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Morphological Analysis in Sentence Reading

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In two experiments, adults' eye movements were monitored while they read sentences containing prefixed (e.g., REVIVE) or pseudoprefixed (e.g., RESCUE) words closely matched on initial letter pattern, frequency, length, and syntactic category. It was found that pseudoprefixed words received longer fixations and were associated with shorter departing saccades than prefixed words. These results supported the hypothesis that words are stripped of their prefixes prior to lexical access, and that stem morphemes are represented and accessed in the lexicon. Two specific models that assume prefix stripping were tested by varying the availability of parafoveal preview of the prefix or pseudoprefix. It was found that prefix stripping seemed to be a foveal rather than a parafoveal process, so that the parafoveal preview results could not readily distinguish between the two models. © 1987 Academic Press, Inc.

Most studies of lexical access have proceeded on the tacit assumption that each entry in the internal lexicon corresponds to one word, but this assumption may be incorrect. Consider the word UNTIE. Readers would agree that it has two meaningful units, UN- and TIE; these are examples of morphemes, the smallest linguistic units that carry meaning. Our ability to make reliable judgments about morphemic structure suggests that an entry in the lexicon may correspond not to one word but to one morpheme. The most detailed model of such a lexicon is that of Taft and Forster (1975, 1976; Taft, 1976, 1979b, 1981). In this model, the lexicon is contacted via search of an access file containing representations of the stem morphemes of the language listed in order of decreasing stem frequency. Each stem representation points to entries in a master file that provide the information needed to comprehend the members of that stem's morphological family. For example, UNTIE is accessed via a representation [TIE].[1]

If words are accessed via stem representations, then in reading there must be a stage of preliminary morphological analysis; that is, there must be a way of prelexically extracting a stimulus word's probable stem in order to know what to search for in the access file. In the case of prefixed words, the stem could be isolated by stripping off the prefix. A small internal inventory of representations of the prefixes in English could be matched against the initial few letters of each stimulus word as it is read; once the prefix has been removed from a stimulus word, then the probable stem is that which remains. In support of

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[1] Brackets are used to denote an accessible representation in the lexicon.

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prefix stripping, Taft and Forster (1975) found that a nonword combining a prefix and a stem (e.g., DEJUVENATE) took longer to reject than one combining a prefix and a nonstem (e.g., DEPERTOIRE), just as a stem alone (e.g., JUVENATE) took longer to reject than a nonstem (e.g., PERTOIRE).

The claim that prefixes are stripped off prior to lexical access predicts delays in processing unprefixed words spelled as if they are prefixed (e.g., RELISH). The "pseudoprefix" RE in RELISH is orthographically identical to the true prefix RE (e.g., in REVIVE), so that RELISH would be stripped down to LISH just as REVIVE would be stripped down to VIVE. REVIVE would be successfully accessed via VIVE, but RELISH could not be accessed via LISH because [LISH] does not exist. On Taft and Forster's model, only after search for *[LISH] has failed is RE reattached to LISH and a search made for the correct stem entry, [RELISH]. Thus, pseudoprefixed words should take longer to recognize than prefixed words.

Several pertinent experiments have been reported. Rubin, Becker, and Freeman (1979) found that lexical decisions on pseudoprefixed words did take longer than those on prefixed words when all the nonword foils were prefixed, but not when all the nonwords were unprefixed. This context dependency was taken as evidence that prefix stripping is merely a special strategy subjects use when there is a predominance of prefixed stimuli. However, Taft (1981) pointed out a flaw in the Rubin et al. design: When all the nonwords were unprefixed, subjects could have reliably responded "yes" on the basis of the presence of an apparent prefix,[2] leading to equal and fast response times on prefixed and pseudoprefixed words in the unprefixed-nonword condition only. In support of his view that prefix stripping is not a context-dependent strategy, Taft reported an experiment showing that pseudoprefixed words took longer to name than prefixed words even when no nonwords were used. Also, later studies showed that pseudoprefixed words had longer lexical decision times than prefixed words in various heterogeneous contexts (Bergman, Eling, & Hudson, 1986; Henderson, Wallis, & Knight, 1984). Converging evidence came from a study in which subjects read text while cancelling every exemplar of the letter "e" (Smith & Sterling, 1982). It was found that the "e" in a prefix or a pseudoprefix was missed more often than the "e" in a nonprefix, suggesting that apparent prefixes are unitized in reading. Most importantly, true prefixes did not yield greater miss rates than pseudoprefixes, suggesting that apparent prefixes are unitized prior to lexical access of the stimulus word or its stem.

One drawback of the available evidence is that it rests on tasks unrepresentative of normal reading, such as lexical decision and letter cancellation. Accordingly, the first goal of the experiments reported here was to examine the role of morphological analysis in normal silent reading. To this end, subjects' eye behavior was monitored as they read sentences containing prefixed or pseudoprefixed words. In reading, the eyes make saccadic movements of short duration (20 to 40 ms) separated by fixations of longer duration (200 to 250 ms, on average) (Rayner, 1978), and it has been shown that fixation duration is sensitive to momentary cognitive processing load (e.g., Ehrlich & Rayner, 1981; Lima & Inhoff, 1985; Rayner, 1977). If prefix stripping is part of normal reading, then pseudoprefixed words should require more fixation time than prefixed words. If, on the other hand, prefix stripping is not part of normal reading, then pseudoprefixed words should require no more fixation time than prefixed words.

There are at least two models consistent with the prefix stripping view, and the second goal of the experiments was to find

[2] The term *apparent prefix* refers to both prefixes and pseudoprefixes.

evidence that would empirically distinguish them. As we have seen, one model is that of Taft and Forster; on this model, any word has one and only one accessible representation, the representation of its stem morpheme. Lexical access of a pseudoprefixed word follows a sequential time course: (1) The first attempt is made via the putative stem; if this attempt fails, then the apparent prefix is reinstated and (2) a second attempt is made via the whole word. Prefixed words take less time to recognize than pseudoprefixed words because they undergo one access attempt rather than two.

An alternative to the single-representation, sequential model of Taft and Forster is a dual-representation, parallel model, which assumes that a prefixed word has an accessible whole-word representation as well as an accessible stem representation. Like the first model, this model also assumes that prelexical prefix stripping occurs. However, on this model, lexical access follows a parallel rather than a sequential time course: An access attempt via the prefix-stripped putative stem is carried out in parallel with an access attempt via the whole word. Consider REVIVE and RELISH. The search for [VIVE] can succeed and the search for [REVIVE] can succeed; the search for *[LISH] cannot succeed and the search for [RELISH] can succeed. On average prefixed words take less time to recognize than pseudoprefixed words because they have two chances of being accessed whereas pseudoprefixed words have only one.

Both of the above models predict that pseudoprefixed words will require more fixation time than prefixed words, but they make divergent predictions about the usefulness of parafoveal preview of prefixed and pseudoprefixed words prior to their actual fixation. Previous research has shown that much of the useful parafoveal information in reading comes from the beginning few letters of the word immediately to the right of the fixated word (Rayner, Well, Pollatsek, & Bertera, 1982). Because prefixes form a small set of short and highly familiar word-initial letter patterns, they are excellent candidates for parafoveal identification, and it is therefore possible that apparent prefixes are identified and stripped off before the prefixed or pseudoprefixed word is fixated.

In the present experiments, the sentences were presented under conditions allowing or denying parafoveal preview of the prefixed or pseudoprefixed words. What would distinguish the single-representation, sequential model from the dual-representation, parallel model is the nature of the interaction of prefixedness/pseudoprefixedness with parafoveal preview. Consider the first model. On the assumption of strictly sequential access attempts, any attempt based on the whole word must wait for the negative outcome of the attempt based on the putative stem. Therefore, both prefixed and pseudoprefixed words cannot be successfully identified until after their apparent prefixes have been stripped. If the apparent prefix were isolated parafoveally, then on fixation a prefixed or a pseudoprefixed word would each have recieved an equal "head start" by already having had its apparent prefix isolated, so that prefixed and pseudoprefixed words would benefit equally from the apparent prefix having been processed in the parafovea prior to fixation.

Now consider the second model. On the assumption of parallel access attempts, a pseudoprefixed word does not benefit when its apparent prefix is stripped, because the ultimately successful whole-word access attempt does not wait for the outcome of the doomed "stem" access attempt. However, a prefixed word does benefit when its prefix is stripped, because one of the ways it can be accessed is via its stem. Therefore, if the apparent prefix were isolated parafoveally, then on fixation a prefixed word would have received a head start whereas a pseudoprefixed word would have received no special help beyond having had some of its letters identified, so that prefixed words would benefit more than pseudoprefixed words from the apparent prefix having been processed in the parafovea prior to fixation.

To summarize, the predictions are as follows. If prelexical prefix stripping occurs in reading, then pseudoprefixed words will receive longer fixations than prefixed words. Both the single-representation, sequential model and the dual-representation, parallel model assume that prelexical prefix stripping occurs, and both make this prediction. However, the first model predicts equivalent parafoveal preview benefit for the two types of words, whereas the second model predicts greater benefit for prefixed words than for pseudoprefixed words.

Experiment 1

Experiment 1 employed an eye-contingent display change technique (Rayner, 1975) to examine the foveal and parafoveal processing of prefixed and pseudoprefixed words matched in a pairwise fashion on frequency, length, initial letter pattern, and syntactic category. Sentence pairs were like the following:

> The boy didn't remind his mother to pick him up after school.
> The boy didn't relish the thought of eating liver for dinner.

The first sentence contains the prefixed critical word REMIND and the second contains the matched pseudoprefixed critical word RELISH. A subject read only one sentence of a pair. Prior to the saccade that brought the critical word into foveal fixation, the contents of the critical location consisted of either the critical word, the word's apparent prefix followed by X's, or a string of X's. During the saccade to the critical location, the presaccade contents were replaced with the critical word itself, so that on fixation the subject always saw the critical word. In effect, the whole word condition allowed full parafoveal preview of the critical word, the prefix + X's condition allowed parafoveal preview of only the apparent prefix, and the X's condition denied any parafoveal preview.

Method

Subjects

Eighteen members of the University of Massachusetts community were paid to participate. All had normal vision or could read the sentences without wearing corrective lenses.

Materials

Sentence pairs. Sentences were drawn from a set of 36 pairs. One member of a sentence pair contained a prefixed critical word, and the other contained a matched pseudoprefixed critical word in the same location. The two members of a sentence pair were identical up to the critical word and usually differed from each other after that. Care was taken to make each sentence-beginning neutral and equally appropriate for either critical word. Sentence pairs were approximately matched on length (for both types, M = 10.2 words, range = 7 to 16). On average, the critical word was preceded by 2.5 words in the sentence (range = 1 to 4).

Word pairs. Each of the 36 pairs of prefixed and pseudoprefixed words was exactly matched on initial letter pattern (apparent prefix) and on length in letters (M = 7, range = 5 to 10). Word pairs were closely matched on word frequency (Kucera & Francis, 1967); the means were 22.2 per million (range = 1 to 195) for prefixed words and 21.4 (range = 1 to 171) for pseudoprefixed words. Pairs were approximately matched on number of syllables (M = 2.3 for prefixed words and M = 2.4 for pseudoprefixed words, range = 1 to 4). Also, pairs were exactly matched on syntactic category, although some words had more than one possible syntactic category.

Assessing prefixedness and pseudoprefixedness. Each of the prefixed words is listed as having a prefix + stem etymology in *Webster's Ninth New Collegiate Dictionary* (1985). to be used as a prefixed critical word, a word had to satisfy additional criteria: It combined a prefix and a free stem, resulting in a compositional meaning (e.g., MISTRUST), or it combined a prefix and a bound stem (e.g., REVIVE) that was combinable with at least one other prefix (e.g., VIVE is combinable with SUR-). Assessing pseudoprefixedness was somewhat less straightforward. Most of the pseudoprefixed critical words were obviously unprefixed (e.g., REMNANT), but a few did have a prefix + stem etymology (e.g., ABSURD). These were counted as pseudoprefixed because they violated the criteria of at least partial semantic compositionality and combinability of the bound stem.

Design

Two lists were constructed, each containing 18 prefixed-word and 18 pseudoprefixed-word sentences. The prefixed-word member of a sentence pair appeared in a different list than its pseudoprefixed-word mate. Half of the subjects were randomly assigned to each list.

Each subject read six prefixed-word and six pseudoprefixed-word sentences in each of three viewing conditions: the whole word condition, the prefix + X's condition, and the X's condition. In all conditions, the sentence was displayed intact throughout the trial except for the critical location. In the whole word condition, the letter string in the critical location was always the critical word itself. In the prefix + X's condition, the critical location contained the word's apparent prefix followed by X's until the subject's saccade crossed an invisible boundary three character spaces to the left of the critical location, at which time the prefix + X's string was replaced by the critical word (e.g., REXXXX became REMIND). The X's condition proceeded in an analogous fashion, with REMIND replacing XXXXXX in the critical location after the subject's saccade crossed the invisible boundary. Note that the display change occurred during a saccade; because the uptake of visual information is suppressed during saccades, subjects were generally unaware of the display changes.

Order of presentation of sentences and viewing conditions was randomized for each subject. A set of six subjects provided one eye movement record for each sentence under each viewing condition, barring the occasional loss of data due to eyetracking failure. Also, any trial on which a subject fixated the boundary location or one character to its right was discarded to ensure that the data did not reflect disruption due to possible conscious awareness of the display change under these circumstances.

Apparatus

A bite plate was prepared for each subject to reduce head movement during eyetracking. The subject's eyes were held 46 cm from a Hewlett–Packard 1300A cathode ray tube (CRT) that was used to present sentences. The CRT has a P-31 phosphor with the characteristic that removing one character results in a drop to 1% of maximum brightness in 0.25 ms. Three character spaces equalled one degree of visual angle. A black theater gel covered the screen to enhance sharpness and the CRT was adjusted to a comfortable brightness level for each subject. Each sentence was presented in conventional upper- and lowercase format.

Eye movements were recorded with a Stanford Research Dual Purkinje Eyetracker interfaced with a Hewlett–Packard 2100A computer. The eyetracker's resolution is 10 min of arc and its output is linear over the angle subtended by a line of text. The computer sampled the signal from the eyetracker every millisecond, and each 4 ms of output was compared with the output of the previous 4 ms to determine whether the eyes had moved. Display changes were accomplished within 5 ms after crossing the boundary. The computer kept a record of the duration, sequence, and location of each fixation.

Procedure

Subjects were tested individually. A two-dimensional calibration ensured that the eyetracker was accurately determining the coordinates of the subject's point of fixation. After the calibration, three crosses were displayed: one at the left, one in the center, and one at the right of the screen. The subject's fixation point was marked by a fourth cross moving in synchrony with the eyes. The subject was instructed to superimpose this cross on the cross at the left of the screen; when this was accomplished, the experimenter displayed the first sentence. When the subject finished reading it, he or she pressed a key that removed it from the screen. The cycle of superimposing the fixation marker on the cross, reading a sentence, and pressing the key was repeated for each trial.

A sentence occupied two lines on the CRT, each line of text being 42 or fewer characters in length. Each subject read nine practice sentences before going on to the experimental sentences. Subjects were told nothing about the linguistic variable or the viewing conditions; they were simply told to read for normal comprehension. As a comprehension check, they were occasionally asked to come off the bite plate and repeat or paraphrase the sentence they had just read.

Scoring of Data

A critical word was considered fixated if the subject's point of fixation fell on one of its component letters or on the space immediately preceding it. Fixations of unusually long duration (more than 600 ms) were discarded because they were probably due to eyeblinks. Very short fixations (less than 100 ms) occurring in succession on identical or adjacent characters were cumulated and counted as one fixation. Extremely short fixations (less than 80 ms) occurring in isolation were discarded. The dependent measure of primary interest was the duration of the first fixation on the critical word, which should be sensitive to early processing of that word. Of secondary interest was gaze duration, which includes the duration of the first and any subsequent fixations on the critical word before another word is fixated.

In the subject analyses, a data point was the mean value for the six prefixed-word or the six pseudoprefixed-word sentences in each of the three viewing conditions. In the item analyses, a data point was the mean value for the three prefixed-word or the three pseudoprefixed-word sentences in each of the three viewing conditions.

Results and Discussion

Mean first fixation durations and gaze durations on prefixed and pseudoprefixed critical words are presented in Table 1.

Effects of Prefixedness/Pseudoprefixedness

Pseudoprefixed words received longer first fixations (240 ms) than prefixed words (226 ms); this 14-ms difference was reliable [$F(1,17) = 19.03, p < .0004$ by subjects and $F(1,35) = 6.49, p < .015$ by items]. Because the duration of the first fixation on a word is likely to reflect early processing, this result suggests that the effect originated early in the recognition of the critical word. It can be concluded that prelexical prefix stripping occurred during fluent silent reading.

TABLE 1

MEAN FIRST FIXATION DURATION AND GAZE DURATION (IN PARENTHESES) ON PREFIXED AND PSEUDOPREFIXED CRITICAL WORDS AS A FUNCTION OF VIEWING CONDITION (EXPERIMENT 1)

Viewing condition	Word type	
	Prefixed	Pseudoprefixed
X's	222 (293)	243 (306)
Prefix + X's	232 (277)	244 (288)
Whole word	223 (277)	234 (286)

Pseudoprefixed words received gaze durations averaging 293 ms, compared to 282 ms for prefixed words. Although the direction of the difference is consistent with prefix stripping, the difference was not reliable [$F(1,17) = 2.83$, $p < .11$ by subjects; $F(1,35) < 1$ by items]. It can be concluded that the delay in processing pseudoprefixed words was primarily due to the longer first fixations they received.

Effects of Viewing Condition

The expected decrease in first fixation duration on the critical word due to prior parafoveal availability of the word or its apparent prefix failed to materialize [$F(2,34) = 1.06$, $p < .36$ by subjects and $F(2,70) < 1$ by items]. In the condition allowing full parafoveal preview (the whole word condition), the mean first fixation duration was 232 ms, compared to 228 ms in the condition denying any parafoveal preview (the X's condition). In the condition allowing preview of the apparent prefix only (the prefix + X's condition), the mean first fixation duration was 238 ms.

Unlike the first fixation durations, the gaze durations did suggest a decrease in foveal processing time on the critical word due to prior parafoveal availability. In the whole word condition, the mean gaze duration was 282 ms, compared to 300 ms in the X's condition. Gazes in the prefix + X's condition, like those in the whole word condition, averaged 282 ms, suggesting that the useful parafoveal information was the apparent prefix. Although the pattern of gaze durations was as expected, the effect of viewing condition did not reach reliability [$F(2,34) = 2.33$, $p < .11$ by subjects; $F(2,70) = 1.62$, $p < .20$ by items].

Interaction of Prefixedness/ Pseudoprefixedness with Viewing Condition

For both first fixation durations and gaze durations, the interaction of prefixedness/ pseudoprefixedness with viewing condition was not reliable [$F < 1$ in all analyses]. However, this null interaction only indicates that prefixed words and pseudoprefixed words were equally unaffected by parafoveal preview of the entire word or the apparent prefix, not equally helped by it. What the single-representation, sequential model predicted was equal parafoveal preview *benefit* for the two types of words, due to prefix stripping having occurred parafoveally. Therefore, the null interaction in this experiment is not decisive, so that a second experiment was undertaken.

Experiment 2

Experiment 1 established that pseudoprefixed words received longer first fixations than prefixed words, providing support for prelexical prefix stripping. However, the absence of reliable parafoveal preview effects made it impossible to decide between the single-representation, sequential model and the dual-representation, parallel model. Experiment 1 may have been deficient in power with respect to effects of parafoveal preview. Accordingly, in Experiment 2 power was increased by using more items and more subjects. In addition, the sentences were changed in three ways. First, critical words were placed in somewhat more medial sentence positions than in Experiment 1, in order to encourage more reliance on parafoveal processing. Second, whenever possible, the word after the critical word was of the same length whether it followed a prefixed word or its pseudoprefixed counterpart, and third, sentence pairs were nearly identical not only in length in words but also in length in character spaces; these were attempts to remove possible sources of extraneous variability.

As in Experiment 1, there were three viewing conditions, one allowing full parafoveal preview of the critical word, one allowing prefix preview, and one allowing no preview. However, no "X's" were used in Experiment 2. The X's condition of Experiment 1 was replaced by a nonsense string condition, and the prefix + X's condition was replaced by the other-word condition, in which the other member of the critical word pair was the presaccade contents of the critical location. The other-word condition allowed parafoveal preview of the apparent prefix common to both words.

Method

Subjects

Twenty-four members of the University of Massachusetts community were paid to participate. All had normal vision or could read the sentences without wearing corrective lenses, and none had been in Experiment 1.

Materials

Sentence pairs. Sentences were drawn from the set of 60 pairs listed in the Appendix. As in Experiment 1, each member of a pair contained a prefixed or matched pseudoprefixed word in the same location following the same neutral sentence-initial context. Sentence pairs were matched on the same variables as in Experiment 1. In addition, they were closely matched on the length of the word after the critical word ($M = 3.6$ letters, range = 2 to 7). Critical words followed from 1 to 6 other words in the sentence ($M = 2.9$). Sentence length averaged 10.5 words for prefixed-word sentences and 10.4 words for pseudoprefixed-word sentences (range = 6 to 16). Finally, sentence pairs were approximately matched on length in character spaces.

Word pairs. In addition to the 36 pairs of prefixed and pseudoprefixed words from Experiment 1, 24 new pairs were selected and matched according to the same criteria. The resulting set of 60 pairs had the following characteristics: For both prefixed and pseudoprefixed words, mean length was 7.3 letters (range = 5 to 10) and mean frequency (Kucera & Francis, 1967) was 20.2 (range = 1 to 195 for prefixed words and 1 to 171 for pseudoprefixed words). The mean number of syllables was 2.4 for prefixed words and 2.5 for pseudoprefixed words (range = 2 to 4).

Design

Two lists were constructed, each containing 30 prefixed-word and 30 pseudoprefixed-word sentences. No list contained both members of a pair, and half of the subjects were randomly assigned to each list.

Each subject read 10 prefixed-word and 10 pseudoprefixed-word sentences in each of three viewing conditions: the correct word condition, the other-word condition, and the nonsense string condition. The correct word condition was identical to the whole word condition of Experiment 1. In the other-word condition, the other member of the word pair appeared in the critical location prior to the saccade crossing the invisible boundary, at which time the other word was replaced by the correct word. In the nonsense string condition, the presaccade contents of the critical location was an unpronounceable nonsense string equal in length to the critical word. For example, the three possible contents of the critical location prior to fixation on REMIND were REMIND, RELISH, and CWXYJQ. As in Experiment 1, order of presentation of sentences and viewing conditions was randomized for each subject.

Apparatus, Procedure, and Scoring of Data

The apparatus and procedure were the same as in Experiment 1. Data were scored as in Experiment 1 except for the addition of a new dependent variable, saccade length.

Results and Discussion

Mean first fixation durations and gaze durations on prefixed and pseudoprefixed critical words are presented in Table 2.

TABLE 2
MEAN FIRST FIXATION DURATION AND GAZE DURATION (IN PARENTHESES) ON PREFIXED AND PSEUDOPREFIXED CRITICAL WORDS AS A FUNCTION OF VIEWING CONDITION (EXPERIMENT 2)

	Word type	
Viewing condition	Prefixed	Pseudoprefixed
Nonsense string	232 (301)	247 (313)
Other word	224 (295)	241 (320)
Correct word	218 (272)	224 (284)

Effects of Prefixedness/ Pseudoprefixedness

As in Experiment 1, pseudoprefixed words received longer first fixations (237 ms) than prefixed words (225 ms); this 12-ms difference was reliable [$F(1,23) = 20.59$, $p < .001$ by subjects and $F(1,59) = 3.97$, $p < .05$ by items]. Similarly, pseudoprefixed words received longer gazes (306 ms) than prefixed words (289 ms), and in contrast to Experiment 1, the difference in gaze durations was reliable [$F(1,23) = 9.25$, $p < .01$ by subjects and $F(1,59) = 3.97$, $p < .05$ by items]. Once again, the claim of prelexical prefix stripping was supported.

Effects of Viewing Condition

The mean first fixation durations for the correct word, other-word, and nonsense string conditions were 221, 232, and 240 ms, respectively. Thus, in contrast to Experiment 1, Experiment 2 provided evidence of reliable benefit due to parafoveal preview [$F(2,46) = 9.06$, $p < .005$ by subjects and $F(2,118) = 9.89$, $p < .0001$ by items]. Specifically, Newman–Keuls comparisons on the subject means revealed that there was a reliable benefit due to parafoveal preview of the entire critical word; that is, the correct word condition yielded reliably shorter first fixations than the nonsense string condition [$q(3,46 = 5.38$, $p < .01$]. However, there was not a reliable benefit due to preview of just the apparent prefix; that is, the other-word condition did not differ reliably from the nonsense string condition [$q(2,46$, $p > .05$].

Like the first fixation durations, the gaze durations show a main effect of viewing condition [$F(2,46) = 13.19$, $p < .0001$ by subjects and $F(2,118) = 11.82$, $p < .0001$ by items]. The mean gaze durations in the correct word, other-word, and nonsense string conditions were 278, 308, and 307 ms, respectively. Once again, the difference between the correct word condition and the nonsense string condition was reliable [$q(2,46) = 5.38$, $p < .01$], indicating a benefit due to full parafoveal preview. Prior preview of just the apparent prefix did not lead to any benefit; in fact, gaze durations in the other-word condition averaged 1 ms more than those in the nonsense string condition.

Interaction of Prefixedness/ Pseudoprefixedness with Viewing Condition

The interaction of prefixedness/pseudoprefixedness with viewing condition did not approach reliability [first fixation durations: $F(2,46) = 1.65$, $p < .20$ by subjects and $F < 1$ by items; gaze durations: $F < 1$ on both analyses]. The null interaction indicates that prefixed and pseudoprefixed words benefited approximately equally from full parafoveal preview but were equally unaffected by parafoveal preview of the other member of the word pair. Although there was a suggestion in the first fixation durations that prefixed words benefited less from full parafoveal preview (14 ms) than pseudoprefixed words (23 ms), this interaction (comparing just the correct word condition and the nonsense string condition) was not reliable [$F(1,23) = 2.31$, $p < .14$ by subjects and $F < 1$ by items]. In the gaze durations, both types of words benefited exactly equally (29 ms) from full parafoveal preview.

Because preview of the other member of a word pair entailed preview of the correct apparent prefix, the lack of benefit due to preview of the other word suggests that prefix stripping was not occurring parafoveally. Therefore, the pattern of results suggests that although preview of the correct prefixed or pseudoprefixed word was beneficial, the parafoveal processing going on did not include a component of prefix stripping. Because deciding between the single-representation, sequential model and the dual-representation, parallel model required the underlying assumption that prefix stripping could occur parafoveally, the lack of an interaction is not decisive evidence.

It seems, then, that prefix stripping occurred during foveal fixation of the critical words. However, it is still possible that prefix stripping occurred parafoveally but manifested itself only in the correct-word data. The lack of facilitation in the other-word condition may have been due to the incorrect letters that followed the correct prefix. Although in previous research the parafoveal presence of correct initial bigrams or trigrams did lead to facilitation relative to a nonsense string condition (Rayner, et al., 1982), the bigrams and trigrams in those studies were not apparent prefixes. It is possible that because prefixes are such highly familiar word-initial units, subjects can "see farther" into a parafoveal word if it is prefixed or pseudoprefixed than if it is unprefixed. On this account, the presence of incorrect medial letters in the parafoveal preview word would lead to reduced facilitation or even interference when the correct prefixed or pseudoprefixed word is fixated, and this could be true even if (perhaps especially if) the prefix were stripped parafoveally. If this account is correct, then the lack of an interaction between prefixedness/pseudoprefixedness and viewing condition in Experiment 2 (when the other-word condition is omitted) can be taken as evidence in favor of the single-representation, sequential model. However, because the claim that subjects "see farther" into a word with an apparent prefix than one without has not been tested here, it seems safest to leave open the sequential vs parallel controversy.

Saccade Length

One unpredicted but interesting finding was that the saccade leaving a critical word was reliably shorter if the word was pseudoprefixed than if it was prefixed [$F(1,23) = 9.25$, $p < .01$ by subjects and $F(1,59) = 4.76$, $p < .03$ by items]. Saccades from pseudoprefixed words averaged 8.1 character spaces, compared to 8.6 character spaces for prefixed words. Viewing condition had no reliable effects on saccade length. The relatively shorter saccades from pseudoprefixed words can be taken as corroborative evidence that these words are more difficult to process than prefixed words. If the increased time needed to access a pseudoprefixed word in the fovea reduces the time or resources available for processing initial letter information from the word in the parafovea, then this word may subsequently be fixated in a more leftward position than it would have been had it followed a prefixed word rather than a pseudoprefixed word.

Shorter saccades from pseudoprefixed words were not due to a different number of refixations on the two types of words. On average, pseudoprefixed words received 1.34 fixations, and prefixed words, 1.36 fixations. Also, there was no reliable difference in the length of the saccades to the critical words themselves: The first saccade to a pseudoprefixed word averaged 8.2 character spaces, compared to 8.3 character spaces for prefixed words.

General Discussion

It appears that in normal reading, words are prelexically stripped of any initial letter pattern that could be a prefix regardless of whether the remainder of the word is a stem. In support of this claim, it was found that pseudoprefixed words were associated with longer fixations and shorter departing saccades than were closely matched prefixed words. These findings further suggest that the lexicon contains accessible representations of true stems but not of nonstems. It remains an open question whether polymorphemic words are accessible via stem representations only, as in the single-representation, sequential model, or are accessible via stem representations or whole-word representations, as in the dual-representation, parallel model.

Some evidence for the primacy of stem representations in accessing prefixed words comes from the priming experiments of Stanners, Neiser, and Painton (1979), who found that when the target word was a stem (e.g., AWARE), prior presentation of the stem alone was not reliably more facilitory than prior presentation of a prefixed form (e.g., UNAWARE). This finding suggests that UNAWARE was always accessed via [AWARE], as claimed by the single-representation assumption. Reversing the prime-target relationship reduced the size of the priming effect. This is what would be expected on the single-representation assumption, which claims not that prefixed words have no whole-word information in the lexicon but that this information is only accessible via a stem representation. Taft (1981) pointed out that presenting AWARE would activate [AWARE] in the access file but not the check on UN + AWARE in the master file.

The single-representation assumption is also consistent with the finding that a prefixed word with a high-frequency stem was recognized more quickly than an equally frequent prefixed word with a low-frequency stem (Taft, 1979b). It has not yet been investigated whether the frequency of a prefixed word has an effect beyond that of stem frequency. However, on the single-representation assumption, effects of word frequency would not be unexplainable because they could reflect an ordering of the master file representations accessed via a given stem representation. For example, because PER + SUADE is a more frequent combination than DIS + SUADE, PERSUADE may be recognized faster than DISSUADE even if both are accessed via [SUADE].[3]

I have argued for the existence of a prefix-stripping procedure, but another possibility is that stems are detected directly without prior prefix detection, and that a difference in stem frequency is what leads to the longer fixations observed on pseudoprefixed words. Like most prefixed words, the ones in the present experiments have combinable stems, so that they are probably higher in stem frequency than the pseudoprefixed words despite the matching on word frequency. For example, the stem frequency of REVIVE is the sum of the frequencies of the morphological variants of both REVIVE and SURVIVE, whereas because RESCUE is its own stem, its stem frequency is the sum only of the frequencies of the morphological variants of RESCUE. One could imagine a logogen model similar to that of Murrell and Morton (1974) in which logogens representing stem morphemes respond on the basis of any stem morpheme present anywhere in a stimulus word, regardless of whether the stem is part of the word or the entire word. Note that such a model denies prefix stripping but does not deny a lexicon that represents stem morphemes.

Several findings cast doubt on the adequacy of the pure stem detection view. First, Taft (1981) found a delay in naming pseudoprefixed words relative to prefixed words with uncombinable stems (e.g., ADVANCE), and these prefixed words would not tend to have higher stem frequencies than pseudoprefixed words. Second, Smith and Sterling (1982) found that the increase in error rates on letter detection in apparent prefixes relative to other letter patterns did not depend on whether the apparent prefix was genuine or not, arguing that apparent prefixes are unitized before

[3] Relevant experiments have been done with suffixed words, and the results are mixed (Bergman, Eling, & Hudson, 1985; Bradley, 1979; Burani, Salmaso & Caramazza, in press; Taft, 1979b).

the word or its stem is identified. Third, Taft (1976) found that prefixed nonwords without stems (e.g., DENOLD) took longer to reject than unprefixed nonwords (e.g., LOMALK). On the stem detection view, DENOLD and LOMALK would have equal response times since neither contains a stem. Fourth, a word with a pseudostem but no pseudoprefix (e.g., CLOVE) took no longer to accept than a control word (e.g., THUMB) (Taft, 1979a). One interpretation is that no abortive access attempt was made via [LOVE] because the C in CLOVE is not a possible prefix and so was never stripped off.

Indirect evidence in favor of the prefix stripping view comes from studies suggesting that word-initial letters are processed before other letters. For example, presenting word-terminal information before word-initial information is more detrimental to word recognition than presenting word-initial information before word-terminal information (Lima & Pollatsek, 1983; Mewhort & Beal, 1977). The implication for prefixed words is that prefixes, not stems, are the first part of the word to be processed.

On the prefix stripping view but not on the stem detection view, a pseudoprefixed word should take longer to recognize than an unprefixed word. Taft (1981) did find that pseudoprefixed words took longer to recognize than unprefixed words (e.g., LAMENT), but Henderson, Wallis, and Knight (1984) did not. Unfortunately, these comparisons between pseudoprefixed and unprefixed words are complicated by a confounding of pseudoprefixedness and familiarity of word-initial letter pattern. Lima and Inhoff (1985) have shown that words with common initial letter patterns (e.g., CLOWN) received shorter fixations than words with rarer initial patterns (e.g., DWARF). The disadvantage of pseudoprefixedness may be offset by the advantage of a very familiar word-initial letter pattern, and this could diminish the difference between the recognition times for pseudoprefixed and unprefixed words.

Of course, prefix stripping is not sufficient to isolate the stem of any word; a word can have suffixes as well as prefixes. However, prelexical suffix stripping has proven difficult to demonstrate (Bergman, Eling, & Hudson, 1986; Henderson et al., 1984; Manelis & Tharp, 1977). If suffixes are not prelexically stripped, then how is the probable stem of a suffixed word isolated? One possibility is a left-to-right parse of the stimulus word. Taft and Forster (1976; Taft, 1979a) suggested this hypothesis based on findings that a stem or pseudostem in an unprefixed word affected lexical decision time only if it was in word-initial position. For example, PAINT (with the pseudostem PAIN) took longer to accept than a control word but CLOVE did not (Taft, 1979a). Presumably, if preliminary morphological analysis does entail prefix stripping, as has been argued here, then the left-to-right parse in search of the putative stem would commence only after any prefix has been marked off. It remains to be discovered whether a prefixed word like REPAINT (with the pseudostem PAIN in stem-initial position) will take longer to recognize than a control like REPRINT (with no pseudostem), and whether a prefixed word like REAPPEAR (with the pseudostem REAP in word-initial position) will *not* take longer to recognize than a control. These predictions follow from the claim that prefixes are stripped before stem search starts.

APPENDIX

Sentence Pairs for Experiment 2

In each of the following pairs of sentences, the prefixed-word sentence is shown above the corresponding pseudoprefixed-word sentence.

1)
The student's REACTION to his bad grade was to cry.

The student's RELIGION is very important to him.

2)
The helpful teacher PROCURED new supplies of chalk and erasers for the classroom.
The helpful teacher PROMPTED the tongue-tied student in the school play.

3)
The teenager's ABRUPT answer made his parents angry.
The teenager's ABSURD answer made his parents angry.

4)
Her husband's MISTRUST of women made her life miserable.
Her husband's MISTRESS is living in an apartment downtown.

5)
He knew that the DESCENT down the mountain would be dangerous.
He knew that the DENTIST kept his patients waiting for hours.

6)
The major INCREASE in sales was due to lower prices.
The major INDUSTRY in this area is the making of shoes.

7)
Edward cannot IMPROVE the poor conditions at the hospital.
Edward cannot IMAGINE why he isn't a famous movie star yet.

8)
Daniel is truly UNABLE to chew gum and walk at the same time.
Daniel is truly UNIQUE in his ability to juggle six things at once.

9)
The young man's INDECISION about what courses to take bothered him.
The young man's INITIATION into the fraternity was very unpleasant.

10)
This particular PRONOUN makes the sentence hard to understand.
This particular PROPHET talks about the end of the world.

11)
The child's DIALECT made it difficult for us to understand him.
The child's DIAPERS were falling off as he crawled on the floor.

12)
The company's new REFUND offer expires next month.
The company's new RENTAL rates are extremely cheap.

13)
We feared that the ANARCHY in the city would spread to the suburbs.
We feared that the ANTENNA on the roof would fall off in the violent storm.

14)
The queen's BEHEADING brought tears to the eyes of the crowd.
The queen's BECKONING glances soon caught the king's attention.

15)
The network president was DEMOTED to a less important position.
The network president was DELUGED with mail about the new program.

16)
Joe thought that the IMPURITY in the air was intolerable.
Joe thought that the IMBECILE on the platform should stop talking.

17)
The officials will DETAIN the prisoner for further questioning.
The officials will DEEPEN the reservoir to provide more water.

18)
Most parents DISCOURAGE their children from smoking cigarettes.
Most parents DISCIPLINE their children when they misbehave.

19)
Sarah really wanted to ENJOY the party tonight.
Sarah really wanted to ENTER the beauty pageant.

20)
The man on the stage was DEVOID of any real acting ability.
The man on the stage was DEVOUT in his religious beliefs.

21)
The bored, tired COMMUTER was sick of the heavy traffic.
The bored, tired COMEDIAN was sick of show business.

22)
Everyone should UNTIE their shoes before removing them.
Everyone should UNITE in the fight against racism.

23)
The mysterious INTRUDER was never identified by the secret agents.
The mysterious INTRIGUE was understood only by the secret agents.

24)
The group will DENOUNCE the recent actions taken by the administration.
The group will DECORATE the shopping mall for the Christmas season.

25)
They tried to REVIVE the dying man, but they were too late.
They tried to RESCUE the dying man, but they were too late.
26)
The corporation has IMPORTED many gallons of oil from abroad.
The corporation has IMITATED many products of its competitors.
27)
My sister's BELOVED kitten was run over by a car yesterday.
My sister's BEARDED friend is a guitar player in New York.
28)
He said that the DELAY was unavoidable, but no one really believed him.
He said that the DEVIL had possessed his mind when he committed the murder.
29)
The judge will REAPPEAR soon after the courtroom recess.
The judge will REGULATE the behavior of the entire jury.
30)
The student ADMITS that he cheated on the math exam.
The student ADORES that handsome geology professor.
31)
The little fish PERSISTS in trying to jump out of the tank.
The little fish PERISHES if he is not given fresh food.
32)
The woman's INJUSTICE will be dealt with by the governing board.
The woman's INTELLECT will help her get very high test scores.
33)
Margaret would often PRONOUNCE words incorrectly.
Margaret would often PROMENADE around town in her Volvo.
34)
He received UNWELCOME letters in the mail yesterday.
He received UNANIMOUS support from the committee.
35)
A good bartender should ENCOURAGE his customers to remain sober.
A good bartender should ENTERTAIN his customers with witty stories.
36)
He knows that the ACCOUNT has to be paid by tomorrow.
He knows that the ACADEMY has a very fine reputation.
37)
The gym teacher ASSEMBLED his pupils for a basketball game.
The gym teacher ASTOUNDED his students with his athletic ability.
38)
We learned that the RENEWAL of library books could be done by mail.
We learned that the REALTOR who sold our house was actually a crook.
39)
This small computer CONTAINS every bit of information that we need.
This small computer CONTROLS every aspect of the experiment.
40)
The reporter obtained INDIRECT evidence about Brooke Shield's love life.
The reporter obtained INTIMATE details about Brooke Shield's love life.
41)
Her father PREDICTS that the candidate will be elected.
Her father PREACHES at the church in town every week.
42)
We expected a REBIRTH of interest in the ancient art of astronomy.
We expected a REMNANT of the falling meteor to land in our yard.
43)
He reported that the PROTEST march was entirely non-violent.
He reported that the PROTEIN content of peanut butter is high.
44)
The great ACCLAIM that the movie received made us want to see it.
The great ACTRESS made a spectacular entrance at the movie premiere.
45)
This little DIAGRAM is an explanation of the phases of the moon.
This little DIAMOND is worth more than ten thousand dollars.
46)
The boy didn't REMIND his mother to pick him up after school.
The boy didn't RELISH the thought of eating liver for dinner.
47)
Unfortunately, Sally's DEMAND for a raise was refused by her unappreciative boss.
Unfortunately, Sally's DEGREE from Harvard did not guarantee a good job offer.

48)
He didn't like the REVIVAL of the old broadway musical at the theater.
He didn't like the RESIDUE of mud that settled to the bottom of the river.
49)
The man will REACT with anger when he finds out that his car is missing.
The man will REIGN as the king of his country for the rest of his life.
50)
The wonderful EMBRACE was still on her mind even after John left.
The wonderful EMERALD was a birthday present from her boyfriend.
51)
They feel that the INSANE should not run around loose in society.
They feel that the INFANT should be brought home in a few more days.
52)
The most famous MONARCH is Queen Elizabeth of England.
The most famous MONSTER is King Kong, the great ape.
53)
Charlotte should RESTRICT her comments to the facts.
Charlotte should REGISTER her car in Northampton.
54)
This amazing INNOVATION will revolutionize the science of biology.
This amazing INSTRUMENT will revolutionize surgery in the future.
55)
The arrogant tycoon BESTOWED his entire fortune on his favorite son.
The arrogant tycoon BELLOWED his orders to the frightened servants.
56)
Erica can DETACH the front wheel from her bicycle.
Erica can DEVOUR the entire batch of cookies at once.
57)
Our boys were nearly DEFEATED by the visiting team.
Our boys were nearly DEAFENED by the shouts of the crowd.
58)
The huge DISCOUNT on winter clothes was successful in attracting buyers.
The huge DISTANCE between the stars makes interstellar travel difficult.
59)
The family noticed many CONFLICTS between the dog and the cat.
The family noticed many CONTRASTS between the two children.
60)
We studied the ABUSE of children in our state.
We studied the ABBEY where nuns lived long ago.

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