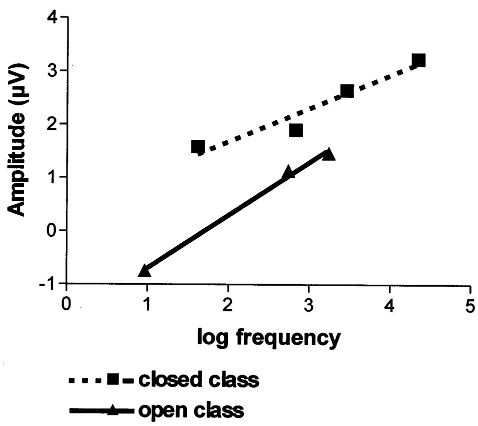

Fig. 7. Experiment 1: mean amplitude in the 350–420 ms window (Cz derivation) plotted against mean logarithmic frequency of the different word categories. A clear frequency sensitivity of N400 is shown for both word types with closed class words having lower amplitudes. Note that, because N400 is superimposed on a positivity, actual voltages can be positive.

class words of similar frequency varied greatly, with closed class words' N400 being considerably smaller. Numerous studies have shown that besides word frequency, the N400 amplitude is sensitive to semantic, contextual and associative relations [7,18]. Rather than a failure to generate an N400 per se, such factors as an impoverished meaning, less semantic and associative relations to other entries in the mental lexicon might be responsible for the smaller overall N400 in this word class.

2.3.4. N400–700

A more negative going wave was present only for the very high frequency closed class words beginning approximately 400 ms after word onset and extending for the rest of the recording epoch. This N400–700 component had a distribution similar to the one seen in Neville et al. [21] in that it had an anterior maximum but extended well into parietal areas. On the other hand, its distribution differed considerably from the anterior negativity first described by Van Petten and Kutas [28]. As pointed out above, it appeared from the waveform morphology that the extended distribution of the N400–700 in this experiment might be due to a frontal negativity to the closed class words of very high frequency overlapping with a posterior late positivity for the other word categories. To our knowledge, an N400–700 has not been demonstrated in word lists before and neither Van Petten and Kutas [28] nor Neville et al. [21] reported frequency effects on this negativity. An obvious question is why this negativity is only observed for the very high frequency closed class words. It has been [28] suggested that the anterior negativity observed in their sentence-reading study for closed class words might be related to expectancy, as closed class items often serve as the initial word in a new sentence unit. It is conceivable that different closed class words differ in the degree of expectancy that they elicit. For example, determiners appear to be more closely linked to the following word and might therefore entail a higher degree of expectancy. Examination of our stimulus lists shows that determiners are accounting for slightly over a third (12/35) of the very high frequency closed class words but for considerably smaller proportions of the high (14/108), medium (6/65) and low (1/32) frequency closed class words.

One might argue that in a word-list experiment as used in the present study there is no reason for the subject to develop expectancies regarding the next stimulus. In view of the highly automatized and overlearned character of language, it appears not unlikely, however, that many of the usual processing routines would also be engaged in the word-list experiment. Nevertheless, it is critical for the interpretation of the N400–700 in the present experiment to replicate the differential effects of closed class word frequency on this component in a sentence paradigm (see experiment 2).

A second very obvious difference between the very high frequency closed class words and the closed class words from the other frequency classes is that they are shorter. While shorter words can be associated with a more negative waveform than longer words over anterior scalp sites [21], this effect has been reported to have a different morphology and an earlier onset latency.

3. Experiment 2

Several findings of the first experiment called for a replication by a sentence-reading experiment similar to those already published [15,21,23]. However, again we wanted to exclude repetitive presentations of the same stimuli. Critical stimuli were very high frequency and medium frequency closed class and medium frequency open class words (see experiment 1) that were embedded in simple declarative sentences.

The following questions were asked:

1. Will the N400–700 effect obtained for very high frequency closed class items only in experiment 1 be found in a similar fashion in the sentence-reading study?
2. Does the LPN difference between closed and open class words reported by others but not seen in experiment 1 reoccur when stimuli are presented in sentences?

3.1. Methods

3.1.1. Subjects

Twelve young healthy German speaking subjects (six women, age range 23–36, mean 25 years) participated. All were right-handed by self-report and had normal or corrected to normal vision. No subject had participated in experiment 1.

3.1.2. Stimuli

From the stimuli of experiment 1 we selected words from the following three categories: *very high frequency closed class* (35 words, mean length 3.17 letters, mean frequency 21,948); *medium frequency closed class* (54 words, mean length 6.66, mean frequency 689); and *medium frequency open class* (66 words, mean length 6.85, mean frequency 549). These were presented in simple declarative sentences with the critical words always being shown at the fifth position of the sentence. The length of the sentences varied between 6 and 10 words.

Examples:

1. closed class high frequency: Der Patient wird heute *noch* entlassen.
2. closed class medium frequency: Der schöne Mann wurde *schon* oft verwechselt.
3. open class medium frequency: Mit Geld kann man *Eindruck* machen.

Each sentence started with a blank screen (2400 ms) followed by the successive presentation of the words (SOA 700 ms, duration 400 ms). Stimuli were presented in yellow letters against a dark blue background. The task of the subject was to read the sentences in order to answer a questionnaire presented after the experimental blocks. The stimuli were presented in two blocks of approximately 9 min duration.

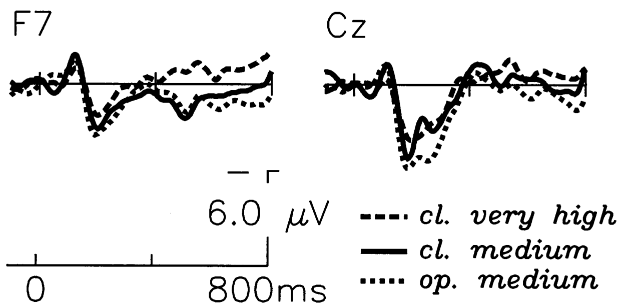

Fig. 8. Experiment 2: grand average of the critical (fifth) word of the sentences. Only the very high frequency closed class words are associated with an N400–700 component.

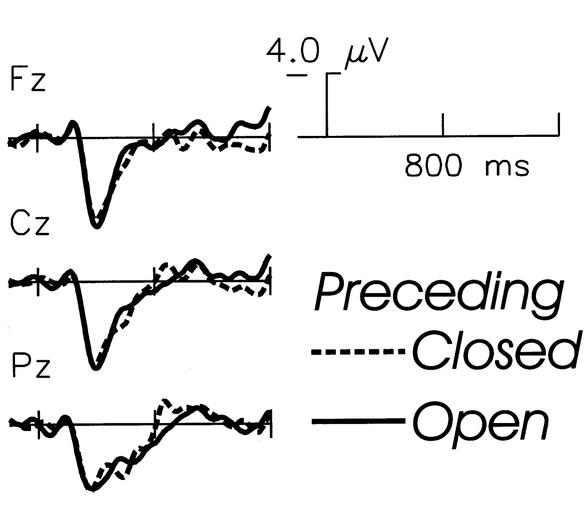

Fig. 9. Experiment 2: ERPs to words preceding the open and closed class words at the fifth position. No difference is found.

3.1.3. Recording and analysis

All aspects of recording and analysis were similar to experiment 1.

3.2. Results

The grand average ERPs to the critical words are shown in Fig. 8. A number of differences between the three word classes are readily apparent. At the left fronto-temporal sites a negativity was seen, which appeared to be similar for medium frequency open and closed class words but earlier and of higher amplitude for the very high frequency closed class words. This was reflected in a main effect word-type in an ANOVA on the 250–350 mean amplitude measure at the F3, Fc5, F7 electrodes ($F(2,22) = 5.68$, $\varepsilon = 0.78$, $p < 0.015$).[2] The latency of this component was (measured on band-pass-filtered data, 4–13 Hz) 335 ms (SD 29) for the very high frequency closed class, 344 (SD 30) for the medium frequency closed class, and 353 ms (SD 25) for the medium frequency open class words ($F(2,22) = 5.35$, $\varepsilon = 0.60$, $p < 0.04$).

As in the word-list experiment, only the very high frequency closed class words elicited a ramp shaped negativity starting at approximately 400 ms. However, in the sentence task the distribution was confined to anterior electrode sites and showed a left-sided maximum. Statistically, there was no main effect of word type for the 400–700 ms mean amplitude measure, but the circumscribed distribution of the N400–700 gave rise to word type by electrode site (ps: $F(8,88) = 3.23$, $\varepsilon = 0.376$, $p < 0.035$; te: $F(4,44) = 4.12$, $\varepsilon = 0.47$, $p < 0.03$; ml: $F(4,44) = 3.10$, $\varepsilon = 0.821$, $p < 0.05$) and word type by electrode site by hemisphere interactions (ps: $F(8,88) = 3.13$, $\varepsilon = 0.776$, $p < 0.04$; te: $F(4,44) = 3.18$, $\varepsilon = 0.67$, $p < 0.04$). With regard to the N400 component, no clear-cut difference at the centro-parietal electrode sites emerged between closed and open class words of medium frequency. Statistical analyses did not reveal any significant main or interaction effects of word type.

As it was of concern that the closed class and open class words at the critical fifth position were preceded by different words, which might have led to differential carry over effects into the recording epoch of interest, the ERPs to the words preceding open and closed class words are shown in Fig. 9. Neither on visual inspection

[2] In the ANOVA on all temporal electrodes, this LPN effect was reflected by a word-type × electrode-site × hemisphere interaction ($F(4,44) = 7.28$, $\varepsilon = 0.45$, $p < 0.004$).

nor on statistical analysis (time windows as above, all $F < 1$ for main and interaction effects of word type) were differences seen between the words that preceded open and those that preceded closed class words.

3.3. Discussion

Several important differences emerged between the sentence-reading task and the word-list task used in experiment 1. The N280/LPN effect was seen more easily in the sentence data and the latency measure taken on this component showed its sensitivity to frequency of the eliciting word, thus confirming the observations of King and Kutas [15] and Osterhout et al. [23].

The N400–700 effect for only the high frequency closed class items was replicated. However, in comparison to the word-list experiment the effect had a much more circumscribed topographical distribution with a maximum at left anterior sites, and now resembled the distribution shown by Van Petten and Kutas [28].

As for the third component of interest, the N400, no significant differences emerged between the different word types in the present experiment. This can be attributed to a number of differences to the first experiment. The medium frequency words were chosen to have a very similar frequency and length in the present experiment. Second, it is well established that effects of word frequency on open class words are attenuated in sentence contexts. For example, at positions 5 and onward, Van Petten and Kutas [28] did find an attenuation of the N400 and abolished differences between low and high frequency open class words in congruent sentences.

4. General discussion

Only a few previous studies have addressed electrophysiological differences between closed class and open class words. One group of studies sought to define qualitative differences between ERPs to closed and open class items with the notion that such differences would support the idea of different neural subsystems subserving the processing of the different word classes (see [21,22,24]). These studies are in the tradition of neuropsychological observations in aphasic patients [1,10].

Other researchers have stressed similarities between the two word classes [5,23,28]. For example, King and Kutas [15] observed that differences in the LPN-latency of the two word classes can be explained by taking the frequency (and length) of the eliciting words into account. While Osterhout et al. [23] analyzed their data with a different strategy, they similarly found a sensitivity of an early negativity to normative frequency and length.

The current set of data can be taken to support the line of reasoning of the latter two studies. Both the N280/LPN and N400 components seemed to be present in both lexical classes and the fact that the N400–700 effect was present only for the very high frequency closed class items does not, as will be discussed below, indicate a difference in terms of lexical organization of these items.

The N280/LPN has been viewed by Neville et al. [21] as being specific to closed class words and was therefore tentatively interpreted as reflecting the faster and automatic access to the representation of the eliciting word, while King and Kutas [15] showed the frequency dependency of the LPN and its similarity across lexical classes. The latter authors put forward the hypothesis that the LPN might be related to the control of eye movements during reading, based on its topography and similarities to no-go potentials in other tasks. In the present experiment, the LPN in the word-list task was not very well defined and rendered visible only after bandpass-filtering (Fig. 3), while it was clearly present in the sentence-reading task. This suggests that the LPN might indeed be related to natural reading processes requiring precise timing of saccades and inhibition of premature saccades as they might be engaged by the sentence-reading task to a greater extent. In turn this would lead to the prediction that an LPN should be absent in ERPs to auditorily presented words, a study that has not been undertaken to our knowledge. The LPN in the present experiment showed some latency effect as a function of word frequency (significant in the sentence-reading task) and was present in both lexical classes, thus confirming the observations of King and Kutas [15] and supporting the view that this brain potential does not reflect different neural systems for the processing of the two word classes.

For the N400 component, the word-list task showed its presence for open and closed word classes. Thus, the N400, as the LPN, can be ruled out as an electrophysiological feature supporting distinct neural systems for closed and open class words. However, while both classes were capable of eliciting an N400 response, the amplitude of the N400 of comparable frequency items of both classes differed markedly, being much smaller for the closed class words. In light of the evidence showing the sensitivity of the N400 amplitude to semantic aspects of the eliciting words [7,18], this difference is not surprising, as open class words are likely to be much more richly associated with synonyms, antonyms, super- and subordinate words and associatively related words in semantic memory than closed class words.

The only ERP effect that appeared unique to one of the word categories was the N400–700, which was seen only for the very high frequency closed class items. This finding has its precedences in the studies of Van Petten and Kutas [28] and Neville et al. [21]. In both of these studies, however, no attempt was made to differentiate the closed class words as a function of frequency. In their discussion of the effect, Van Petten and Kutas [28] emphasized that it was seen only in congruent text but not in syntactic prose and random word string conditions. This condition-specificity, they argued, indicated that this ERP component cannot be an obligatory marker of word class, but rather reflects a process tied to the processing of words in coherent text. In our study, however, we saw similar N400–700 effects in both, the word list and the sentence tasks, rendering the Van Petten and Kutas interpretation difficult.

The most intriguing aspect of the current data was the frequency dependency of the N400–700 that heretofore had not been reported. An interesting speculation regarding this frequency sensitivity concerns the fact that the closed class words in the different frequency brackets are composed quite differently, with determiners being much more common in the very high frequency than in the other categories. Adapting the argument of Van Petten and Kutas [28], it is conceivable that the N400–700 effect is tied to the function that a specific subset of the closed class words exerts. Assuming this, the present results would be compatible with the hypothesis of a single lexicon and a common mode of lexical access for open and closed class words, while a second process is responsible for syntactical information (cf. [26]). The N400 and the LPN found with both types of words could be tentatively interpreted as reflecting some aspects of lexical processing, while the N400–700 effect might reflect the activity of the syntactic processor. In order to test this hypothesis, experiments have to be done contrasting closed class words of different functions (e.g. determiners, conjunctions, prepositions), that are matched for length and frequency.

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