

## The Identification of Morphologically Complex Spoken Words: Continuous Processing or Decomposition?

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Models of word recognition differ in the claims they make about the processing and representation of morphologically complex words. The research reported here on the processing of spoken prefixed words contrasts predictions made by continuous left-to-right processing models and by models adhering to the notion of decomposition and discontinuous access to the mental lexicon. In left-to-right models, the speech input is mapped onto full-form representations in the lexicon in a continuous manner. In discontinuous models, the particular stretch of input corresponding to the stem of a complex word is used as the access unit, irrespective of where this information is located in the speech signal. Three sets of experiments, using gating and phoneme monitoring tasks, investigate whether the processing of prefixed (and pseudo-prefixed) words is determined by the complete, full-word form, or by the stem of the word. The results clearly disconfirm the decomposition model of word-recognition. None of the experiments provide evidence for the stem as the crucial unit in lexical access. Moreover, the results are not compatible with continuous processing models which claim that the lexicon contains only full-word forms. The implications of these findings for the processing and representation of morphologically complex spoken words are discussed. © 1991 Academic Press, Inc.

An important question in word recognition concerns the processing and representation of morphologically complex words. This issue has been studied extensively in the visual domain (see Henderson, 1985, for an overview), but until recently it was largely neglected in the domain of spoken-word processing. The experiments to be reported here were designed to fill this gap by contrasting in detail two theoretical approaches which have been put forward during the last decade: the decomposition and the full-listing approach.

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In the decomposition approach, the unit of lexical representation—and therefore the unit for lexical access—is not the full-word form, but rather the stem of a morphologically complex word. A well-known representative of this approach is the affix-stripping model proposed by Taft and Forster (1975; Taft, 1985). For morphologically complex words, this model claims that the mental lexicon contains separate entries for the stems of words and for affixes, rather than full-word forms. This view of lexical representation has consequences for the ways in which the input is processed. To gain access to the representational units in the mental lexicon, the processing system has to decompose the incoming speech sig-

nal; that is, certain parts of the input have to be identified as corresponding to the stem of a word, while others have to be categorized as affixes. In Taft and Forster's model, decomposition into stems and affixes is an obligatory process; only in circumstances where decomposition fails—as is the case with monomorphemic words—will the system try to locate a full-form entry. For morphologically complex words, the stretch of input corresponding to the stem of a word will be mapped onto the stem entries in the mental lexicon, independent of the position of this information in the actual input. For polymorphemic words, therefore, the model claims that lexical access, defined here as the mapping of the input onto representations in the mental lexicon, proceeds in a discontinuous, rather than in a continuous, left-to-right fashion.

The discontinuous processing view contrasts with models in which the speech input is processed in a left-to-right manner, and in which the information contained in the sensory input is continuously mapped onto representations in the mental lexicon, irrespective of whether the word is monomorphemic, or morphologically complex. Since claims about processing and lexical representation are always intimately linked in theories of word recognition, the continuous processing claim is complemented by the full-listing hypothesis of lexical representation, where for each word—be it mono- or polymorphemic—there is one corresponding word form in the mental lexicon (Butterworth, 1983). Prominent examples of models of spoken-word recognition which adhere to this view of continuous processing and full-form representation are the Cohort model (Marslen-Wilson & Welsh, 1978; Marslen-Wilson, 1987) and the Trace model (McClelland & Elman, 1986).

Discontinuous and continuous models make different predictions as to the point in the sensory input at which morphologically complex words can be recognized. For the domain of spoken-word processing, the in-

teresting case in point is prefixed words. For a word such as "upgrade," the first part of the word—i.e., "up," the prefix—reaches the processing system earlier than the stem of the word, given the intrinsic directionality in time of the speech input. According to the decomposition model, a prefixed word cannot be recognized before the prefix has been stripped off, and the word's stem has been identified. For the word "upgrade," this can happen at the segment /d/, as soon as the sensory input has discriminated between "grade" and competing stem entries such as "grave" or "grape."

In continuous left-to-right processing models, in contrast, the processing and recognition of prefixed words is in no way different from the recognition of words without prefixes. According to the Cohort model, recognition will take place at the point in which, going from left-to-right in the signal, a word diverges from all other words beginning with the same sound sequence. This point will hereafter be referred to as the "uniqueness point" (UP). The UP of the word "upgrade" corresponds to the segment /ei/; it is at this point that the word diverges from competing entries such as "upgrowth." The UP is not a behavior-based concept; a word's UP is usually established with the aid of a dictionary. There is no such concept as UP in the Trace model, but it shares with the Cohort model the view that there are no a priori processing differences between morphologically complex and monomorphemic words.

#### *Previous Research*

In the auditory domain, only a few studies have investigated morphologically complex words. Most of this work concentrated on the role of suffixes in word processing (Kempey & Morton, 1982; Fowler, Napps, & Feldman, 1985; Tyler & Marslen-Wilson, 1986). Two studies have specifically looked at derivational prefixes: a study by Taft,

Hambly, and Kinoshita (1986), and the research reported by Tyler, Marslen-Wilson, Rentoul, and Hanney (1988). Taft et al. obtained evidence supporting their decomposition view in an auditory lexical decision experiment using quadruples of non-words, each quadruple consisting of the four combinations of real and non-existing prefixes (e.g., "de" and "te") with real and non-existing stems (e.g., "joice" and "jouse"). Since the items starting with a real prefix, and the items starting with a non-prefix, became non-words at the same point in the signal, left-to-right processing models would predict equal non-word decision latencies within each subset. Taft and Forster's (1975) affix-stripping model, however, predicts an interaction between stem status and prefix status. Taft et al. indeed found that response latencies were faster for items beginning with a non-prefix, as compared to their real-prefix counterparts, and that the difference was larger when the items contained a real stem. The results, therefore, confirmed the predictions of the affix-stripping model. It is, however, important to note that Taft et al. used reaction times to *non-word* material to prove their point. It is unclear whether one can generalize from non-word data to the processing of morphologically complex real words (see Henderson, 1985).

Tyler et al. (1988) used test material consisting of real words only, comparing monomorphemic words such as the verb "lead" to corresponding prefixed words such as "mislead." Whereas the decomposition model claims that both words should be recognized at the same segment /d/, continuous processing models make different predictions. The word pairs were constructed such that the UP for the prefixed words was always earlier than the UP for the free stems. Thus, whereas "lead" can be recognized when the segment /d/ has been identified, the UP for "mislead" arises earlier. As soon as the vowel /i:/ has been identified, this word separates from its full-form competitors such as "mislay" and

"mislike." The Cohort model, therefore, predicts that—measured from the onset of the stem—the prefixed word should be recognized earlier than its corresponding stem.

Tyler et al. tested these competing claims in three experiments on the same material. First, they used the gating paradigm to establish the recognition point (RP) for each word. The RP is considered to be an empirical estimate of the theoretical UP. Presenting the subjects with successively larger onset increments of a word, the point in the sensory signal can be established at which subjects correctly identify the presented word with a certain amount of confidence, usually 8 on a 10-point scale (Grosjean, 1980; Tyler & Wessels, 1983). The gating data showed a clear difference in RP between prefixed words and monomorphemic stems. Correcting of the length of the prefixes, the prefixed words were recognized some 200 ms earlier than the stems. Two additional tasks, auditory lexical decision and naming, corroborated these basic findings. In both tasks, reaction times to the prefixed words were—again subtracting the length of the prefix—about 140 ms shorter than the latencies in the stem condition.

Despite the commendable use of real words and multiple tasks, we have some reservations with respect to the Tyler et al. study. The first concerns their experimental material. The stem-parts of their prefixed words and the corresponding free stems were different speech tokens. As Tyler et al. note, the free stems were about 28 ms longer than the stem parts of the prefixed words, but they claim that this cannot explain the observed differences in mean RP and reaction time between the two conditions. There is, however, more involved here than a pure durational difference. With different tokens in the two conditions, it is impossible to know when exactly the critical sensory information that separates a word from all other words in the lexicon becomes available to the listener.

A second reservation, contingent on the first, concerns in particular the use of the

gating task in situations where the speech tokens are not identical. Mean RPs are calculated and reported in terms of the amount of sensory input—in milliseconds—needed for correct and confident identification. This measure suggests continuity, but the responses on which these RPs are based are gathered in a discontinuous fashion. Subjects give a response at regular intervals, in Tyler et al.'s case, after each 50 ms increment. In particular since all stimuli, prefixed and unprefixed words alike, were segmented into incrementing "gates" from the onset of the word, it is highly unlikely that, for a given free stem, the sensory information is distributed across gates in the same way as for the non-identical stem token of the corresponding prefixed word. The a posteriori subtraction of the length—again in milliseconds—of the prefix does by no means remedy this.

A final criticism concerns the fact that morphological complexity is confounded with word length. It is a well-known fact that for gated words presented in isolation, the amount of confidence a subject has in her response varies as a function of the length of the presented word (Grosjean, 1980). Effects of word length have also been demonstrated with lexical decision and naming (Hudson & Bergman, 1985; Seidenberg, 1989; Jared & Seidenberg, 1990).

Despite these criticisms the Tyler et al. study is the first to provide clear evidence, in the auditory domain, against the decomposition view. The consistent processing advantage for prefixed words—200 ms in gating and 140 ms in reaction-time tasks—is clearly too robust to be nullified by the above observations. Our main point of concern, however, is whether Tyler et al.'s data really provide the crucial evidence in favor of a particular continuous left-to-right processing model: the Cohort model.

#### *Experimental Considerations*

The aim of the experiments to be reported here is to investigate in detail

whether morphologically complex words are processed in a continuous left-to-right manner or whether lexical access requires decomposition into constituent morphemes. The types of morphemes under investigation are derivational prefixes and stems.

The first two sets of experiments investigate the processing of prefixed and non-prefixed words. A third set deals with pseudo-prefixed words, that is, with monomorphemic words starting with a first syllable which can be a real prefix (e.g., "sublime"). In our study, we tried to take into account the points of critique formulated with respect to the studies by Taft et al. (1986) and by Tyler et al. (1988). First, we used real-word material only. Second, by cross-splicing the original speech tokens, the material in our prefixed and unprefixed conditions always shared the same stem tokens. Third, we included additional conditions to investigate potential confounding effects of stimulus length. Whereas in the Tyler et al. study the critical test always involved a comparison between mono- and polymorphemic words, this is not necessarily the case in our experiments. In Experiments 1a and 1b, an additional test of the predictions made by the different approaches involves the comparison of two prefixed words with the same stem and the same number of syllables.

Within each set of experiments, two experimental tasks were used: gating and phoneme monitoring. To avoid confounding effects of word length in our gating experiments, we calculated identification points (IP) instead of RPs. The calculation of IPs does not involve confidence ratings, which are mainly responsible for the length effects observed in gating data (Grosjean, 1980). With the gating paradigm, we investigated whether the point at which a prefixed word is identified (the IP) is a function of properties of the full-word form (i.e., the UP), or of the point at which the stem is uniquely defined relative to competing entries. The second experiment within each set investi-

gated the same question with the phoneme monitoring task, in which subjects are first presented with the visual specification of a phonemic segment, before hearing a short list of spoken stimuli. The task of the subject on each trial is to press a response button as soon as the segment corresponding to the target phoneme is detected in the word list (Foss, 1969, 1970; Cutler, Mehler, Norris, & Segui, 1987; Frauenfelder & Segui, 1989).

Our reasons for combining these two experimental tasks are as follows. The gating paradigm is the only task which provides information on the amount of sensory input necessary for word identification; that is, it provides an empirical estimate of the UP. For words presented in isolation, word-identification data obtained with the gating task closely correspond to results obtained with reaction-time tasks (Zwitserslood, 1989). However, a potential problem with the task which is of specific relevance to the questions addressed here, is the fact that the presentation of incrementing speech fragments might artificially induce a left-to-right processing strategy. Such a strategy would then artifactually provide support for the continuous left-to-right models of word recognition.

This objection does not apply to the phoneme monitoring task; it is unlikely that this task induces a left-to-right processing strategy. Contrary to what is common practice in most phoneme monitoring experiments (see Cutler & Norris, 1979, for an overview), subjects did not monitor for word-initial segments in our version of the task. The segment corresponding to the target phoneme could appear anywhere later in the word. We used this variant of the phoneme monitoring task (generalized phoneme monitoring; cf. Frauenfelder & Segui, 1989) because of its observed sensitivity to the UP (Frauenfelder, Segui, & Dijkstra, 1990; Marslen-Wilson, 1984). Our experiments exploited the empirical finding that phoneme monitoring is faster when the critical segment occurs after, as opposed to be-

fore, the UP. Moreover, it has been shown that monitoring latencies for phonemes occurring *before* the UP do not vary as a function of the position of the critical segment (Frauenfelder et al., 1990). In other words, the task seems to be insensitive to general effects of word length.

#### EXPERIMENTS 1a AND 1b

In the first two experiments we used triplets of Dutch words, consisting of an unprefix verb (e.g., "staan"; to stand) and two verbs which were derived from this verb by adding a prefix (e.g., "opstaan"; to get up, and "toestaan"; to allow).<sup>1</sup> With the aid of a dictionary (van Sterkenburg & Pijnenburg, 1984), triplets were selected such that the unprefix verb (hereafter referred to as STEM) and one of the two derivations had the same UP (e.g., /n/ in "staan" and "opstaan"). This first prefix condition will be referred to as =STEM. The second prefix verb of each triplet (hereafter referred to as <STEM) always had a UP which was located at least one segment before the UP of the two other words (the UP for "toestaan" being the /a:/).

The labelling of the three conditions reflects the predictions made by left-to-right processing models adhering to the full-listing hypothesis. Such models predict that STEM and =STEM should be identified at the same segment, whereas <STEM should be identified earlier. In contrast, on a discontinuous affix-stripping approach, the verbs in all three conditions should be identified at the same segment, namely at the point at which the stem diverges from its competing stem entries.

#### Material

The material consisted of 24 triplets of the type described above. In half of the triplets, the prefixed words had prefixes which

<sup>1</sup> Most of the unprefix verbs in our material are morphologically complex, consisting of a root (e.g., "help") and the inflectional affix "en," marking the infinitive citation form of Dutch verbs. We will refer to these infinitive forms in terms of "stems."

cannot become separated from their stem (e.g., "verdiene[n]," to earn). Main stress falls on the verb stem in these cases. The other half had prefixes which can become separated from their stems (e.g., "opstaan," to get up, used in a sentence like "zij staan meteen op," they get up immediately); the prefix carries the main stress in these items.

The triplets were recorded, together with filler material, by a female native speaker of Dutch. All material was subsequently digitized at a sampling rate of 20 kHz, and stored onto a VAX 750. The words in each triplet were cross-spliced, such that the same acoustic token served as stem for each verb. The prefixed words were spliced into stems and prefixes with the aid of a speech editing program, under acoustic and visual control. For the 12 triplets with unseparable prefixes, the originally recorded unprefixed verb was used as the stem token in all three conditions. For the 12 triplets with separable prefixes, the spliced-off stem token from one of the two prefixed verbs (the one that sounded best according to the experimenters' intuitions) was used in all conditions. The cross-splicing was always done such that the point of transition from prefix to stem token was at a negative-to-positive zero crossing. As a consequence, no clicks were audible in the cross-spliced words.

For the gating experiment, the cross-spliced words were segmented into speech fragments of incrementing length. The first fragment was 50 ms long, the second 100 ms, and so on. To ensure that the stem fragments contained exactly the same information in each condition, prefixes and stems were segmented separately. Since the length of prefix and stem tokens did not exactly correspond to a multiple of 50 ms, the last gate of both prefix and stem often contained more than 50 ms of speech information. The gating procedure resulted in a series of speech fragments for each word, increasing in length by 50 ms steps (except for prefix-final and stem-final gates). The

acoustic offset of each gate was smoothed using a cosine smoothing function with a 5 ms window.

For the phoneme monitoring task, the same cross-spliced material was used, this time of course not presented in fragments. A 5 kHz pulse was placed on the acoustic onset of the critical segment corresponding to the phoneme for which the subjects had to monitor. Phoneme monitoring times were measured from this pulse to the subjects' response. The use of identical stem tokens for the verbs in a triplet guaranteed that in each condition, the pulse was located at precisely the same position. The pulses were inaudible to the subjects in the experiment.

#### *Experiment 1a: Gating*

##### *Procedure*

For the gating experiment, three experimental versions were constructed. Only one gated word from each of the 24 triplets occurred in each version: the STEM word from eight triplets, the =STEM word from another eight triplets, and the <STEM word from the remaining eight triplets. The 24 test trials were embedded in 60 gated filler trials, consisting of 40 nouns and 20 adjectives. Six of these nouns or adjectives had a prefix. In addition, five practice trials were constructed. A separate audiotape was made for each experimental version, containing five practice trials, 24 test trials, and 60 fillers.

On each trial, fillers and test alike, the subjects heard a carrier sentence (e.g., "The next word is . . .") and the first 50 ms gate of a word, presented binaurally via closed headphones. The subjects' task was to decide after each fragment which word they thought they were hearing. Subjects typed their responses into a TANDY 2000 computer. After a 6-s interval, the next gate was presented (e.g., the first 100 ms), this time without the carrier phrase. The subjects responded after each gate; their responses were automatically registered by a PDP 11/55 computer. Each audiotape lasted

2½ h. Therefore, each subject participated in three experimental sessions, on three consecutive days. Each session lasted approximately 50 min.

### Subjects

Thirty-six native speakers of Dutch participated in the experiment, 12 in each experimental version. The subjects were tested in groups of 2 to 4, and were paid for their participation.

### Results

Of the 24 original triplets, seven were excluded from further analysis. With four triplets, one of the words was apparently distorted by the cross-splicing procedure; some subjects did not succeed in correctly identifying these words. Another three triplets were excluded because we had determined a wrong UP for one of the words. The subjects' gating responses showed that these words had competitors which were not listed in the dictionary (e.g., strong verb-forms). These competitors changed the a priori defined relationship between the UPs within a triplet, thereby violating the operationalization of the three conditions. Appendix 1 lists the remaining 17 triplets.

Identification points were computed for each word and each subject. The IP was defined as the first gate at which a subject produced the correct word as a response, without subsequently changing her mind about the identity of the word. Here, and in all experiments to be reported below, the IPs for the prefixed words are always calculated from the onset of the stem. The data, therefore, show at which mean gate within the identical stem token the words in each condition are identified.

In the subject analysis, mean IPs over items for each subject in each condition were submitted to an analysis of variance (ANOVA), with UP-Position (STEM, =STEM, and <STEM) as within-subject factor and subjects as replication dimension. For the item analysis, mean IPs over

subjects for each word were submitted to an ANOVA with UP-Position as within-item factor and triplets as replication dimension. The mean IPs were 234 ms for STEM, 204 ms for =STEM, and 194 ms for <STEM.

The ANOVAs showed a significant main effect of UP-position,  $F_1(2, 70) = 10.7, p < .0002$ ;  $F_2(2, 32) = 7.6, p < .003$ . On a Newman-Keuls post hoc test ( $p < .05$ ), significantly more sensory information was needed to identify the words in the STEM condition, compared to both the =STEM and in the <STEM conditions, but the latter two conditions did not differ significantly from each other.

Since we had prefixed words with separable prefixes ( $n = 6$ ) and prefixed words with non-separable prefixes ( $n = 11$ ) in our material, we ran an additional ANOVA with the factors Prefix Type and UP-Position (STEM, =STEM, <STEM). With unequal numbers of items nested under the two levels of the factor Prefix Type, only an item analysis was performed. The main effect of UP-Positions was significant ( $F_2(2, 30) = 8.8, p < .005$ ), but there was no main effect of Prefix Type nor an interaction between UP-Position and Prefix Type,  $F_2(1, 15) = 1.9, p > .15$ ,  $F_2(2, 30) = 1.2, p > .30$ , respectively.

### Experiment 1b: Phoneme Monitoring

#### Procedure

The test material consisted of 18 triplets from Experiment 1.<sup>2</sup> One phoneme for which the subjects had to monitor was determined for each triplet. This phoneme always corresponded to the identical segment constituting the UP of the STEM and the =STEM condition (e.g., /n/ in "staan" and "opstaan"). In the condition <STEM, however, this critical segment occurs *after*

<sup>2</sup> Preliminary gating analyses were done on 18 triplets; only after running Experiment 1b it did become clear that one additional item set had to be excluded for the reasons mentioned earlier. Therefore, this triplet was still included in Experiment 1b.

the UP (the UP of "toestaan" being the /a:/). Whereas the decomposition model predicts equal monitoring times in all three conditions, a continuous left-to-right account predicts faster monitoring times in the <STEM condition than in the remaining two conditions, where monitoring times should be identical.

To avoid the subjects' predicting when words containing a target phoneme occurred, the test words were presented as the last word of short lists, varying in length from one to six words. None of the fillers preceding the test word contained the target phoneme. Three experimental versions were constructed. In the first version, the STEM words of six triplets, the =STEM words of another six triplets, and the <STEM words of the remaining six triplets were presented. In the other two versions, these sets of six triplets were rotated across conditions. In each version, the 18 words from the triplets were distributed equally across list positions (one to six).

In addition, 54 lists, also varying in length from one to six words, were constructed as filler material. The words in these lists were chosen such that of all words presented in the experiment, one third were verbs, one third nouns, and one third adjectives. Finally, 12 lists were constructed as practice trials. Three audiotapes were prepared, one for each version. These audiotapes only differed with respect to the test words.

Each word list was paired with one phoneme, such that all phonemes of Dutch occurred about equally often. On one third of all trials, the target phoneme did not occur in the corresponding list. These catch trials were drawn from the 54 filler lists. In the non-catch trials, half of the words containing a target phoneme were prefixed and half were unprefixed, and target phonemes were distributed equally across within-word positions (early, middle, and late in the spoken word).

On each experimental trial, the subject was first presented with a character speci-

fying a phoneme on a CRT screen. The subject then heard a list of words and reacted by pressing a button as soon as she identified the target phoneme. Subjects did not respond on the catch trials. Reaction times were measured from the onset of the critical phoneme in the spoken word.

### Subjects

Thirty-six native speakers of Dutch, 12 in each experimental version, were paid to participate in the experiment. Two subjects were tested simultaneously, in separate carrels. Each experimental session lasted approximately 20 min.

### Results

Subjects did not react in 4 percent of the test trials. For each subject, these missing values were substituted by the mean of the remaining reaction times in the relevant condition. Another 2% of the reaction times were outside the range of two SDs of the relevant subject's and item's mean. These extreme values were substituted by the procedure proposed by Winer (1971). In order to keep the results of Experiment 1a and 1b comparable, the same 17 triplets (see Appendix 1) were included in the analysis. As in Experiment 1a, subject- and item-based ANOVAs were performed. Table 1 gives the mean monitoring latencies and the percentage of missing responses for the three UP-conditions STEM, =STEM, and <STEM.

Both the subject and the item ANOVA showed a significant main effect of UP-Position,  $F_1(2,70) = 6.3, p < .005$ ;  $F_2(2,32) = 5.09, p < .05$ . A Newman-Keuls posthoc

TABLE 1  
EXPERIMENT 1b: MEAN MONITORING LATENCIES IN  
CONDITIONS STEM, =STEM AND <STEM  
(PERCENTAGE OF MISSING  
RESPONSES IN PARENTHESES)

STEM	=STEM	<STEM
486 (3.9)	445 (4.4)	454 (3.4)

test ( $p < .05$ ) revealed that monitoring latencies were longer in the STEM condition than in the =STEM and <STEM conditions, and that the latter two conditions did not differ significantly from each other.

As in Experiment 1a, we performed an additional ANOVA with the factor Prefix-Type (separable vs. non-separable). Again, the main effect of UP-Positions was significant ( $F_2(2,30) = 5.1, p = .05$ ), but there was no main effect of Prefix-Type and no interaction,  $F_2(1,15) = 1.7, p > .20$ ;  $F_2(2,30) < 1$ , respectively.

#### *Discussion of Experiments 1a and 1b*

Both experiments show a general advantage of prefixed words over their corresponding stems. No difference was obtained between the <STEM and =STEM conditions; therefore, the "prefixation effect" is independent of the position of the UP in the prefixed word. Before discussing the implications of this result for the left-to-right and the discontinuous processing models, we want to evaluate whether the obtained effect could be particular to our stimulus material.

Since we were not successful in obtaining a difference, as a function of the UP, between the two prefixed conditions—where words of similar length were used—a first question is whether the prefixation advantage can be due to a difference in length between prefixed words and stems. With prefixed words, more acoustic material precedes the segment at which the word should become unique or the segment for which the subject has to monitor. With respect to the gating task, Grosjean (1980) has shown that word length has an influence on the subjects' confidence ratings, not on the actual gate at which subjects report the correct word for the first time. Given that our gating data do not take confidence ratings into account, they are presumably free of such length effects. For the monitoring task, one might suspect that subjects are less inclined, or slower to respond to tar-

gets early in the word. Under this view, the prefixation effect would simply be a serial position effect. There is, however, good evidence against this interpretation. Frauenfelder, Segui, & Dijkstra (1990) compared phoneme monitoring latencies to targets in four different positions in matched words and non-words. The monitoring latencies for non-words were unaffected by the within-stimulus position of the target phoneme. For words, monitoring latencies only decreased for target positions *after* the UP. These data show that the detection times for phonemes do not vary simply as a function of their position in the spoken stimulus, that is, as a function of word length (see also Marslen-Wilson, 1984).

A second question concerns the cross-splicing of the material. Is it possible that the cross-splicing distorted the tokens presented in the STEM condition such that they became "unnatural" stimuli? Two observations contradict this possibility. First, in our material, the majority of the tokens presented in the STEM condition in fact consisted of the originally recorded unprefixated verbs (namely the material set with non-separable prefixes). If cross-splicing creates "unnatural" stimuli, it should have had a negative effect on the processing of the prefixed stimuli, *not* on the processing of the unprefixated words. In six of the 17 triplets (namely those with separable prefixes), this situation was reversed. The acoustic tokens for the STEM condition were spliced-off from one of the prefixed verbs. It should, however, be noted that the factor UP-Position showed no signs of an interaction with Prefix Type and that the same prefixation effect was also obtained by Tyler et al. (1988), who did not use cross-splicing in the construction of their material.

Let us turn next to the implications of the present results for left-to-right and discontinuous processing models. The prefixation effect clearly runs counter to the latter model, for which the identification of a prefixed word cannot occur before its stem has

been identified. The differences obtained between prefixed words and their corresponding stems cannot be accounted for by such a model.

Whether the present results support a continuous left-to-right processing account is more difficult to decide. First, as far as the conditions STEM and <STEM are concerned, our results can be seen as a clear replication of the results obtained by Tyler et al. (1988): the <STEM prefixed words show an advantage over their corresponding stems. However, despite the fact that the words in the =STEM and the STEM conditions share the same UP, the prefixed =STEM words also show an advantage over their corresponding STEM words, and the two prefixed conditions show very similar results, although the UPs are different. This general effect of prefixation is all the more surprising, given that the words in the STEM condition were of a higher frequency than their prefixed counterparts (mean frequency 116 vs. 19, respectively, corpus size 720,000; Uit den Boogaart, 1975). In sum, the data are not only incompatible with a decomposition account, but they also question Tyler et al.'s (1988) interpretation of the difference between STEM and <STEM as evidence in favor of a continuous processing account adhering to the full-listing view.

It has to be kept in mind, however, that—on a left-to-right view—the three words of a triplet generate different word-initial cohorts, each cohort containing different word candidates competing with the target word for recognition. This implies that the number of competitors, and their frequency, can differ for the three words of a triplet. It might be that such factors concerning lexical environment are responsible for the pattern observed in Experiments 1a and 1b. This possibility will be investigated in Experiments 2a and 2b.

#### EXPERIMENTS 2a AND 2b

The second set of experiments tries to obtain further insight into the adequacy of a

TABLE 2  
AN ILLUSTRATION OF THE EXPERIMENTAL  
CONDITIONS IN EXPERIMENTS 2a AND 2b

	Stem	Prefix
EARLY	leRen	afleRen
LATE	leveRen	afleVeren

*Note.* Uppercase letters indicate the uniqueness point.

left-to-right account for the processing of prefixed words by controlling for the factors word frequency and lexical environment. The conditions realized in Experiments 2a and 2b are illustrated in Table 2.

The material consisted of quadruples of words.<sup>3</sup> Within each quadruple, the STEM condition contained two unprefixed words, sharing the same word onset. The word in the EARLY condition (e.g., "leRen," to learn) has an earlier UP than the word in the LATE condition (e.g., "leveRen," to supply), the difference in UP being minimally two speech segments. The two prefixed verbs in the condition PREFIX were derived from the two STEM words, by adding an identical prefix (e.g., "af-leRen," to unlearn; "af-leVeren," to deliver). Both prefixed words share the same word-initial information, and therefore, the same lexical environment. As can be seen in Table 2, the addition of a prefix does not result in a change in the UP within the EARLY condition: "afleRen" and "leRen" have the same UP. In the LATE condition, however, on a left-to-right account, the addition of the prefix results in a leftward shift of the UP of at least two segments (e.g., /r/ in "leveRen" vs. /v/ in "afleVeren"). Moreover, the two prefixed verbs separate from each other—and from all other words in the language—at the same segment position (e.g., /r/ in "afleRen"; /v/ in "afleVeren").

<sup>3</sup> Not all unprefixed words in this experiment are verbs; three of the stems were adjectives (e.g., "helder," clear), three were nouns (e.g., "talen," languages) but the corresponding prefixed words were always verbs (e.g., "verhelderen," to clarify; "vertalen" to translate).

As pointed out above, we could not control for factors of the lexical environment in Experiments 1a and 1b. In Experiments 2a and 2b, the lexical environment for the prefixed words is identical up to the point where the subject identifies the segment constituting the UP. Precisely at that moment in time, no more competitors are available. Moreover, the prefixed words were matched in frequency (mean frequency of 5.8 and 5.3 for PREFIX-EARLY and PREFIX-LATE, respectively). The gating data on the two STEM words will provide us with information as to the amount of sensory input necessary for word-identification. On all accounts, given their early UPs, less sensory information—in milliseconds—should be needed for identification of the STEM-EARLY words (e.g., “leRen”) than for the STEM-LATE words (e.g., “leveRen”). Moreover, the difference in mean word frequency between the STEM-EARLY and STEM-LATE words (85.8 and 27.9, respectively) should also favor an earlier identification in the STEM-EARLY condition.

On a continuous left-to-right account, the prefixed verbs should be identified at the same segment position. Therefore, a left-to-right model predicts an interaction between the factor EARLY–LATE and the factor STEM–PREFIX, with earlier identification for STEM-EARLY than for STEM-LATE, but no difference between the two prefixed words. This result is illustrated in Fig. 1a.

Given the UPs of the stems, it is clear that a decomposition approach predicts a main effect of EARLY vs. LATE only, but no effect of the STEM vs. PREFIX factor and no interaction (see Fig. 1b).<sup>4</sup>

Finally, we can envisage a third potential

outcome. In Experiments 1a and 1b we found an overall advantage of prefixed words over their stems, independent of the position of the UP. If this pattern is replicated in the present experiments we should find a main effect of EARLY vs. LATE as well as a main positive effect of “prefixation,” but no interaction (see Fig. 1c). Such a pattern of results is not predicted by either model, nor could it be explained in terms of lexical environment, nor of word frequency, nor of the position of the UPs.

### *Material*

The same material was used in Experiments 2a and 2b, consisting of 24 quadruples of words of the kind listed in Table 2. In half of the quadruples the prefixed words were of the separable type, the other half were unseparable.

All prefixed words were recorded by a female speaker of Dutch, and digitized at a sampling rate of 20 kHz. Subsequently, the prefixes were spliced off the stems. Each word in the STEM condition was created from its prefixed counterpart, with identical stem tokens for both. For the gating experiment, the prefixes and the stems were separately segmented into fragments in the same way as in Experiment 1a. For the phoneme monitoring task, inaudible pulses set at the onset of the segment corresponding to the target phoneme served to start reaction-time measurement.

Controlling for lexical environment of the prefixed words, of course, forces us to give up the possibility of using identical stem tokens in all conditions. For comparisons between STEM words and prefixed words within each level of the EARLY–LATE dimension identical stem tokens are used. But when comparing EARLY vs. LATE, different words are involved. As stated earlier, on a left-to-right view, the EARLY and LATE prefixed words become unique at the same segment position (see Table 2). It is, however, an empirical question whether—again going from left-to-right—

<sup>4</sup> According to the decomposition model, only the frequency of the stem-entries, not of the full word forms, should play a role in the recognition of the prefixed words here. A differential effect of frequency, over and above the advantage of the EARLY over the LATE condition, is not expected.

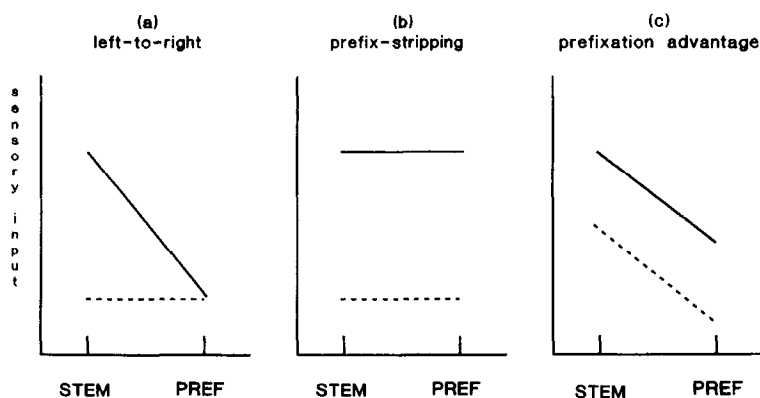


FIG. 1. Predicted patterns of results for Experiment 2a; straight lines for words in the LATE conditions, dotted lines for words in the EARLY conditions.

the sensory information constituting these UPs is available exactly at the same point in time. To determine this, we first ran a control study using a variant of the gating task: the segment-identification task. In the standard version of the gating task, subjects are instructed to always give word responses. In the segment-identification task, in contrast, subjects are told to write down, or to transcribe, exactly what they hear at each gate. To avoid lexical biases, subjects are explicitly instructed not to complete the presented stimulus information such that a word is formed (unless, of course, the whole word is presented). Non-word material was included further to discourage the use of lexical strategies. The first gate at which a subject writes down the segment constituting the UP of the prefixed word (e.g., the /r/ for "afleRen"), is the subject's segment-identification point for the word.

The control study had two experimental versions, each containing 12 of the prefixed words from the LATE condition, and 12 from the EARLY condition. Twenty-four subjects participated in the task, 12 in each version. The results showed that for the prefixed words entering the final analysis of Experiments 2a and 2b, the segments constituting the UP in the EARLY and the LATE condition were identified at the same point in the word, measured from the onset of the stem-tokens (250 and 246 ms, respectively; both  $F_s < 1$ ).

### Experiment 2a: Gating

#### Procedure

Four experimental versions were constructed. Only one word from each of the 24 quadruples occurred in each version; the STEM-EARLY word from six quadruples, the STEM-LATE word from another six quadruples, the PREFIX-EARLY word from still another six quadruples, and the PREFIX-LATE word from the remaining six quadruples, with these sets rotating across versions. A separate audiotape was prepared for each version, consisting of four practice trials, three pseudo-prefixed words, and 24 test words.

The subjects were presented on each trial with word fragments of incrementing length (i.e., the first 50 ms, 100 ms, and so on). After the presentation of each fragment, the subjects were given 5s to write down what they thought the word was going to be.

#### Subjects

Forty-eight native speakers of Dutch participated in the experiment. The subjects were randomly assigned to one of the four versions, 12 subjects per version. Subjects were tested in groups of three to six, and paid for participation. An experimental session lasted approximately 30 min.

#### Results

Of the original 24 quadruples, seven were excluded from further analysis. As in Ex-

periments 1a and 1b, either one of the members of a quadruple was distorted by the splicing procedure, or one of the words turned out to have a competitor in the Dutch vocabulary which changed its UP. Appendix 2 contains the 17 item sets entering the analyses.

The IP for the remaining 17 items were submitted to subject- and item-based analysis of variance with the factors EARLY vs. LATE, and STEM vs. PREFIX. Each quadruple was treated as one item, so that items were treated as crossed with these two factors. Table 3 gives the mean IPs.

The main effects for both factors were significant, for EARLY vs. LATE:  $F_1(1,47) = 213.4, p < .0005$ ;  $F_2(1,16) = 17.8, p < .001$ ; for STEM vs. PREFIX:  $F_1(1,47) = 33.46, p < .0005$ ;  $F_2(1,16) = 28.9, p < .0002$ . There was no interaction between the two factors,  $F_1(1,47) = 1.28, p > .20$ ;  $F_2(1,16) < 1$ . These results clearly replicate the overall advantage of prefixed words over their stems, which was already observed in Experiment 1a.

To investigate potential influences of Prefix Type (separable vs. non-separable), an item-ANOVA was performed with the factors EARLY vs. LATE, STEM vs. PREFIX, and Prefix Type, with items nested under this factor. In nine of the 17 quadruples the prefixes were separable, the remaining eight quadruples were of the unseparable type. This analysis showed significant main effects of EARLY vs. LATE ( $F_2(1,15) = 16.8, p < .005$ ) and of STEM vs. PREFIX ( $F_2(1,15) = 27.0, p < .005$ ). Neither the main effect of Prefix Type nor any interaction reached significance (all  $F_s < 1$ ).

TABLE 3  
EXPERIMENT 2a: MEAN IDENTIFICATION POINTS FOR  
STEMS AND PREFIXED WORDS IN CONDITIONS  
EARLY AND LATE

	Stem	Prefix
EARLY	221	178
LATE	310	248

### Experiment 2b: Phoneme Monitoring

The same 24 quadruples were used as in Experiment 2a. For each stem/prefixed word pair, the same phoneme was chosen as target. In principle, this was the phoneme corresponding to the segment constituting the UP of the stem (e.g., /r/ in both "leveRen" and "afleVeren"). For five pairs in the LATE condition, however, this was not possible, because this phoneme already occurred earlier in the spoken word (e.g., /r/ in the pair "radeRen/uitraDeren"). In these cases, the segment constituting the UP of the prefixed word was chosen as target phoneme (e.g., /d/ in the above example).

Given the position, relative to the UPs, of the target phonemes the same predictions as illustrated in Fig. 1 can be made with respect to the effect STEM vs. PREFIX and to the interaction with the factor EARLY vs. LATE. Any main effect of EARLY vs. LATE, however, cannot be interpreted since this comparison would be based on monitoring latencies to different phonemes in different acoustic tokens.

### Procedure

Four audio tapes were prepared, one for each experimental version. The words of the quadruples were assigned to the four experimental versions in the same way as in Experiment 2a. The test words always occurred at the end of a short list, varying in length from one to four words. The four experimental versions only differed with respect to the test words. In addition, 52 lists were used as filler trials; 25 of these were catch trials where the prespecified phoneme did not occur in the list. The fillers also contained pseudoprefixed words. In all other aspects, the procedure was the same as in Experiment 1b.

### Subjects

Forty-eight subjects were paid to participate in the experiment, 12 subjects per ver-

sion. An experimental session lasted approximately 20 min.

### Results

The same seven quadruples as in Experiment 2b were excluded from the analyses. On 0.6% of the test trials, subjects did not detect the target phoneme. These missing values were treated in the same way as in Experiment 1b, and the same holds for the extreme values, 2.9% of the reaction times. Table 4 gives the mean reaction times and the percentage of missing responses for the four experimental conditions.

The monitoring times were analyzed in subject and item analyses of variance, with the two factors EARLY vs. LATE and STEM vs. PREFIX. The main effect of STEM vs. PREFIX was significant by subjects and by items,  $F_1(1,47) = 31.1, p < .0005$ ;  $F_2(1,16) = 7.6, p < .05$ . The main effect of EARLY vs. LATE was only significant by subjects,  $F_1(1,47) = 11.4, p < .005$ ;  $F_2(1,16) = 2.24, p > .10$ . The interaction between the two factors was not significant,  $F_1(1,47) = 1.73, p > .20$ ;  $F_2(1,16) < 1$ .

In an additional item ANOVA with Prefix-Type (separable vs. non-separable) as a factor, again only the main effect of STEM vs. PREFIX was significant,  $F_2(1,15) = 7.4, p < .05$ . No other main effect or interaction reached significantly.

### Discussion of Experiments 2a and 2b

The results of Experiments 2a and 2b conform with the predictions given in Fig. 1c;

that is, they replicate the results of Experiments 1a and 1b. Prefixed words are identified earlier than their corresponding stems, irrespective of the position of the UP. This result was obtained in Experiment 1 for prefixed words with the same acoustic stem token, but with no control over factors of lexical environment, as well as in Experiment 2 for prefixed words with different stem tokens, but with complete control over the lexical environment of the prefixed words. Thus, in Experiments 1 and 2 we find evidence for a general effect of prefixation which is neither predicted by the affix-stripping account nor by continuous left-to-right processing models of the cohort type.

### EXPERIMENTS 3 AND 4: THE PROCESSING OF PSEUDO PREFIXED WORDS

Until now, our tests of the predictions made by continuous and discontinuous models have focused on the processing of morphologically complex words with prefixes. Neither the affix-stripping model, nor left-to-right models adhering to the full-listing view of lexical representation can account for the obtained results. Where prefixed words are concerned, the UP apparently is not a good predictor of what happens during word processing. The question now is whether this finding is particular to morphologically complex words with real prefixes. Experiments 3 and 4 make use of a different diagnostic tool for testing the competing claims made by continuous and discontinuous models: the processing of pseudo prefixed words. Pseudo prefixed words start with a sequence of segments constituting a real prefix of the language, but the part of the word which follows is not a stem. For example, "uit" in "uitbundig" is a prefix (roughly corresponding to the English "out"), but "bundig" is not a stem.

According to the decomposition hypothesis, the listener will identify the first part as being a prefix. He will then try to find a match between the acoustic input following

TABLE 4  
EXPERIMENT 2b: MEAN MONITORING LATENCIES FOR STEMS AND PREFIXED WORDS IN THE CONDITIONS EARLY AND LATE (PERCENTAGE OF MISSING RESPONSES IN PARENTHESES)

	Stem	Prefix
EARLY	551 (1.0)	509 (0.4)
LATE	519 (0.5)	491 (0.5)

the prefix and a stem representation in his mental lexicon. For pseudoprefixed words, however, there is no such match. We will label the point in the acoustic signal at which this mismatch can be detected the "pseudostem point."<sup>5</sup> In the above example, the /i/ in "bundig" tells the system that potential stems such as "bundel" (bundle) no longer match the particular stretch of speech following the (pseudo-)prefix. The system then has to backtrack, to find a match for the whole word in the mental lexicon. It is clear, therefore, that under the affix-stripping view a pseudoprefixed word cannot be recognized before the subject has reached the pseudostem point. On a left-to-right account, in contrast, identification and recognition of pseudoprefixed words should be completely independent of the pseudostem point. Pseudoprefixed words are morphologically simple, and a consistent finding in the literature is that the word processing system is sensitive to the UP in these cases (Marslen-Wilson, 1984; 1987). A continuous model, therefore, predicts that if the UP is earlier in the word than the pseudostem point (as in "uitbUndig," where the /u/ is the UP), then the word should be identified before the pseudostem point.

### Experiment 3

Experiment 3 used both the normal gating and the segment-identification task. Twelve pseudoprefixed words were selected, four nouns, four verbs, and four adjectives (see Appendix 3). In these words the pseudostem point (e.g., /i/ in "uitbUndig") was located at least two segments later than the UP (e.g., /u/ in "uitbUndig"). The material was recorded by a female speaker of Dutch and digitized at a sampling rate of 20 kHz. The words were then

<sup>5</sup> The pseudostem points were determined by means of a Dutch dictionary (van Sterkenburg & Pijnenburg, 1984). It was checked at which segment, calculated from its onset, the pseudostem separated from real stems listed in the dictionary.

segmented into fragments increasing in length by 50 ms steps. For each of these words, we first determined, using the segment-identification task, the point at which the speech segments constituting the UP and the pseudostem point are identified. In a normal gating experiment, we then determined the IPs for these words.

### Procedure

The segment-identification test for the 12 pseudo prefixed words was run concurrently with the segment-identification test described above with Experiment 2a. Two of the four nouns, two of the four verbs, and two of the four adjectives were assigned to each of the two versions of the segment-identification test. The gating experiment for the 12 pseudoprefixed words was run concurrently with Experiment 2a. This experiment had four experimental versions. One of the four nouns, one of the four verbs, and one of the four adjectives was assigned to each of these versions. For details on the procedure see Experiment 2a.

### Results and Discussion

The mean IP for the 12 pseudoprefixed words was 419 ms. A comparison with the pseudostem point as determined in the segment-identification test (566 ms) shows that the pseudoprefixed words are identified well before the pseudostem point,  $F_1(1,22) = 91.7, p < .001$ ;  $F_2(1,11) = 33.5, p < .001$ . In contrast, the point at which the subjects identify the segment constituting the UP (414 ms) perfectly coincides with the obtained mean IP,  $F_1(1,22) < 1$ ;  $F_2(1,11) < 1$ . These results are not compatible with the affix-stripping view; the identification of pseudoprefixed words is not a function of the point in the word at which the input is no longer compatible with existing stem entries. Instead, as predicted by continuous left-to-right processing models, pseudoprefixed words are identified at their UP.

### *Experiment 4*

Experiment 4 investigates the processing of pseudo prefixed words with a phoneme monitoring task. The material consisted of pairs of words, matched with respect to word frequency. The words of each pair started with a syllable which is a real prefix for one of the words and a pseudoprefix in the other (e.g., "be" in "bedriegen" and "beliegen"). Within each pair, the segment constituting the UP of the word with the real prefix (e.g., /g/ in "belieGen") coincided with the segment constituting the pseudostem point of the pseudoprefixed word (e.g., /g/ in "bedriegen"). The actual UP of the pseudoprefixed word, however, was located at least one segment before this pseudostem point (e.g., /i:/ in "bedrIEgen").

Subjects had to monitor for the phoneme constituting the UP for words with real prefixes, and the pseudostem point for the pseudoprefixed words (the /g/ in the above example). Under a left-to-right view, longer monitoring latencies are expected for the prefixed words than for the pseudoprefixed words, since for the latter the segment corresponding to the target phoneme falls after the UP. For the decomposition model, however, the reverse prediction holds. Since the system will try to access the pseudoprefixed word via its "pseudostem," the target phoneme corresponds to the point at which the system will be forced to give up the attempt to locate a stem in the mental lexicon and will have to backtrack.

### *Material and Procedure*

Sixteen pairs of prefixed and pseudoprefixed words were selected (see Appendix 4). In order to keep coarticulatory information constant for both words of a pair, the vowels preceding and following the critical segment for which subjects had to monitor were the same in both words. The words were recorded by a female speaker of Dutch, digitized at a sampling rate of 20 kHz, and a pulse was set at the onset of the

critical segment. The words were presented at the end of word lists, varying in length from one to four, with words distributed equally across list types. Experiment 4 was run concurrently with Experiment 2b, which had four experimental versions. The first two experimental versions contained the pseudoprefixed words from the first eight pairs, and the prefixed words from the remaining eight pairs. For versions 3 and 4 this assignment was reversed. For further details on subjects and procedure see Experiment 2b.

### *Results and Discussion*

Missing monitoring responses and extreme values were treated in the same way as in Experiment 2b. The mean monitoring latency for pseudoprefixed words was 444 ms, and for prefixed words it was 494 ms (with 1.6% and 1.3% missing responses, respectively). This difference is significant by subjects and by items,  $F_1(1,47) = 35.1, p < .0001$ ;  $F_2(1,15) = 13.6, p < .01$ .

These results are in conflict with the affix-stripping view, which states that access to pseudoprefixed words cannot be initiated before the pseudostem point has been reached. Contrary to this prediction, and consistent with a left-to-right processing view, monitoring times for the pseudoprefixed words are faster than for prefixed words. Apparently, listeners do not attempt to locate a stem first, and, if they fail, then to find a representation for the word as a whole.

### GENERAL DISCUSSION AND CONCLUSIONS

None of the data from our experiments provides evidence in favor of the decomposition model proposed by Taft and Forster (1975). Contrary to what this model predicts, the identification of prefixed as well as pseudoprefixed words is independent of the point at which the stem (or pseudostem) of a word can be identified. This is not only demonstrated with the gating paradigm, a task which might artificially induce left-to-right processing, but also with the timed

phoneme monitoring task. We therefore conclude, in agreement with Tyler et al., that the decomposition model—at least for the auditory modality—is not a suitable account of what happens during the processing of prefixed words.

Another class of models which was tested in our experiments are the continuous left-to-right processing models, in particular, the Cohort model developed by Marslen-Wilson and his co-workers (Marslen-Wilson, 1987; Marslen-Wilson & Welsh, 1978; Tyler et al., 1988). The most robust result from our experiments is what we have labelled the “prefixation effect.” Our data show a consistent advantage of prefixed words over their unprefixed stems, both with the gating and the phoneme monitoring task. Moreover, this advantage is shown to be independent of the position of the UP, that is, the critical point at which—according to the Cohort model—a word should be identified. Positive evidence for the importance of the UP was only obtained with words without prefixes. The data for the unprefixed words (e.g., “leren” and “leveren”) show a sensitivity to properties of word forms such as UP and word frequency; the same is true for the monomorphemic words containing pseudoprefixes. The fact that our general prefixation effect seems to be independent of the UP of the prefixed words clearly casts doubts on the interpretation of the data discussed in Tyler et al. (1988). They only compared prefixed words and free stems, with earlier UPs for the former, and obtained a clear advantage for prefixed words relative to their unprefixed stems. Tyler et al. interpret this finding as corroborating evidence for models of continuous processing and full-form representation, in particular, the Cohort model. Our data, however, indicate that this conclusion is premature. When comparing sets of prefixed words with different UPs—as in Experiments 1a and 1b—we do not obtain an advantage for words with earlier UPs. Granted that we could not control for fac-

tors of lexical environment in these experiments, this result, nevertheless, was clearly replicated in Experiments 2a and 2b, where lexical environment and full-form frequency was controlled.

The result from our experiments which is most detrimental to the Cohort model is in Experiment 2a, where we saw the advantage of the prefixed words in the LATE condition over those in the EARLY condition. These words (e.g., “afleRen” and “afleVeren”) are from the same word-initial cohort; that is, they share the same lexical environment. Moreover, the words were matched for frequency, and the segment-gating results show that exactly the same amount of sensory information is needed to identify the different speech segments constituting the UPs of these words. Nonetheless, some 70 ms less sensory information is needed to identify the prefixed words in the EARLY condition.

Thus, there are two experimental findings which need to be explained: the general prefixation effect and the earliness of the identification of the prefixed words in the EARLY condition in Experiment 2a. In the following, we will argue that the prefixation effect is due to a sensitivity of the lexical processing system to the internal structure of morphologically complex words. Moreover, we will claim that the locus of the effect is at the level of lexical representation. So far, the interpretation of the prefixation effect in terms of morphological complexity has only been based on the exclusion of other explanations such as full-form frequency, lexical environment, and word length. We would now like to provide some more direct evidence for this morphological interpretation, based on a reanalysis of the data from Experiment 2a. An often used diagnostic tool for the effects of morphological structure on lexical processing is the investigation of effects of full form vs. stem frequency. If reaction times to sets of morphologically complex words which are matched in all aspects, including full-form frequency, nevertheless vary as a

function of a difference in the mean frequency of their stems, then this is taken as evidence for the role of morphological complexity during word processing (Cole, Beauvillain, & Segui, 1989).

The only factor which was not controlled in our Experiments 2a and 2b was the frequency of the stems. The stems in the EARLY condition were much higher in frequency than those in the LATE condition. This, together with the different position of the UP in these conditions, resulted in the earlier identification of the EARLY stems. The question now is whether this difference in frequency of the stems can also account for the extreme earliness of the identification of the prefixed words in the EARLY condition, which of course share their stem part with the corresponding high-frequency unprefixed words. If the frequency of the stem of a prefixed word—and, by implication, morphological complexity—plays a role, the strength of the prefixation effect should vary as a function of the frequency of the stem. We can investigate this prediction by dividing our material from Experiment 2a into two sets. In Set 1, we included seven item sets where the mean frequency of the two stems of a quadruple is lower than 50 (mean frequency 29.1 for EARLY stems, 48.1 for LATE stems, corpus size 720,000 Uit den Boogaart, 1975). The corresponding prefixed words are matched in frequency (4.0 for PREFIX-EARLY; 5.2 for PREFIX-LATE). For the seven item sets in Set 2, the EARLY stems are much higher in frequency than the LATE stems (172.8 vs. 18.7), whereas the frequency of the prefixed words is again balanced (12.4 for PREFIX-EARLY; 9.4 for PREFIX-LATE).

Given the considerable frequency advantage in Set 2 of EARLY over LATE stems, the stem-frequency account predicts a large prefixation effect for the prefixed words in the EARLY condition. That is, these words should not only be identified well before their stems, but also before the prefixed words in the LATE condition, although the

position of the UP is identical in these three conditions. For Set 1, where the mean frequency of the two stems is more or less balanced, we expect an overall advantage of prefixed words over their stems, but no difference in IP between the two prefixed words. Table 5 provides the mean IPs for the words in both sets, as well as the points at which the segments constituting the UP of the prefixed words were identified in the segment-identification task.

In Set 1, there is no difference in mean IP between the two prefixed words. Moreover, the IP for these words corresponds quite well to the point at which the segments constituting the UP are identified. Despite their identical UP, however, the prefixed words in the EARLY condition show a small advantage relative to their stems (23 ms). This is precisely what is predicted; given that the mean frequency of the stems is rather low, but still higher than the full-form frequency, a small advantage due to morphological complexity is expected. The difference between the prefixed words and the stems in the LATE condition, however, is quite large (80 ms). It should be kept in mind that, contrary to the EARLY condition, the prefixed words in the LATE condition have an earlier UP than their unprefixed counterparts. The large advantage, in this condition of prefixed words over their stems can be explained in terms of the combination of a (weak) prefixation effect with a stronger effect of the position of the UP.

TABLE 5  
EXPERIMENT 2a: MEAN IDENTIFICATION POINTS  
AND SEGMENT-GATING RESULTS, AS A  
FUNCTION OF STEM FREQUENCY

Set		IP stem	IP prefix	Identification of UP segment
1	EARLY	234	211	224
	LATE	292	212	222
2	EARLY	257	170	285
	LATE	366	291	282

Exactly the same explanation holds for the 75 ms difference, in Set 2, between prefixed words and stems in the LATE condition. Again, there is good correspondence between the mean IP for the prefixed words in the LATE condition, and the point at which the segment constituting the UP is identified (291 and 282 ms, respectively). A completely different pattern emerges in the EARLY condition in Set 2. First, the stems are identified some 28 ms before the point at which the segment constituting the UP is identified: probably a general effect of word frequency picked up by the gating task. Second, contrary to Set 1, there is a large advantage of prefixed words over their stems (87 ms). Although the UP for stems and prefixed words is identical, we see that the prefixed words are identified some 115 ms before the point at which the segment constituting the UP is identified. This surprising earliness of identification of prefixed words, relative to the UP and to the stems, only shows up when their stems have a high frequency count. In all other prefix-conditions, the frequency of the stem was rather weak, and small prefixation effects were observed. This pattern of results supports an interpretation of the prefixation effect in terms of a lexical effect of morphological structure, where the magnitude of the effect varies as a function of stem frequency.

When lexical-morphological influences are weak (as in Set 1), there is a close correspondence between the point at which prefixed words are identified and the UP. The fact that the point at which a prefixed word separates from its full-form competitors determines word identification in these cases, together with the finding that pseudoprefixed and unprefixed words are identified approximately at their UP, leads us to believe that there is no prelexical process which identifies certain parts of the input as potential affixes or stems. This underlines the validity of a left-to-right processing account over a decomposition

approach. Our data, however, show that the continuous processing models have to be modified with respect to their claims about what is lexically represented. The recognition of morphologically complex words not only depends on properties of the full-word form, but also on lexical information stored with its composite morphemes.

To summarize, the process of identifying morphologically complex spoken words is neither completely blind to word-internal structure, as suggested by a full-listing-only view, nor is it mediated by prelexical decomposition of the spoken input into stems and affixes. Rather, complex words seem to be processed essentially in a left-to-right manner, but their identification is dependent on certain properties of their constituent morphemes. As a consequence, we assume that, in addition to full-word forms, the mental lexicon also contains information about the constituents of morphologically complex words and that this information is used in word identification. Similar proposals of lexical organization have been made in the literature (e.g., Fowler, Napps, & Feldman, 1985; Dell, 1986; Caramazza, Laudanna, & Romani, 1988; Schreuder, Grendel, Paulisse, Roelofs, & van der Voort, 1990). Such a view of lexical representation could also account for the processing, in sentence contexts, of prefixed words of the separable type. The stems of these words frequently precede their prefix when heard in a sentence. Given that the meaning of these prefixed words is often not compositional in nature (Schreuder, 1990; Zwitserlood, 1990), the lexical processing system has to combine the constituents at some level of lexical representation. Our findings could be incorporated in existing continuous word recognition models, such as the Cohort model or Trace, by adding a lexical level representing the composite morphemes of complex words. Whether the addition of a morphological level of lexical representation to a process-

ing architecture as proposed in Trace can account for the present findings is, of course, a question which can only be answered by computer simulations.

APPENDIX 1

THE 17 TRIPLETS OF EXPERIMENT 1a AND 1b

STEM	=STEM	<STEM
<i>a. Separable prefix</i>		
sluiPen (sneak)	aansluiPen (steal upon)	doorslUIpen (slip through)
slaaN (beat)	uitslaaN (knock/break out)	toeslAAAn (slam/strike)
grijPen (grasp)	aangrijPen (seize upon)	ingrIJpen (intervene)
staaN (stand)	opstaaN (get up)	toestAAAn (allow)
sluiTen	aansluiTen (connect)	opslUIten (lock up)
braNden (burn)	doorbraNden (burn on)	uitbrAnden (burn out)
<i>b. Nonseparable prefix</i>		
dieNen (serve)	verdieNen (earn)	bedIEnen (serve)
groefen (grow)	ontgroefen (outgrow)	vergrOEien (grow together)
treKken (pull)	betreKken (move into)	vertrEkken (leave)
werPen (throw)	verwerPen (reject)	ontweRpen (design)
strijKen (spread/iron)	bestrijKen (cover/encompass)	verstrIJken (expire)
deKken (cover)	bedeKken (cover up/over)	ontdeKken (discover)
traPPen (kick)	betaPPen (catch)	vertrAppen (trample upon)
loPen (walk)	verloPen (elapse/expire)	ontlOpen (avoid)
vallEn (fall)	vervallEn (decay)	ontvaLlen (let slip)
drinKen (drink)	verdrinKen (drown)	bedrInken (get drunk)
zeTTen (put)	verzeTTen (shift/resist)	bezEttten (occupy)

Note. Capitals indicate the UP.

APPENDIX 2

THE 17 QUAPDRUPLES OF EXPERIMENT 2a AND 2b

EARLY	
STEM	PREFIX
<i>a. Separable prefix</i>	
leNen (borrow)	uitleNen (lend)

buiGen (bend)	neerbuiGen (bend down)
raKen (touch)	uitraKen (get out)
kniPPen (cut)	uitkniPPen (cut out)
waSSen (wash)	uitwaSSen (wash out)
jaTTen (steal)	afjaTTen (steal of)
leRen (learn)	afleRen (unlearn)
schaLen N (scales)	inschaLen (put on a scale)
naaIen (sew)	toenaalen (sew up)
LATE	
STEM	PREFIX
lepeLen (spoon)	uitlePelen (spoon)
buiteLen (tumble)	neerbuiTelen (tumble down)
radeRen (erase)	uitraDeren (scratch out)
knikkeRen (play marbles)	uitkniKkeren (chuck out)
wandeLen (walk)	uitwaNdelen (walk out)
jakkeRen (hurry)	afjaKkeren (hurry through/exhaust)
leveRen (supply)	afleVeren (deliver)
schakeLen (link/change gear)	inschaKelen (plug in/call in)
nadeRen (approach)	toenaDeren (approach)
EARLY	
STEM	PREFIX
<i>b. Nonseparable prefix</i>	
helPen (help)	verhelPen (remedy)
maLen (grind)	vermaLen (grind)
lePPen (wilt)	verlePPen (wilt)
haNGen (hang)	verhaNGen (hang elsewhere)
neMen (take)	verneMen (be told)
duNNen (thin out)	verduNNen (dilute)
worMen N (worms)	ontworMen (remove worms)
taLen N (languages)	vertaLen (translate)

LATE	
STEM	PREFIX
heldeR A (clear)	verhelDeren (clarify)
mageR A (thin)	vermaGeren (reduce weight)
lekkeR A (good)	verleKKeren (make keen)
handeLen (act/trade)	verhaNdelen (deal in)
neveLen (spray)	verneVelen (spray)
dubbeLen (double)	verduBBelen (duplicate)
worsteLen (wrestle)	ontworStelen (break away from)
takeLen (hoist)	vertaKelen (rig)

Note. Capitals indicate the UP; A = adjective; N = noun.

## APPENDIX 3

## THE 12 PSEUDOPREFIXED WORDS OF EXPERIMENT 3

bekWamen (qualify)	bezoLdigen (pay)	beknlbbelen (stint on)	verdeDigen (defend)
verieGen (shy)	benArđ (awkward)	uitbUndig (profuse)	bedrEmmeld (bashful)
begoNia (begonia)	versnApering (snack)	gehalTe (content)	aanstaLjen (intention)

Note. Capitals indicate the UP; underlining indicates the pseudostem point.

## APPENDIX 4

## THE 16 WORD PAIRS OF EXPERIMENT 4

Target phoneme	Prefixed	Pseudo prefixed
k	bestrijKen	bezwIJken
l	gewimpeLd	beduiMeld
n	verschijNen	verdwIJnen
k	gedeKt	gebrEK
g	belieGen	bedrIEgen
d	onnoDig	besteNDig
m	beraMen	bekWamen
g	onhandIg	beheNDig
g	verhevlGen	bezoLdigen
d	gebieDen	geschIEden
d	geharDe	benArde
p	beroePen	berisPen
l	bedruPPelen	beknlbbelen
l	getrommEld	bedrEmmeld
t	geroT	genOt
ng	verwerkIng	ontglnning

Note. Capitals indicate the UP; underlining indicates the pseudostem point.

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