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Bernadette M Jansma
Maastricht University


Anna Zilverstand
University of Minnesota Twin Cities


Pienie Zwitserlood
University of Münster

Derivational morphology approached with event-related potentials

Jens Bölte[1], Bernadette M. Jansma[2], Anna Zilverstand[2] and Pienie Zwitserlood[1]
[1]Westfälische Wilhelms-Universität, Münster, Psychologisches Institut II, Germany / [2]Maastricht University, Faculty of Psychology, Department of Cognitive Neuroscience, The Netherlands

We investigated the processing of derived adjectives in German using event-related potentials (ERPs). ERPs were registered to existing adjectives (*freundlich*, 'friendly'), to morphologically complex pseudowords that were synonymous to an existing adjective and thus interpretable (**freundhaft*), and to complex pseudowords that were structurally and semantically anomalous (**freundbar*). Stimuli were embedded in sentence contexts, displayed word by word. An ERP effect with a left-frontal maximum was observed around 450–500 ms after stimulus onset. In this window, both pseudoword types differed from existing adjectives. We interpret this data pattern as a LAN, reflecting structural problems due to morphological parsing, a process that is distinct from semantic processing.

Keywords: morphology, derivation, ERP, semantics, visual word recognition, German

Skilled readers process and integrate graphemic, semantic, morphological, and syntactic information within a few hundred milliseconds, without apparent difficulty and with low demands on attention. The exact nature of the processes involved, as well as the time-course of specific linguistic information access, the degree of modularity or interaction is still the subject of debate. One way to disentangle on-line processes relevant to language understanding, which has become more prominent in the last two decades, is the use of event-related potentials (ERPs).

ERPs are electrical potentials induced by external stimulation and/or neuronal processing, reflected in onset or amplitude modulations of distinctive event-related potential (ERP)-components. Different ERP-components are associated with different types of linguistic processing, the most prominent distinction being between semantic and syntactic processing. The N400, a centro-parietally distributed

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negativity with an amplitude maximum around 400 ms after critical word-onset, is sensitive to the semantic fit of the word and its context and thus taken as an index of lexical-semantic processing and/or semantic integration (Kutas & Hillyard, 1980; see Kutas & Federmeier, 2007; van Petten & Luka, 2006, for overviews).

Other components are sensitive to structural processing. First, the left-anterior negativity (LAN), occurring between 300 and 500 ms post stimulus, resembles the N400 with respect to the time domain, but has a different scalp distribution. LAN effects are reported for word-category errors in sentences, and for morphosyntactic violations (Moreno, Federmeier, & Kutas, 2002; Münte, Heinze, & Mangun, 1993). An early variant of the LAN, occurring about 150 ms after stimulus onset, is supposed to reflect coarse syntactic processing at the level of word-class information (Friederici, Pfeifer, & Hahne, 1993). Second, a positive-going component with a maximum about 600 ms after stimulus onset, referred to as P600 or syntactic positive shift (SPS), is elicited by a whole range of syntactic violations such as number, gender, case-structure, phrase-structure and sub-categorization violations. It is taken to reflect structural reanalysis and repair processes (Friederici, 1995; Hagoort, Brown, & Groothusen, 1993; for overview, see Hagoort, Brown, & Osterhout, 1999).

The current study uses ERPs to investigate the processing of morphologically complex words — derived adjectives in our case. It is still controversial whether complex words are parsed into constituent morphemes during word recognition. Some suggest that morphological effects, as obtained in priming studies with pairs such as *fiendish – fiend*, are the by-product of semantic and phonological similarity (Plaut & Gonnerman, 2000; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997; Seidenberg & Gonnerman, 2000). Others believe that all morphological variants of a word are listed (Butterworth, 1983). More prominent are models in which morphological complexity is represented in addition to form and semantic information (Caramazza, Laudanna, & Romani, 1988; Drews & Zwitserlood, 1995; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Schreuder & Baayen, 1995).

The data that fuel this debate mainly come from research on the processing of verbal or nominal inflection. In fact, most evoked-potential and evoked-field (MEG) data on morphology are about inflection, and concern differences in processing and representation between regular (or default) inflection and irregular forms. The potentials that are affected by the regular/irregular distinction concern the N400 (Justus, Larsen, de Mornay Davies, & Swick, 2008; Münte, Say, Clahsen, Schiltz, & Kutas, 1999; Rodriguez-Fornells, Münte, & Clahsen, 2002; Weyerts, Münte, Smid, & Heinze, 1996), the P600 (Allen, Badecker, & Osterhout, 2003; Newman, Ullman, Pancheva, Waligura, & Neville, 2007), and the LAN (Gross, Say, Kleingers, Clahsen, & Münte, 1998; Lück, Hahne, & Clahsen, 2006; Morris & Holcomb, 2005; Newman et al., 2007; Penke et al., 1997; Rodriguez-Fornells, Clahsen, Lleó, Zaake, & Münte, 2001). Thus, ERP data support differences between regular and irregular words, as many behavioural (Clahsen, 1999, for an overview) and fMRI studies (e.g., Tyler & Marslen-Wilson, 2008; Tyler, Stamatakis, Post, Randall, & Marslen-Wilson, 2005) do. The common conclusion is that irregular forms are stored in lexical memory, and that parsing into constituent morphemes applies to regular words only. Interestingly, the distribution of ERP-effects over paradigms is extremely consistent. Studies showing N400-effects predominantly had a priming design, those who found LAN-effects used violation paradigms (regularising irregulars, and vice versa).

ERP studies on word formation — either by derivation or by compounding — are not abundant, but the evidence for early decomposition of derived or compounded words, provided by a host of behavioural studies (Feldman, 1995; Rastle & Davis, 2008; Schriefers, 1999, for overviews), is by now complemented by data from early EEG or MEG components. A number of studies using a (masked-) priming design revealed decomposition/parsing effects as early as 250 ms after stimulus onset (Barber, Dominguez, & de Vega, 2002; Dominguez, de Vega, & Barber, 2004; Lavric, Clapp, & Rastle, 2007; Morris, Frank, Grainger, & Holcomb, 2007; Morris, Grainger, & Holcomb, 2008). Interestingly, these parsing effects were similar when primes and targets shared their base morpheme (*hunter – hunt*, or Spanish *hijo – hija*, 'son' – 'daughter') than when this was not the case (*corner – corn*, or Spanish *rato – rata*, 'moment' – 'rat'). Thus, early decomposition proceeds even when it results in a wrong analysis.

Fiorentino and Poeppel (2004, 2008) observed an earlier onset of the M350 from MEG for compounds (*teacup*) than for frequency-matched simple words (*crescent*). Given that the M350-component is taken to reflect prelexical and early lexical processes (Pylkkänen & Marantz, 2003), the authors interpreted their findings as evidence for early decomposition. This conclusion was endorsed by Pylkkänen, Feintuch, Hopkins, and Marantz (2004), who observed an increased M350 amplitude for words with a high as compared to a lower morphological-family frequency.

Decomposition can also be investigated with the gender-agreement task used by Koester, Gunter, Wagner, and Friederici (2004; see also Koester, Gunter, & Wagner, 2007), who observed a LAN when constituents of German compounds had a different gender than the compound itself. Given that the constituents' gender can only play a role when a compound is indeed parsed into its constituents, this supports morphological parsing.

How do the designs that rather consistently showed particular EEG-effects with respect to inflectional morphology fare with derivation or composition? Not all priming designs elicit N400-effects. Some of the above-mentioned studies that observed early effects of decomposition also reported N400 effects even when parsing leads astray (as with *corner*). In fact, Barber et al. (2002) and Domínguez et al. (2004) regard their early parsing effect reported above — with an identical pattern for truly morphologically related pairs (*hijo* – *hija*, 'son – daughter') and pairs with stem homographs (*rato* – *rata*, 'moment – rat') — as an early N400 effect. They observed a dissociation between morphological and homographic pairs in a later N400 time window, reflecting the fact that morphological pairs are semantically related, and thus easily integrated, whereas homographic stem pairs are not. Thus, this is a semantic rather than a morphological effect.

Lavric et al. (2007), with masked primes, showed that the N400 was similar for morphologically complex words (*hunter* – *hunt*) and parsable words, whose decomposition results in the wrong analysis (*corner* – *corn*), but that both differed from words that were merely form-related to their primes (*brothel* – *broth*). But this result was not replicated by Morris et al. (2007), who found that complex words differed from both parsable and form-related words in the N400 window — again an effect that can easily be understood in terms of semantic processing. Yet another pattern was reported by Morris et al. (2008), who — with the same materials as Morris et al. (2007) — observed N400 priming effects for all three types of stimuli. So, the picture for the N400 component is not as clear with derivation as with inflection. All studies show early effects of decomposition, but it is not easy to reconcile the different N400 effects.

Data for derivation with pseudowords, with or without combinatorial violations, also show an inconsistent picture. Palmović and Maričič (2008) compared existing Croatian prefixed words with pseudowords consisting of illegal combinations of stem and prefix. They observed a LAN, followed by a P600, and argue for decomposition of derived words in Croatian. There were no differences in the N400 window between existing words and prefixed pseudowords. This is surprising, because existing words and (monomorphemic) pseudowords consistently diverge in the N400 (cf. Pulvermüller, Shtyrov, Kujala, & Naatänen, 2004). In fact, Palmović and Maričič replicated the N400 difference between words and monomorphemic pseudowords in their study. The same pattern was found by McKinnon, Allen, and Osterhout (2003), who used morphologically complex pseudowords such as **exceive*, and monomorphemic pseudowords such as **flermuf*. The latter showed the expected enhanced negativity in the N400 window when compared to existing words. But again, morphologically complex pseudowords and existing complex words (e.g., *receive*) did not differ at any point. So clearly, morphologically complex pseudowords and monomorphemic pseudowords are treated differently. The lack of an N400- "pseudoword effect" for derived pseudowords is indicative of decomposition (see Longtin & Meunier, 2005, for similar behavioural results).

In contrast to these findings, Janssen, Wiese, and Schlesewsky (2006), with a lexical decision task, observed an N400-like effect for pseudowords violating the rules of German derivation. It should be noted that the number of items used (10) was exceptionally low for an ERP study, which hampers generalisation. But Leinonen, Brattico, Järvenpää, and Krause (2008) also found a N400 for violations with respect to root and affix combinations in Finnish, in a sentence-acceptability task. So again, the data from pseudoword/violation studies are inconsistent — but the stimuli and tasks used are also quite diverse.

What can we learn from ERP studies on morphological complexity? First, N400 effects for morphological pseudowords have been taken to mean that they are processed as whole units (cf. Lück et al., 2006, Weyerts et al., 1996), just like pseudowords such as **flermuf*. As a consequence, not much can be learned about decomposition. If, on the other hand, no N400 effects are observed for morphologically complex pseudowords, they apparently are not treated as normal pseudowords. Such null result is usually considered as evidence for successful parsing and access to constituent morphemes. As noted above, N400 results for derived words or compounds are quite inconsistent, both with priming and with violation paradigms. As Morris et al. (2008, p. 22) note: "the N400 component might not be the best part of the ERP signal to use when seeking evidence for morphological processing". More promising for morphological decomposition are LAN-effects, given that this component reflects structural processing, at the level of complex words or sentences.

The present study

Our study is concerned with derivational morphology, a word generation process in which at least one free and one bound morpheme are combined (e.g., *cat* + *like* or *un* + *law* + *ful*). Contrary to inflection, derivation often involves a word class and/or meaning change. We focused on German derived adjectives, consisting of a base and a suffix. Interestingly, some German derivational suffixes are synonymous (e.g.,-*abel*, -*bar*, comparable to -'able'; Fleischer & Bartz, 1995). The language is free to choose one or the other suffix to create an adjective, as long as certain constraints are obeyed. There are a few instances where two derived adjectives with the same meaning exist: *akzeptierbar* and *akzeptabel* ('acceptable') are both derived from the verb *akzeptieren* ('accept'). Given that languages avoid synonymous forms, cases of full synonymy are rare, compared to partial synonymy (*bullenhaft*, 'bull-like'; *bullig*, 'beefy', 'stocky'). Suffix synonymy is restricted to certain classes of bases. For example, -*haft* and -*voll* can be synonymous when attached to nominal bases (as in the two existing forms *grauenhaft* and *grauenvoll*, 'gruesome') but not with verbal bases (*glaubhaft*, 'credible', but not **glaubvoll*). In fact, -*voll* is hardly ever attached to verbal bases.

This synonymy of the derivational suffix system is known, at least at an uncontrolled and unintended level, to German speakers, as erroneous productions show (*flitzend* → **flitzig* (Leuninger, 1993); *ersichtlich* → **ersichtbar*, personal observation). The fact that synonymous suffixes exist provides an interesting test case for morphological processing, allowing the construction of new, semantically interpretable adjectives that happen not to exist in German. These novel combinations are pseudowords, but given the meaning and use of the suffix, semantic analysis should be easy. In contrast, morphological parsing may lead to a structural problem, given that the two particular morphemes do not map onto an existing lexical representation. We labelled this condition "synonymous pseudoword".

The fact that constraints exist with respect to the combinability of suffixes and bases allowed for the construction of an additional condition. Here, we put together bases and suffixes that violate combinatorial constraints, for example by adding *-voll* to verb bases. In contrast to pseudowords of the synonymous condition, such combinations are often difficult to interpret (which we pretested), and we refer to this condition with "anomalous pseudoword". Thus, this condition combines a structural problem (the failure to map onto a lexical entry), a rule violation (the illegal combination of base and affix), and a semantic integration difficulty. As a baseline, we also included a condition with the adjective ("existing adjective"), from which all above mentioned novel combinations were derived. This adjective and the two derived pseudoword adjectives were presented in mid-sentence, in adverbial position in a sentence which was semantically appropriate for the existing adjective (see Table 1 below for examples).

Our predictions were the following. First, if both pseudoword types are treated like monomorphemic pseudowords of the **flermuf* type, we expected a difference between existing adjectives and both pseudowords in the N400 component. With respect to morphological parsing, this would be an uninteresting result because it implies that no decomposition has taken place. In contrast, the lack of a difference in the N400 between words and complex pseudowords is usually interpreted as evidence for successful parsing, and access to constituent morphemes. Of course, there could be N400-differences between the two types of pseudowords. If the anomalous condition shows an N400 effect relative to the existing and synonymous condition, this would imply that only the anomalous pseudowords are treated as monolithic wholes, for which lexical access (even to constituents) fails.

With respect to LAN effects, we expect the following. If the LAN effect, relative to existing adjectives, is similar for both pseudoword types, this implies that morphological parsing has taken place, resulting in a structural problem because there is no lexical match for the morphemes combined. The LAN might also differentiate between the two pseudowords, with larger effects for the anomalous adjectives. Given that the LAN is sensitive to structural rather than semantic aspects of stimuli, this would be indicative of the double structural problem — a combination failure plus a rule violation — in the anomalous condition. Finally, we might expect a P600 for the anomalous condition, showing a difficulty to reanalyse and "repair" the violations.

Method

Participants

Fifteen (11 female, 4 male) native speakers of German completed the experiment (mean age 22.6 years). All participants were right-handed, neurologically healthy and had normal or corrected-to normal vision.

Stimuli

We selected 60 existing morphologically complex adjectives which were presented in a semantically neutral, syntactically correct context. These existing adjectives constituted the *existing adjective* condition. Two different classes of pseudowords were made from the existing adjectives by altering the suffix. For existing adjectives such as *freundlich* ('friendly'), a synonymous suffix was added to the stem in the *synonymous pseudoword* condition (*freundhaft). Combining the same stem with a suffix which violates combinatorial constraints for this type of stem created the *anomalous pseudoword* condition (*freundbar). The synonymous pseudowords and the anomalous pseudowords were presented in the same context as the existing adjectives. Table 1 displays more examples.

Note, first, that none of the adjectives in the synonymous and anomalous conditions exist. Thus, both conditions represented morphological structure violations. Second, the pseudowords of the anomalous condition contained types of

Table 1. Example Materials

Condition	Sentence
existing adjective (existing adjective condition)	Der Aufsichtsrat wählt *einstimmig* den neuen Präsidenten. ('The supervisory board unanimously votes for the new chairman.')
synonymous pseudoword	Der Aufsichtsrat wählt **einstimmlich* den neuen Präsidenten.
anomalous pseudoword	Der Aufsichtsrat wählt **einstimmreich* den neuen Präsidenten.

Note. *Target stimuli* in context sentences with literal English translations. Pseudowords are marked with an asterisk. Adjectives in adverbial use do not require an equivalent of English "-ly". ERP measurement was aligned to the onset of target stimuli.

Table 2. Questions

	Sentence	Question
Yes question	Die Schwester verlässt *neidisch* die Fete. (The sister leaves the party enviously.)	Verlässt die Schwester die Fete *neidisch*? (Does the sister leave the party enviously?)
No question	Der Student erledigt strebsam seine Pflichten. (The student does his duties ambitiously.)	Erledigt der Student seine Pflichten *nachlässig*? (Does the student do his duties carelessly?)

stems and suffixes that are normally never combined. Moreover, these stimuli were semantically odd, compared to the pseudowords in the synonymous condition. A pretest in which participants rated which of the two pseudowords was a better alternative for the existing one showed that the novel combinations of the synonymous condition were preferred in 80% of the cases to the anomalous ones.

In addition, all experimental stimuli were controlled for close probability of the existing adjective. In a pretest, 42 participants read sentence fragments including the verb (see Table 1). They were asked to complete each sentence fragment in a cloze task. Cloze probability was zero: None of the intended adverbs was ever produced.

In the main experiment, to distract from the relatively fixed position of the critical stimuli in the sentences, we included 60 filler sentences, with the same distribution of existing and pseudoword adjectives as in the test materials. Finally, 30 questions regarding the sentences were included to ensure that the participants were actively reading. The questions referred only to sentences from the existing adjective condition, repeating the sentences in question form, either with the used adjective or with its antonym. Participants were asked to confirm if this was the sentence they had read by pressing a yes or a no button. Examples of questions are given in Table 2.

Procedure

There were three different test versions, each containing one third of the items from each condition (existing adjective, synonymous pseudoword, anomalous pseudoword). The order of the sentences within each version was randomized. From the 15 participants included in the analysis (see below Results), six were tested with the first version, six with the second version and three with the third version. Participants were comfortably seated in a soundproof chamber in front of a computer screen, with their forefingers on the yes and no buttons. They were instructed not to speak, blink, or move their eyes while the sentences were presented and that there would be two longer breaks between sentence presentations. Participants were asked to answer the questions correctly. To familiarize them with the sentence reading task, the session started with ten practice sentences, with the same distribution of conditions as in test materials, and two practice questions referring to them.

Each sentence trial began with the presentation of a fixation point in the middle of a high-resolution 19” computer screen. After a randomized interval of 1000 to 1200 ms, the sentence was presented word by word in the centre of the screen (350 ms word presentation, followed by 300 ms blank screen). The final word ended with a period, indicating the end of the sentence. After 400 to 2500 ms blank screen, the appearance of the fixation cross started a new trial. In a question trial, the sentence was first presented as described. After the sentence-final word, the question was presented as a whole. It remained on the screen until the participant pressed the yes or no button, but maximally 5000 ms.

Apparatus and recordings

The EEG was recorded from 29 scalp electrodes against a reference at the left mastoid process using standard procedures. The sites of electrodes were labelled according to the extended 10/20 system. Blinks and vertical eye movement were monitored by bipolar electrodes placed on the left lower and upper orbital ridge. Lateral eye movements were monitored by a bipolar montage using two electrodes placed on the right and left external cantus. Eye movements were recorded to allow for later off-line rejection. Electrode impedance was kept below 5 kOhm for EEG and eye-movement recording.

Signals were amplified with a band pass from 0.05 to 30 Hz (zero phase shift filter) and digitized at 250 Hz. Data were offline re-referenced to the average of the two mastoid signals A1 and A2. Averages were obtained for 1000 ms epochs, including a 200 ms pre-stimulus baseline period. They were digitally filtered using a band pass, zero phase shift filter of 0.05–30 Hz with 12 db/oct.

The data were baseline-corrected according to the pre-stimulus interval. Trials contaminated by eye movements within the critical time window were rejected using a ± 75 μV threshold. On average, 2.6% of the trials were excluded from further analyses, and the number of rejections did not reliably differ between conditions or participants. The average ERP was calculated for all electrode sites per subject and per condition. Group averages were calculated based on the individual averages.

Results

Memory performance

Analysis of behavioural data showed that, on average, 95% of the questions were answered correctly. Worst performance was 74% correct answers. None of the participants was excluded from further analysis.

Descriptive statistics

The grand-average waveforms of ERPs elicited by the critical adjectives are presented in Figure 1. As can be seen in Figure 1, the ERP waves showed a pattern that is common for visual word processing: an early negativity around 100 ms after word onset (N100), followed by a positivity around 200 ms (P2), a second positive peak around 300 ms (P3) that leads into a late negative deflection between 350 ms and 550 ms after word onset. The strongest effect visible is the difference between the existing adjective condition and the anomalous condition in the time window 450–500 ms, in the descending part of the late negativity, with the anomalous condition being more negative than the existing adjective. This difference is most prominent at left-central frontal sites (see topographic maps in Figure 2). Small differences between the waves of the existing adjective condition and the two pseudoword conditions are visible in the time windows 50–150 ms, 350–450 ms (ascending part of the late negativity) and 600–700 ms after word onset. We hence include these windows in the mean amplitude analysis.

Analysis

Repeated-measures omnibus ANOVAS for mean ERP amplitudes were carried out for the critical time windows with the factors *conditions* (existing adjective, synonymous pseudoword, and anomalous pseudoword), *front-back distribution* (electrodes separated for frontal [F3, Fc3, Fz, Fcz, F4, Fc4] vs. central [C3, Cp3, Cz, Cpz, C4, Cp4] vs. parietal [P3, O1, Pz, Oz, P4, O2]), *left-right distribution* (electrodes separated for left [F3, Fc3, C3, Cp3, P3, O1] vs. central [Fz, Fcz, Cz, Cpz, Pz, Oz] vs. right [F4, Fc4, C4, Cp4, P4, O2]) and the factor *electrode* (two electrodes on each location). For main effects with F-values with more than one degree of freedom in the numerator, p-values were Greenhouse-Geisser corrected to adjust for sphericity-assumption violation. A linear trend (existing adjective < synonymous pseudoword adjective < anomalous pseudoword adjective), planned comparisons (existing adjective ≠ synonymous pseudoword ≠ anomalous pseudoword) and a Helmert-contrast were calculated in case of a significant main effect of *condition*.

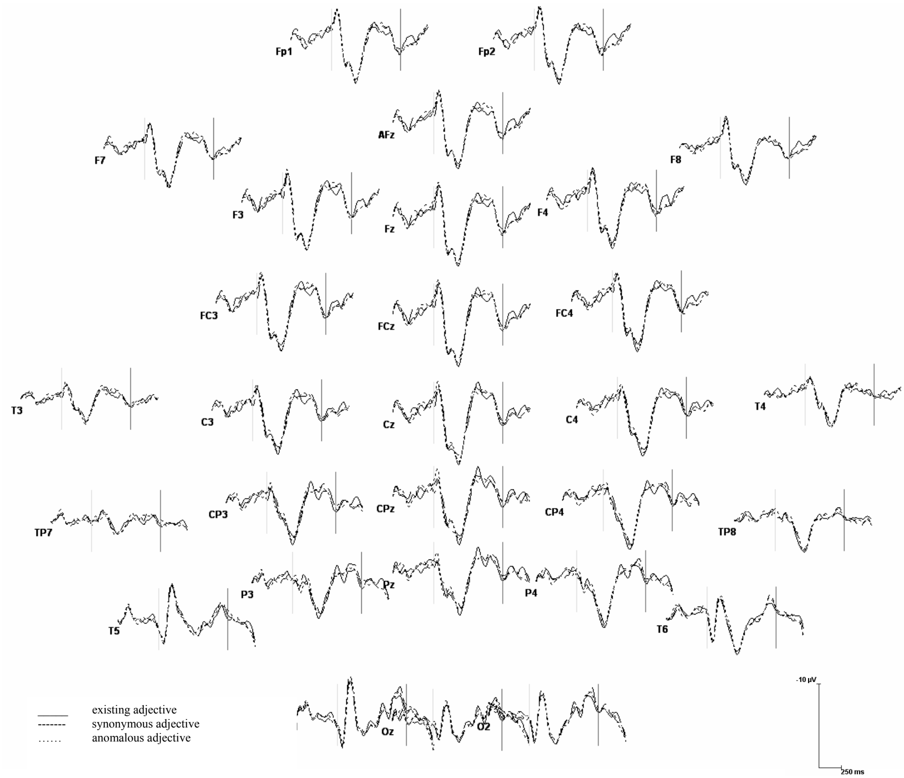

Figure 1. Distribution of the grand average signal of the three conditions. Negative values are plotted upwards (−10 µV).

Furthermore, further analyses using subsets of electrodes, with the factors *conditions* and *electrodes*, were carried out to localize the focus of the effect.

Time windows 50–150 ms, 350–450 ms and 600–700 ms after word onset

Mean amplitude analysis with repeated-measures omnibus ANOVA showed no significant main effect of the factor *conditions*. The same holds for single electrode analysis. The small differences visible in the grand averages are thus not statistically reliable.

Time window 450–500 ms after word onset

The omnibus ANOVA analysis revealed a significant main effect of *conditions*, $F(2, 28) = 4.2$, $p = 0.028$. There was a significant linear within-subjects contrast for the factor *conditions*, $F(1, 14) = 5.9$, $p = 0.029$, indicating a linear relationship, with mean amplitude increasing from the existing adjective condition (−0.40 μV) to the synonymous condition (−0.77 μV) to the anomalous condition (−0.86 μV). However, planned comparisons showed that the existing adjective differed from both pseudoword conditions, $t(14) = 2.497$, $p = .026$; $t(14) = 2.428$, $p = .029$, but the latter did not differ from each other, $t(14) < 1$. An alternative contrast, with the amplitude of the existing adjective against the mean amplitude of two pseudowords (Helmert-contrast), yielded a significant result, $F(1, 14) = 7.522$, $p = .016$. This contrast gives a slightly better fit than the linear contrast ($r_{contrast} = .59$, $r_{contrast} = .54$ respectively; Rosenthal, Rosnow, & Rubin, 2000).

The omnibus ANOVA also revealed a significant main effect *front-back distribution*, $F(2, 28) = 5.6$, $p = 0.029$. The negativity was strongest at frontal electrodes (−1.16 μV) and central electrodes (−0.96 μV), and less activity at parietal electrodes (−0.47 μV). There was also a significant main effect *left-right distribution*, $F(2, 28) = 10.0$, $p = 0.002$. The mean negativity was strongest at the central electrodes (−1.06 μV), less at the left electrodes (−0.79 μV) and had the lowest values at the right electrodes (−0.74 μV). The main effect *electrodes* was not significant and there were no significant interactions of the factors *conditions* and *front–back distribution* or the factors *conditions* and *left–right distribution*.

The distribution of the strength of the negativity across the scalp (see Figure 2) suggests a left-frontal distribution, which is compatible wit a LAN. To lo-

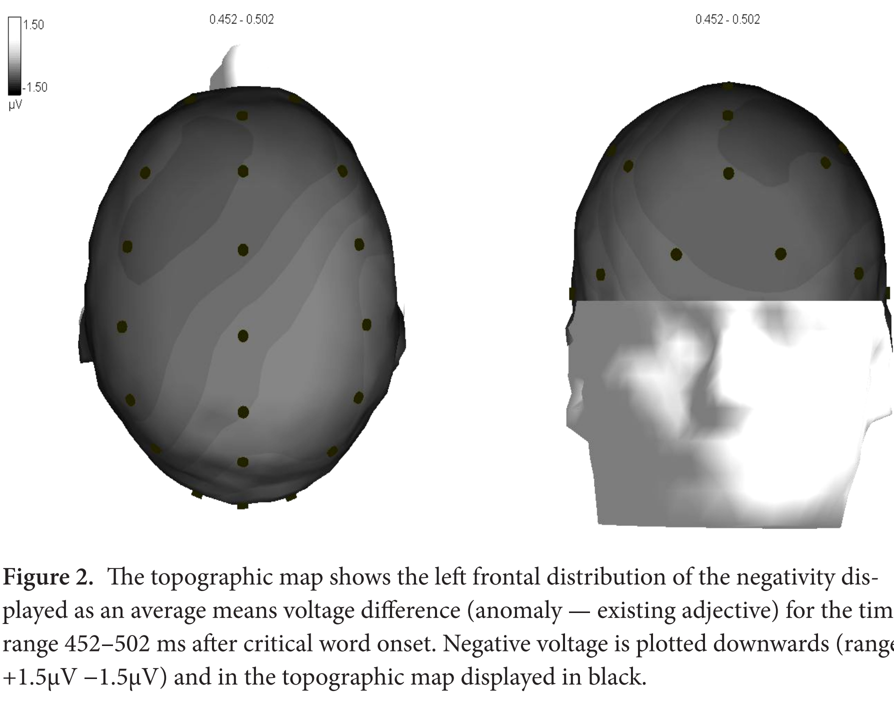

Figure 2. The topographic map shows the left frontal distribution of the negativity displayed as an average means voltage difference (anomaly — existing adjective) for the time range 452–502 ms after critical word onset. Negative voltage is plotted downwards (range: +1.5μV −1.5μV) and in the topographic map displayed in black.

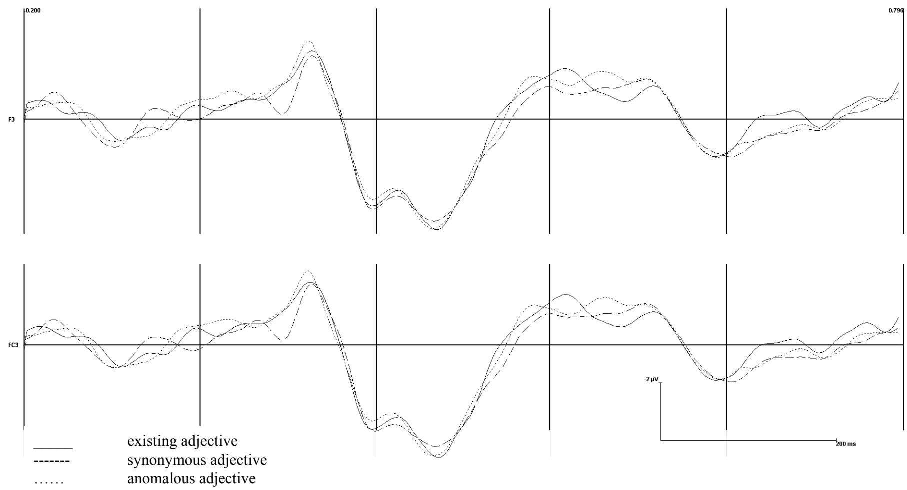

Figure 3. Grand average ERP signal ($N = 15$ participants) of the three conditions at the left frontal electrode F3 (above) and FC3 (below). The solid line represents the existing adjective condition. The dashed line shows the synonymous pseudoword condition. The dotted line represents the anomalous pseudoword condition. Time range is −200 ms to 796 ms. Negative values are plotted upwards (−2 μV).

calize the effect statistically, an ANOVA with the factors *conditions* and *electrodes* of the frontal-left pair of electrodes (electrodes: [F3, Fc3]) was carried out for the 450–500 ms time window (see Figure 3). The main effect of *conditions* was significant, $F(2, 28) = 3.7$, $p = 0.043$, while the main effect *electrodes* and the interaction between *conditions* and *electrodes* were insignificant. The left-frontal focus of the differential activity is thus statistically reliable.

Discussion

The aim of this study was to track the online processing of morphologically complex adjectives embedded in neutral sentence contexts. We investigated the impact of structural (and ensuing semantic) violations provided by two types of pseudoword adjectives on components of event-related potentials, and compared these with ERPs elicited by existing adjectives. We constructed these pseudoword adjectives by exchanging the derivational suffix of the existing adjectives. In the synonymous condition, the existing suffix was replaced by a synonymous one, resulting in a semantically interpretable but structurally non-existing combination. In the anomalous condition, a suffix was added that violates the combinatorial constraints in German, resulting in an adjective which is structurally illegal and difficult to interpret semantically.

We hypothesized that both pseudoword adjectives might show an enhanced N400 amplitude, relative to the existing adjective, an effect that is typically evident when comparing existing words and pseudowords. We argued that such an effect would not be very informative with respect to morphological processing. More interesting are ERP-components related to structural processing, such as the LAN, or to the repair of structural problems, such as the P600/SPS.

We observed significant differences between the existing adjective and the two pseudoword adjectives within 450–500 ms after stimulus onset, and in no other time window. The effect was prominent over left-frontal electrodes. The timing and focus of the effect (see Figures 2 and 3) suggest that the effect is a LAN. There are no additional effects in the data over and above the LAN — neither a N400 nor a P600. LAN effects as an index of erroneous morphological parsing have been observed before, mainly with violations of verbal and nominal inflection (Lück et al., 2006; Morris & Holcomb, 2005; Newman et al., 2007; Rodriguez-Fornells et al., 2001), number or case agreement violations (Moreno et al., 2002), and, in one case, non-existing combinations of bases and derivational prefixes (Palmović & Maričič, 2008).

Our results contrast to data reported by Janssen et al. (2006) and Leinonen et al. (2008), who observed N400-effects for derived pseudowords. Our study differed from these studies both in stimulus timing and task. Our presentation rate was more than twice as fast. Next, whereas we had no task at all for the critical stimuli, Janssen et al. and Leinonen et al. required a response to each. Task and slow timing might have resulted in a less automatic, more strategic, task-adapted processing of the stimuli, in which semantic processing outweighs automatic morphological processing.

How do the LAN effects that we observed relate to the issues of morphological parsing, lexical processing, and semantic appraisal of the morphemes combined? Both pseudoword conditions contained combinations that had no lexical equivalent. The most evident result from our study is the enhanced negativity, relative to existing adjectives, for both pseudowords, prominent at left-at frontal electrodes. Assuming that the observed increase of negativity for violations reflects a higher processing load, our data suggest that more neural activation is necessary to process derived non-existing adjectives than existing ones. Given that the LAN is sensitive to structural rather than semantic violations, the two pseudoword adjectives apparently create similar structural problems. The LAN effect is best understood as a reflection of successful morphological parsing, but, in case of the pseudowords, resulting in a failure to find a structural match for the morphemes combined (Taft, 2004). The fact that we observe a difference between the two pseudoword adjectives in terms of a linear trend, but not in a direct comparison, implies that the LAN is more sensitive to this structural combination failure, than to the additional subcategorization violation present in the anomalous condition only.

In sum, the present ERP data show evidence for morphological decomposition for derived stimuli, resulting in structural problems when these are made up of existing morphemes, but that have no lexical match. We found LAN effects rather than N400 effects. This indicates, first, that the derived pseudowords are treated differently from monomorphemic pseudowords (cf. McKinnon et al., 2003), and second, that the processing costs involve structure rather than semantics. Our results thus speak for a separate handling of structural and semantic information, and support the conception of morphological parsing, followed by a structural process of recombination of decomposed morphemes that fails if there is no lexical representation for the combination. Since we observed the impact of structural violations during fast reading, without a task for the critical stimuli, we believe that morphological parsing and recombination of derived words occurs in an automatic fashion.

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Correspondence concerning this article may be addressed to Jens Bölte, Psychologisches Institut II, Fliedner Str. 21, 48149 Münster, Germany; email: boelte@psy.uni-muenster.de. We thank Bernward Winter for help with the materials, Mona Aicher, Heidrun Bien, Heidi Lüttmann, and Helene Kreysa for data collection in Münster, Germany. Stefanie Pfeifer was so kind to collect the data in Maastricht, The Netherlands. Note that B.M.J. published under her maiden name Schmitt until 2003.

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Author's address

Jens Bölte
Psychologisches Institut II
Westfälische Wilhelms-Universität Münster
Fliedner Str. 21
48149 Münster
Germany
Phone: +49-251-8339137
Fax: +49-251-8334104.

boelte@psy.uni-muenster.de