Journal of Experimental Psychology:
Learning, Memory, and Cognition
1993, Vol. 19, No. 1, 34–50

Prominence of Leading Functors in Function Morpheme Sequences as Evidenced by Letter Detection

Asher Koriat and Seth N. Greenberg

Our previous work indicated that the increased difficulty in detecting letters in function in comparison with content morphemes derives from the role of functors in supporting phrase structure. Presumably, letters disappear in the transition from structure to content. Here the effect was most powerful for leading functors in a sequence of function morphemes (e.g., "that" in "that from the"). This pattern was found for Hebrew function prefixes that can be appended as a sequence to a content word (e.g., *SMH*GN, meaning "that from the garden"; Experiments 1 & 2) and also for sequences of Hebrew and English function words (Experiments 3 & 4). This pattern of results did not hold, however, for *THE*, which maintained its strong disadvantage regardless of position. The results reflect the prominence of leading functors in organizing the local structural frames established in the early stages of text processing.

The missing-letter effect has been amply documented in a great number of studies, particularly by Healy and her associates. This effect refers to the phenomenon in which letter detection in connected text is more difficult in frequent function words such as *THE*, *AND*, and *OF*, than in less common content words (e.g., Corcoran, 1966; Healy, 1976; Healy & Drewnowski, 1983). Although there is little doubt concerning the reality of this effect, its explanation is still unclear.

Three accounts have been offered. According to the first, the redundancy-attentional explanation, function words are merely skipped over in reading because of their high predictability and redundancy in text (e.g., Corcoran, 1966; Krueger, 1989; Schindler, 1978). Because function words can be readily anticipated on the basis of their surrounding context, they tend to receive less attention than the more informative content words. This idea gains most of its support from research on eye movements during reading, which indicates that readers spend less time looking at the more frequent words (Rayner, 1977; Rayner & Pollatsek, 1989) and are more likely to skip the word *THE* than a three-letter content word (see Carpenter & Just, 1983; O'Regan, 1979).

The second account, unitization (see Drewnowski & Healy, 1980; Healy, 1976; Healy & Drewnowski, 1983), assumes that words such as *THE* and *AND* tend to conceal their constituent letters because they allow direct activation of their unitized word-level representation before complete identification of their constituent letters. The pull of reading prohibits readers from pausing long enough to complete the identification of constituents once the higher level representation has itself been accessed. Recent evidence by Besner (1989), however, questions the proposition that function words are more likely to be processed holistically than are content words. In particular, Besner found that distorting the visual pattern of a word had no greater debilitating effect on the processing of function words than on that of the less familiar content words.

Yet a third account has been proposed recently by Koriat, Greenberg, and Goldshmid (1991; see also Greenberg & Koriat, 1991; Greenberg, Koriat, & Shapiro, in press; Koriat & Greenberg, 1991), which ties the missing-letter effect to the role played by function words during reading. This account was motivated by the apparent inconsistency in the reading literature, between those who assign a critical role to function words in helping to signal phrase structure (e.g., Just & Carpenter, 1987) and those who claim that function words convey little semantic information and are simply skipped over during reading. These contrasting views would seem to reflect a discrepancy between those who stress syntactic structure and those who emphasize semantic content. According to the structural account, in contrast, both structure and meaning are coded during reading, but the processing of structure leads the way to the processing of meaning (see Aaronson & Ferres, 1983; Bock, 1990; Forster & Ryder, 1971; Garrett, 1980). Thus, functors play a crucial role in the process of structural analysis, often signaling the construction of a new phrase (see Kimball, 1973) and ought to be monitored early in text processing. However, they recede to the background as the focus shifts from structure

---

Asher Koriat, Department of Psychology, University of Haifa, Haifa, Israel; Seth N. Greenberg, Department of Psychology, Union College.

A brief report of the results was presented at the 32nd Annual Meeting of the Psychonomic Society, San Francisco, California, November 1991. The writing of this article was completed while Asher Koriat was the Irv Acenberg visiting scientist at the Rotman Research Institute of Baycrest Centre, North York, Ontario, Canada.

This research was supported by Grant 88-00395 to Asher Koriat and Seth N. Greenberg from the United States-Israel Binational Science Foundation (BSF), Jerusalem, Israel. The experiments were conducted at the Institute of Information Processing and Decision Making, University of Haifa.

We wish to thank Hamutal Kreiner for her help in setting up the experiments and preparation of the manuscript, and Gali de Marcas for assistance in the preparation and conduct of the experiments. We are grateful to Alice Healy and three anonymous reviewers for their comments on an earlier version of the article.

Correspondence concerning this article should be addressed to Asher Koriat, Department of Psychology, University of Haifa, Haifa, Israel.

to meaning. Presumably, as structure assumes its role in organizing the semantically laden elements, the supports become less available and, hence, their constituent letters are often missed. Thus, according to the structural account, the missing-letter effect for function units is symptomatic of the process of frame extraction that takes place in the early stages of text processing.

Evidence in favor of this latter account comes from a series of studies with Hebrew. In Hebrew, some function morphemes can be expressed as a one-letter prefix appended to a content word. Letter detection was more difficult for the initial letter of a word when that letter represented a function prefix, than when it was part of the stem of a content word (Koriat et al., 1991). A similar effect was found even when the stem part of the prefix words was replaced by a nonword stem (Koriat & Greenberg, 1991). Thus, apparently, frequency or familiarity were not critical for the occurrence of the missing-letter effect. Moreover, the same function word in English was found to reveal or conceal its letters depending on its role within the phrase (Greenberg & Koriat, 1991). For example, *N* in *ON* was missed less often in *ON SWITCH* than when the critical word *ON* appeared in its usual function role, for example, *ON MY WAY*. These findings and others led the authors to conclude that letter detection errors in function morphemes are associated with the role of these morphemes in supporting syntactic structure and that they occur after phrase structure has been identified.

Our study focuses on the contribution of context in supporting the missing-letter effect, particularly the role of the immediately surrounding words. Several observations indicate that the missing-letter effect is sensitive to contextual factors. Thus, the scrambling of words in a sentence was found to reduce omission errors on *THE*, relative to normal text (Drewnowski & Healy, 1977, 1980; Healy, 1976). Furthermore, Healy, Oliver, and McNamara (1987) observed that frequent function words engendered a significant letter-detection disadvantage when they were embedded in two- or three-word displays but not when they appeared alone. These contextual effects are consistent with all three accounts of the missing-letter effect. Thus, context may affect letter detection by (a) increasing the redundancy or predictability of function words; (b) producing unitization at the phrase level (see later discussion); or (c) facilitating the extraction of syntactic structure and the interpretation of functors in their structure-supporting capacity.

Evidence in favor of the latter account comes from several sources. Koriat et al. (1991, Experiment 4) used Hebrew ambiguous words that could be interpreted either as unprefixed content words or as a combination of a function prefix and a content word. The detection of the initial letter of these words was more difficult when previous context biased its interpretation as a function prefix than as part of the stem of a content word. Thus, the effect of context lies in revealing the syntactic role of a function morpheme. A similar conclusion was suggested by the experiments with misspelled words (Koriat & Greenberg, 1991). In particular, more detection errors were made in the nonword *FOL* when it replaced the function word *FOR* in text than when it replaced the content word *FOG* (Experiment 1). In a similar vein, the initial letter of a Hebrew nonword was more difficult to detect when context favored its interpretation as a function prefix than as part of the stem of a content word (Experiments 2 and 4).

More evidence came from experiments that used the same function word in different contexts. Thus, placing a function word in a content slot in a sentence (i.e., a slot appropriate for a content word) improved letter detection (Koriat & Greenberg, 1991, Experiments 3 and 5). In addition, Greenberg and Koriat (1991) found that even when as many as seven words preceding a critical functor *FOR* were held constant, letter detection in *FOR* differed significantly as a function of the interpretation of *FOR* instantiated by the following context or by the overall structure of the sentence: *FOR* engendered more letter detection errors than did control content words but not when it took on more of a content role (e.g., "Are you for or against?"). In sum, therefore, the recent evidence reported by Koriat and Greenberg suggests that context contributes to letter detection in functors by revealing the syntactic status of these functors within the sentence.

In the present study we explored the effects of the immediately surrounding words on the missing-letter effect for function morphemes. In particular, we focused on the situation in which the neighboring units were themselves function morphemes, and the encompassing sequence was also a frequently occurring pattern, for example, *AND IN THE* (see Umeda & Kahn, 1982). Investigation of letter detection across such familiar sequences of functors may shed some light on the extraction of local context that is assumed to occur on-line during text processing. Previous findings suggested that it is the immediately surrounding context that plays a crucial role in the missing-letter effect. For example, the effects of scrambling in improving letter detection on *THE* were much stronger when scrambling destroyed local context (e.g., *THE* + verb) than when scrambling retained local context (e.g., *THE* + noun; see Drewnowski & Healy, 1977, 1980; Healy, 1976). These results are consistent with the proposal of Koriat and Greenberg (1991) that because the missing-letter effect reflects the on-line extraction of syntactic structure, it should be narrowly sensitive to the tentative, local frames that suggest themselves. Presumably, readers automatically monitor text for the presence of a functor that could be used to anchor a tentative structural frame. When these frames are consistent with contextual constraints, the missing-letter effect ought to be strongest. However, even when functors are misplaced, they often permit themselves to be used as anchors in "locally" plausible frames, leading to a moderate, but significant missing-letter effect. This may explain the finding that although rate of detection errors was reduced for functors when they were placed in content slots in a sentence, it was still higher than that characteristic of content words. On the other hand, placing content words in function slots did not increase error detection in those words relative to when they occupied a content slot.

If the extraction of structural frames is based on a fast, on-line, shallow analysis of text that utilizes parafoveal preview (see Hadley & Healy, 1991; Koriat & Greenberg, 1991), then it may be expected that when a phrase contains a series of functors, the first of these will be automatically used as a place holder and will come to play a dominant role in marking syntactic structure. This contention is consistent with the spirit of the immediacy strategy (Just & Carpenter, 1987), according to which a reader interprets a word and decides on its syntactic role before knowing what follows. As Kimball (1973) proposed, a functor often supplies the structural information that signals the beginning of a new constituent. Thus, both the data and our understanding of how functors might operate suggest a distinctive role for the initial functor morpheme in a sequence of such items. It is not clear from Kimball's parsing algorithm, however, what should happen when the initial functor is followed by other functors. Presumably, because the most critical structural information is conveyed by the first functor, perhaps only this functor carries the burden of the structural frame, with the immediately following functors making only small contributions to the early extraction of phrase structure. If such is the case, then the missing-letter effect ought to be most pronounced for the leading functor. Indeed, in a recent study by Greenberg et al. (in press), it was found that when *FOR* appeared at the end of a clause and had nothing to contribute to the construction of the local phrase, letter detection errors dropped significantly as compared with instances when *FOR* signaled the opening of a new phrase and, hence, played a pivotal role in phrase construction.

Our prediction may be contrasted with those that would follow from the redundancy and unitization accounts. According to the redundancy account, sentential context is effective in promoting the missing-letter effect because it increases the predictability and redundancy of function words. Therefore, in a frequently occurring sequence of functors such as *AND IN THE*, detection errors either ought to increase from the leftmost to the rightmost functor or ought to be constant across all functors. In either case, detection errors for a functor should be higher when it appears in the context of a frequent sequence of functors that when it is not preceded or followed by other functors.

In the unitization account, on the other hand, the effects of local context are explained by the notion that unitization can take place at the phrase level, with frequent function words being processed in supraword units such as short syntactic phrases or short *word frames* (e.g., *ON THE* ___ see Drewnowski & Healy, 1977). Thus, in normal text, *THE* often appears in the context of familiar word frames, most notably those including two function words (e.g., *ON THE* or *FOR THE*). It is argued that such frames, which are among the most frequent two-word sequences in English (Umeda & Kahn, 1982), are processed as unitized orthographic patterns, making letter detection in their constituent frequent function words even more difficult (Healy, Conboy, & Drewnowski, 1987).

Some evidence in support of this proposition was provided by Healy, Conboy, and Drewnowski (1987), who also pinpointed more precisely the nature of the unitized supraword pattern encompassing *THE*. When an asterisk was placed between adjacent function words (e.g., *FOR*THE*), thus disrupting the unitization of a familiar pattern, letter detection in *THE* was better than when the asterisk was interposed between *THE* and a noun that followed (e.g., *THE*PARTY*). This result led to the conclusion that the perceptual familiarity of the two-word frame as a whole is more important for the missing-letter effect than is the syntactic function because, although *THE PARTY* forms a syntactic unit (*THE* + noun), *FOR THE* is the more familiar.

The prediction from the unitization account, therefore, is that the missing-letter effect for functors ought to be stronger when these are embedded within a frequently occurring sequence of functors than when they appear elsewhere in text. For example, *THE* ought to engender more detection errors in *FOR THE* than when it is not preceded by another functor.

Thus, the aim of this study was to examine the pattern of letter detection errors for function morphemes embedded in sequences of function morphemes in normal text. In essence, both the redundancy and unitization models predict that a function morpheme embedded in a frequent sequence of function morphemes ought to yield more detection errors than when it appears alone. Furthermore, the redundancy account would, perhaps, expect detection errors to increase with the serial position of a functor within a sequence of functors. In contrast, the structural model leads to the expectation that the missing-letter effect will be most pronounced for the first functor encountered and, even then, it will not be stronger than when that morpheme appears as the only functor in context. Morphemes following the leading functor, however, should produce less of a disadvantage than when they appear by themselves in context, owing to their diminished usage in specifying structure.

Experiment 1

The results reported here were based on data collected as part of Experiment 4 of Koriat and Greenberg (1991). That experiment examined the missing-letter effect for the definite article in Hebrew. Unlike English, in which this definite article is represented by the short, very common word *THE*, in Hebrew it can only be expressed in the form of a single letter (*H*) that is appended as a prefix to the modified word (there is no alternative word form for *THE*, unlike other Hebrew function morphemes which can be expressed either as single words or as single-letter prefixes; see Koriat et al., 1991). Note that when expressed as a prefix, *H* constitutes an attached morpheme, unlike other prefixes (such as *dis* in *dislike*). The question investigated in that previous research was whether *H* at the beginning of a word would produce more omission errors when it represented the definite article *THE* than when it was part of the stem of a content word. Here our focus was on omission errors in *H* when it was embedded in a *sequence* of prefixes appended to a content word (see later), and these findings were compared with those reported earlier, in which *H* was the sole prefix.

The design for the single-prefix words was similar to that of other experiments (see Koriat & Greenberg, 1991; Koriat et al., 1991). Letter detection for the initial letter, *H*, of a word was compared when it was a function prefix designating *THE*, with when it was part of the stem of a content word. The multiprefix words used an additional feature of Hebrew, namely, that different morphemes can be concatenated to the stem. This holds true for *FROM* (represented by the prefix letter *M*) and *THAT* (represented by the prefix *S*; see Koriat & Greenberg, 1991; Koriat et al., 1991), as well as *AND* (represented by the letter *V*). As an illustration, consider the Hebrew word for *garden*, *GAN*. This is spelled as *GN* in the commonly used unpointed orthography (see Frost, Katz, & Bentin, 1987; Koriat, 1984). *HGN* stands for *the garden*, *MHGN* stands for *from the garden*, and *SHGN* stands for *that the garden*. Triple and quadruple prefixes may also be used, as in the following examples: *VSHGN* (*and that the garden*), *SMHGN* (*that from the garden*), *VSMHGN* (*and that from the garden*). Because in the multiprefix units *H* (*the*) is required to appear closest to the stem, by including such units we could examine letter detection for the definite article *H* when it was in the first, second, third, or fourth positions of the string.

As noted earlier, the inclusion of multiprefix strings provided an opportunity for comparing a condition in which the definite article appeared as the only prefix, with conditions in which it joined with other function prefixes. This comparison was important because of the claim of Healy and her associates (e.g., Healy, Conboy, & Drewnowski, 1987) that the missing-letter effect for common function words stems, in part, from a greater unitization of the phrases in which they are typically embedded. If this is also the case with Hebrew, then the missing-letter effect for *THE* should be more pronounced when *THE* is part of a common prefix ensemble (e.g. *MH*, meaning *FROM THE*) than when it appeared as the only prefix.

A second aim of Experiment 1 was to examine the possibility of a function-disadvantage effect occurring, even for nonwords. Accordingly, in some of the sentences, the critical string was a nonword that was placed in a sentential context that biased interpretation of the target letter either as a function prefix (signifying *THE*) or as a part of the stem of a content word. Thus, the design for both the single-prefix and multiprefix strings conformed to a 2 × 2 factorial, Lexicality (word vs. nonword) × Favored Interpretation (prefix vs. stem). The function-word sentences included a critical word that contained the letter *H* signifying *THE*, whereas their matched content-word sentences included a critical content word that also contained *H* in the same position but now constituted part of the stem. In the nonword sentences, the critical unit was a nonword that contained *H*, so that in some sentences the context biased its interpretation as a definite article (prefix-nonword), whereas in others it biased its interpretation as part of the stem of a content word (stem-nonword).

Method

Subjects. Thirty-two University of Haifa students whose native language was Hebrew participated in the study for course credit.

Design. Experiment 1 included conditions defined by whether the focus was on single-prefix or multiprefix strings (Size); whether the critical string was a word or a nonword (Lexicality); and whether the sentential frame favored interpretation of the target letter (*H*) within that string as a prefix letter signifying *THE*, or as part of a stem morpheme (Favored Interpretation). The single-prefix part of the experiment included 48 sentences, whereas the multiprefix part included 112 sentences.

Stimulus materials. For the single-prefix sentences, 16 sets of four Hebrew sentences were composed, wherein each sentence included one critical string that contained the target letter *H* in its initial position. The four sentences in each set represented all combinations of Lexicality × Favored Interpretation conditions and were matched for number of letters in the critical string. In addition, the two word sentences and the two nonword sentences within each set were matched for the number of words and for the ordinal position of the critical string within the sentence.

For the multiprefix part of Experiment 1, 28 additional sets of four sentences were constructed according to the same procedure. The only difference was that the target letter now occupied either the second position (12 sets), the third position (12 sets), or the fourth position (4 sets). In the prefix sentences, the target letter, interpreted as *THE*, was always the last prefix of a prefix ensemble. The critical strings in each set of matched word and nonword *prefix* strings contained the same ordered prefix ensemble at the beginning of the string. In the matched *stem* sentences, the target letter *H* appeared in the same position in the critical content word as it did in the yoked prefix word.

The double-prefix strings were formed by using one of the following prefix patterns (four sets of sentences of each pattern): *MH* (*from the*), *SH* (*that the*), and *VH* (*and the*); for example, the critical string was *SHPOEL* (*that the worker*) in a word–prefix sentence, *ZHIRUT* (*caution*) in a word–stem sentence, *SHDZ* (*that the DZ*, *DZ* being a nonword) in a nonword–prefix sentence, and *NHUZ* (a nonword) in a nonword–stem sentence.

The triple-prefix strings were formed by using the following prefix patterns (four sets of sentences of each pattern): *SMH* (*that from the*), *VMH* (*and from the*), and *VSH* (*and that the*). The four-prefix strings were all formed by using the pattern *VSMH* (*and that from the*). Accordingly, the *H* appeared in the third and fourth positions, respectively, of the critical word in the matched stem sentence.

In both the single-prefix and multiprefix parts of Experiment 1, the critical strings in the nonword sentences were derived by using the same substitution scheme: The entire root was replaced by a different nonword root, keeping the affixation pattern and the initial letter intact. Thus, neither the entire string nor the root part formed a Hebrew word. In the word sentences, one word (other than the critical word) was transformed into a nonword according to the substitution scheme just mentioned. The nonword appeared equally often before and after the critical word, and at least one word apart from the critical word. In this manner, each experimental sentence contained one nonword.

All sentences were assigned to four blocks containing 44 sentences each. Within each block there were 16, 12, 12, and 4 sentences of the single, double, triple, and quadruple categories, respectively. Moreover, within each of these categories, each combination of Lexicality × Favored Interpretation combination was equally represented. Each block required two pages of text which included, in addition to the experimental sentences, three filler sentences that were placed at the beginning of each page.

Procedure. Subjects were told to read the passages at their normal reading speed, but whenever they came to the letter *H* they were to circle it. They were warned that the sentences might include unfamiliar letter strings, but that they should attempt to read the text continuously despite the presence of such strings. They were further instructed not to slow down their reading speed to catch all target letters and not to go back to circle a letter they had missed. They were then given practice with one paragraph. The order of the experimental blocks was counterbalanced across subjects.

Results

Table 1 presents percentages of omissions for prefix-favored (function) and stem-favored interpretations (content) for words and nonwords as a function of the position of the target letter. The results disclosed a consistent pattern across words and nonwords: Single-prefix strings, with *H* occupying the initial position, yielded the typical missing-letter effect, as already reported by Koriat and Greenberg (1991). In contrast, there was no sign of such an effect for multiprefix strings, where *H* occupied the second, third, or fourth positions. Thus, averaging across words and nonwords, percentages of errors for stem and prefix interpretations averaged 4.1% and 17.5%, respectively, for single-prefix strings. The respective means for all multiprefix strings combined were 5.3% and 4.2%.

Several analyses confirmed this pattern. A three-way analysis of variance (ANOVA), Prefix Size (single vs. multiple) × Lexicality (words vs. nonwords) × Favored Interpretation (prefix vs. stem) yielded significant main effects for prefix size, $F(1, 31) = 22.19, p < .0001$; lexicality, $F(1, 31) = 25.31, p < .0001$; and favored interpretation, $F(1, 31) = 21.16, p < .0001$. However, the Prefix Size × Favored Interpretation interaction was highly significant, $F(1, 31) = 50.82, p < .0001$; and the triple interaction was also significant, $F(1, 31) = 6.95, p < .05$. Separate analyses for single-prefix and multiprefix strings indicated the following: For single-prefix strings, a Lexicality × Favored Interpretation ANOVA yielded $F(1, 31) = 18.94, p < .0001$, for lexicality; and $F(1, 31) = 37.53, p < .0001$, for favored interpretation. Although error rate was higher for words (13.9%) than for nonwords (7.7%), the function disadvantage was highly significant for both types of strings: $F(1, 31) = 34.96, p < .0001$, for words; and $F(1, 31) = 16.27, p < .0005$, for nonwords.

In contrast, a similar two-way ANOVA for the multiprefix strings yielded $F(1, 31) = 17.66, p < .0005$, for lexicality; $F(1, 31) = 1.30$, *ns*, for favored interpretation; and $F(1, 31) = 3.57, p < .10$, for the interaction. Percentage of omission errors was higher for words (7.0%) than for nonwords (2.5%), but there was no sign of a function disadvantage. For the word stimuli, the effect of favored interpretation was, if anything, opposite to that found for single-prefix strings, $F(1, 31) = 2.54, p < .15$, whereas nonwords showed little effect ($F < 1$).

Table 1
Means and Standard Errors of Percentages of Omission Errors for Prefix-Favored and Stem-Favored Interpretations for Words and Nonwords as a Function of the Position of the Target Letter (Experiment 1)

	Favored interpretation							
	Words				Nonwords			
	Prefix		Stem		Prefix		Stem	
Position	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
First	22.1	3.3	5.7	1.2	12.9	2.6	2.5	0.9
Second	6.0	1.6	8.3	1.9	3.6	1.1	2.6	1.0
Third	6.8	2.0	8.9	2.4	2.6	0.9	2.3	0.9
Fourth	2.3	1.3	6.3	2.5	0.0	0.0	1.6	1.1

Several additional analyses were carried out to clarify the absence of a function disadvantage for the multiprefix strings. First, we analyzed the results for these strings according to the position of the target letter. Recall that the target letter was always in the last position of the prefix ensemble, so that its position also indexed the size of the prefix ensemble. A three-way ANOVA, Lexicality × Favored Interpretation × Position, yielded only significant main effects for lexicality, $F(1, 31) = 17.76, p < .001$, and position, $F(1, 31) = 5.70, p < .01$.

Second, focusing only on two-prefix ensembles, we analyzed the results separately for the ensembles *VH* (*and the*), *MH* (*from the*), and *SH* (*that the*). None of the ensembles yielded clear evidence for a function-disadvantage effect either for words or for nonwords. Similar results were also found for the three-prefix ensembles.

Discussion

The results of Experiment 1 differed markedly for single-prefix and multiprefix strings. As far as single-prefix strings are concerned, these produced the typical function disadvantage that has been found in both Hebrew and English (see Koriat & Greenberg, 1991; Koriat et al., 1991). This effect was obtained for both words and nonwords, replicating earlier results (Koriat & Greenberg, 1991) and suggesting that the sentential slot that normally houses a definite article morpheme is associated with an inordinately high proportion of errors. In addition, because the definite article in Hebrew is represented by a prefix, the results also imply that the missing-letter effect occurs at a relatively late stage in the reading process, not before the initial letter of a string (*H*) has been defined as representing a definite article.

The multiprefix strings, in contrast, showed no sign of a function-disadvantage effect whatsoever. Rather, the word strings yielded a small (nonsignificant) advantage for the function prefix *H* when it was preceded by other prefixes. This is particularly surprising given the contention of Healy, Conboy, and Drewnowski (1987) that frequent functor sequences, in which *THE* often trails another functor, are processed in terms of word frames, which further conceal the constituent letters. Presumably, the sequencing of prefixes in Hebrew also creates highly familiar letter groupings of embedded function morphemes. Nevertheless, in this instance such sequencing seems to have eliminated the typical missing-letter effect altogether in the trailing definite article.

Experiment 2

The results of Experiment 1 disclosed a curious pattern. When *H* was the initial letter in a string, it exhibited the typical function-disadvantage effect: The proportion of detection errors was higher when the letter was interpreted as the function morpheme *THE*, than when it was interpreted as the initial letter of an unprefixed word. In contrast, when one or more prefixes were placed in front of the prefix *H*, the function disadvantage disappeared entirely, so that it was no more difficult to detect as a prefix than as part of the stem. Thus, as far as letter detection is concerned, the effective boundary is not between the prefix ensemble, on the one hand, and the stem (content) morpheme, on the other, but rather between the initial function morpheme and the remaining function and content morphemes.

Experiment 2 sought to extend the results of Experiment 1 to other function morphemes while also attempting to clarify the source of the observed difference between single- and multiprefix strings in Experiment 1. Specifically, in the multiprefix strings used in Experiment 1 there was a confounding between two factors: the size of the prefix ensemble (number of prefixes included) and the position of the critical target prefix. This confounding stemmed from the constraint that the definite article in Hebrew (as in English) must appear as the prefix closest to the content word. Therefore, in a series of function prefixes, the prefix corresponding to the definite article was always last. Thus, it was not clear whether the critical factor for the occurrence of the function disadvantage in Experiment 1 was the number of function prefixes included (one or more) or the position of the target prefix *H* (initial or other). An explanation in terms of number of prefixes is simply as follows: When more than one prefix is used in front of a stem, the parsing of the letter string into its constituent morphemes is more difficult, thus slowing down text processing and revealing the identities of the target letters. On the other hand, an explanation in terms of ordinal position is more in accord with the structural view of the missing-letter effect, that the first functor encountered carries the burden of structural articulation.

To resolve the confounding between prefix size and prefix position, in Experiment 2 we used four other Hebrew function prefixes that can occupy any of several positions within a prefix ensemble. The four prefixes were those used in our previous studies (see Koriat & Greenberg, 1991; Koriat et al., 1991), each representing a different function morpheme. These morphemes were *IN* (represented by the letter *B*), *TO* (*L*), *FROM* (*M*), and *THAT/WHO* (*S*). Our previous studies have indicated a consistent function disadvantage for these prefixes when they appeared as single prefixes in front of the stem. The question, therefore, was whether the disadvantage obtained when these prefixes were the initial letters in a string would be maintained when they were embedded in a multiprefix ensemble or when they occupied a position other than the first, or both.

To illustrate, the letter *M* can appear as a single prefix signifying *FROM*, but it can also appear as part of multiprefix ensembles such as *MH* (*FROM THE*) and *VM* (*AND FROM*). If the critical factor for the occurrence of a function disadvantage is the size of the prefix ensemble, then this effect should be found only for *M* and not for *MH* or *VM*. In contrast, if prefix position is the critical factor, then although both *M* and *MH* should yield a high proportion of detection errors, *VM* should not.

The design of Experiment 2 was somewhat unbalanced because there were constraints on (a) the number and kind of prefix ensembles that could be formed and (b) the relative position of each prefix within a multiprefix ensemble. Therefore, the representation of different function letters was not equal across different levels of prefix size and ordinal position.

Method

Subjects. Thirty-two University of Haifa students whose native language was Hebrew participated in the study, 22 for course credit and 10 for monetary payment.

Design. The design of Experiment 2 called for an unbalanced representation of four factors: target letter (*B*, *L*, *M*, and *S*), favored interpretation (prefix vs. stem), size of prefix ensemble (1, 2, 3, or 4 letters), and position of target letter within the critical word (first, second, or third).

Stimulus materials. Seventy-two pairs of Hebrew sentences were composed, each pair including one prefix and one stem sentence. These two sentences were matched for the number of words, the location and size of the critical word within the sentence, and the position of the target letter within that word. There was only one critical word in each sentence, and it contained only one target letter. Note that target letters appeared within an experimental sentence in noncritical words as well, but never in the word immediately preceding or following the target letter. In none of the sentences did a function word precede or follow the critical string. Experimental sentences contained between 8 and 17 words each.

In the stem sentences, the critical word was an unprefixed content word that contained the target letter only once. In the function prefix sentences, the critical word was composed of a function ensemble prefixed to a content word. Function ensembles contained one to four function prefixes. These were constructed by using the following Hebrew function prefixes: *V* (*AND*), *H* (*THE*), *B* (*IN*), *L* (*TO*), *M* (*FROM*) and *S* (*THAT/WHO*). Only *B*, *L*, *M*, and *S* were used as target letters, but the inclusion of the prefixes *V* and *H* afforded more flexibility in constructing strings that correspond to different combinations of position and size. However, not all combinations are permitted in Hebrew, and there are also constraints on the order of the prefixes. For example, the sequence *IN THE* is expressed by the single letter *B* (rather than *BH*). Table 2 lists the prefix combinations used. Altogether, there were 14 function prefix sentences that included a single-prefix, 30 with a double-prefix, 22 with a triple-prefix, and 6 with a quadruple-prefix. Some of the patterns were used in 2 sentences, whereas others were used in 4 sentences each, as indicated in Table 2. The combination of sentences provided a nearly equal presentation of the four target letters. In addition, some of the prefix ensembles were used in association with different target letters (e.g., *SM* was used both when the target was *S* and when the target was *M*). The construction of the matched content sentences followed the same procedure as in Experiment 1. Thus, if the critical string for the function prefix *L* was *VLBIT* [*and to* (*a*) *house*], the corresponding content string could be *ALMNH* (*widow*). Across all function and content sentences, there were 24 matched pairs in which the target letter appeared in the first position of the critical word, 32 pairs in which it appeared in the second position, and 16 pairs in which it appeared in the third position. Note that the target letters never appeared in the fourth position of quadruple-prefixes because that position had to contain the nontarget letter *H*. Of the 72 sentence pairs, 16 pairs contained the target letter *B*, 16 the target letter *L*, 20 the target let-

Table 2
Hebrew Prefix Strings (H), Their English Equivalents (E), and Number of Sentences Used (N), Arranged According to Target Letter, Size of Prefix Ensemble, and Ordinal Position of Target Prefix (Experiment 2)

		Position								
		1			2			3		
Size	Target	H	E	*N*	H	E	*N*	H	E	*N*
1	B	B	(in)	4						
	L	L	(to)	4						
	M	M	(from)	4						
	S	S	(that/who)	2						
2	B				SB	(that in)	4			
					VB	(and in)	4			
	L				SL	(that to)	4			
					VL	(and to)	4			
	M	MH	(from the)	4	VM	(and from)	2			
					SM	(that from)	2			
	S	SM	(that from)	2	VS	(and that)	2			
		SH	(that the)	2						
3	B							VSB	(and that in)	4
	L							VSL	(and that to)	4
	M				VMH	(and from the)	2	VSM	(and that from)	4
					SMH	(that from the)	2			
	S	SMH	(that from the)	2	VSH	(and that the)	2			
					VSM	(and that from)	2			
4	B									
	L									
	M							VSMH	(and that from the)	4
	S				VSMH	(and that from the)	2			

ter *M*, and 20 the target letter *S*. The sentences for a particular target letter were evenly divided across two pages, and those pages were devoted exclusively to detection of that target letter. Each page contained an equal number of randomly distributed prefix and stem sentences. However, only one member (either the prefix or the stem sentence) of a matched pair of sentences was inserted on a page; that is, the 2 sentences of each matched set appeared on the two different pages devoted to a target. A page appeared as one long paragraph of continuous text composed of unrelated sentences. The critical string never appeared at the beginning or end of a line.

Procedure. The procedure was similar to that of Experiment 1, except that four different target letters were used. Subjects were instructed that the pertinent target letter for each page would be designated on top of the page.

The eight experimental pages were arranged in two blocks of four successive pages each, wherein each page in a block was devoted to a different target letter. For each subject, the order of the target letters was the same across the two blocks, but this order was counterbalanced across all subjects.

Results

The results were first analyzed for the effects of target position across the various levels of size. Because the four target letters were not equally represented in each of the Size × Position combinations (see Table 2), the analysis was carried out for each of the target letters separately. Note that, for each target letter, each of the target positions was equally represented across the two types of experimental sentences, stem and prefix. Table 3 presents mean detection errors as a function of target position for content and function words. Note that the overall pattern of results is remarkably consistent across the letters *B*, *L*, and *M*. (The letter *S* yielded a negligible number of errors in some cases.) The function disadvantage was observed only for the prefix letter occupying the first position, whereas for the subsequent positions a rather different tendency toward a function

Table 3
Means and Standard Errors of Percentages of Omission Errors for Prefix-Favored and Stem-Favored Interpretations as a Function of Target Letter and Position (Experiment 2)

	Favored interpretation							
	Prefix		Stem		Prefix		Stem	
Position	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
	Letter B				Letter L			
First	28.1	5.6	7.0	2.3	16.4	3.1	2.3	1.7
Second	9.4	2.5	18.0	3.3	9.0	2.1	9.4	2.1
Third	6.2	2.2	18.7	4.2	8.6	3.5	21.1	3.9
	Letter M				Letter S			
First	27.3	3.9	18.7	3.1	10.2	2.3	4.3	1.7
Second	15.2	3.3	24.6	3.7	3.9	1.4	3.1	1.4
Third	10.9	2.4	18.0	3.6				

advantage was found. Two-way ANOVAs, Favored Interpretation (prefix vs. stem) × Position, yielded significant interactions for the letter *B*, $F(2, 62) = 16.29, p < .0001$; the letter *L*, $F(2, 62) = 17.70, p < .0001$; the letter *M*, $F(2, 62) = 9.55, p < .0005$; and the letter *S*, $F(1, 31) = 5.16, p < .05$.

One-way ANOVAs, using the first position only, confirmed the typical function disadvantage for the letter *B*, $F(1, 31) = 14.65, p < .001$; the letter *L*, $F(1, 31) = 15.79, p < .001$; the letter *M*, $F(1, 31) = 6.81, p < .05$; and the letter *S*, $F(1, 31) = 10.92, p < .005$.

In contrast, similar one-way ANOVAs, for the second position only, yielded a significant function advantage for both the letters *B*, $F(1, 31) = 5.80, p < .05$, and *M*, $F(1, 31) = 7.97, p < .01$, but not for *L* or *S* ($Fs < 1$). For the third position, the function advantage was significant for the letters *B*, $F(1, 31) = 5.90, p < .05$; *L*, $F(1, 31) = 10.33, p < .01$; and *M*, $F(1, 31) = 6.84, p < .05$.

To assess the overall effect of position across all target letters, it was necessary to control for the fact that (a) the four target letters differed in their overall detection rate, presumably because of visual factors (see Koriat et al., 1991), and (b) these target letters were not equally represented in all positions in Experiment 2. Therefore, the following procedure was used: First, we calculated the expected percentage of errors in each position, taking into account (a) the likelihood of missing each of the letters, and (b) the distribution of different target letters in that position. The former was estimated from the percentage of omission errors obtained in the filler condition of Experiment 1 in Koriat et al. (1991). This filler condition included all target letters in text other than those used for experimental purposes (see Koriat et al., 1991, Table 1). The expected percentage of errors was then subtracted from the mean observed percentages, and the difference scores were plotted in Figure 1 as a function of position for content and function strings. Figure 1 suggests that the function advantage for the third position was higher than for the second position and was about equivalent to the contrasting function disadvantage observed for the first position.

In the analyses presented so far, the results were collapsed across different ensemble sizes. However, because size and position are confounded, it is important to show that the results depicted in Table 3 and Figure 1 reflected the effects of position rather than the effects of size. Consider the results for *M* in positions 1 and 2. In position 1, percentage of omission errors for *M* was about the same when the letter represented the only function morpheme (26.6%) as when it was the first of two function morphemes (28.1%; $F < 1$). In contrast, this letter engendered fewer errors when it was the second (14.8%) than when it was the first (28.1%) morpheme in a two-morpheme ensemble, $F(1, 31) = 8.24, p < .01$. Note that the decrease in error rate with the ordinal position of the function morpheme cannot be accounted for in terms of a simple serial-position effect because the results for the content words, in fact, disclosed generally the opposite trend (see Table 3 and Figure 1).

A similar pattern was observed for the target letter *S*. This letter engendered similar error rates when it represented the only function morpheme (12.5%) and when it was the first of two function morphemes (13.3%; $F < 1$). Moreover, when *S* was the first of two prefixes, it engendered more errors than when it was the second, $F(1, 31) = 8.30, p < .01$.

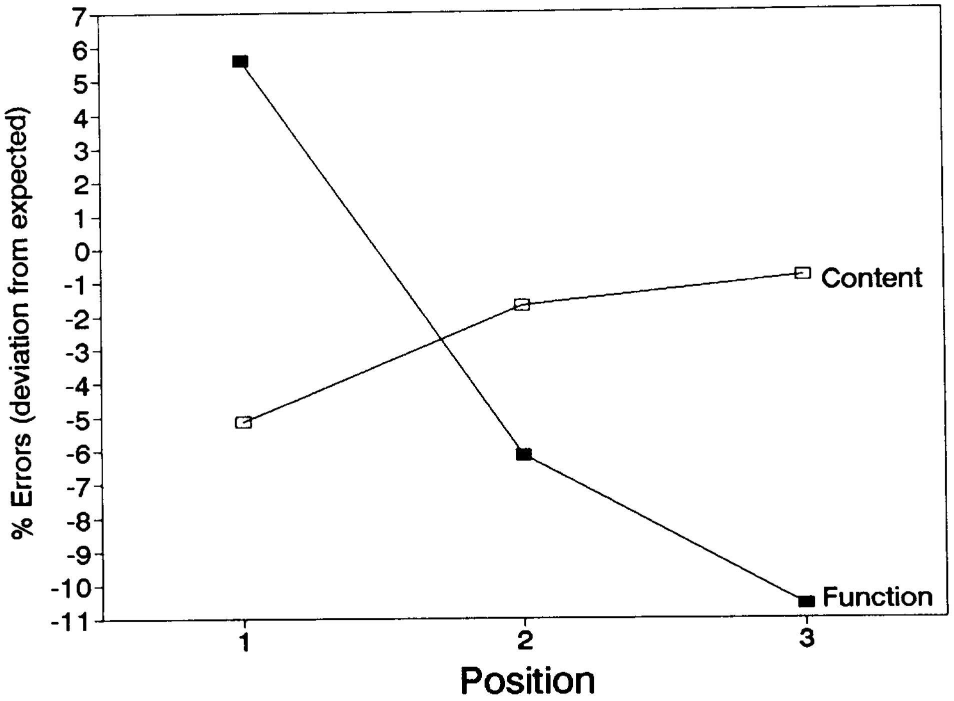

Figure 1. Mean percentages of errors, expressed as deviations from expectations, for function and content words as a function of target position (Experiment 2).

Note, however, that the results for *S* in the three-letter condition deviate from the pattern noted earlier: For this condition, *S* yielded only a negligible error rate when representing the first of three function morphemes (1.6%), and this error rate did not exceed that found for the corresponding content words (4.3%), $F(1, 31) = 1.27$, *ns*, or for the second morpheme of a three-morpheme ensemble (5.5%), $F(1, 31) = 1.49$, *ns*. The reasons for these discrepancies are not clear.

Discussion

The results of Experiment 2 replicated the main finding of Experiment 1 while also indicating that the critical factor in the occurrence of a function disadvantage in a series of function morphemes lies in the position of the prefix within a prefix ensemble rather than in the size of the ensemble. Thus, the missing-letter effect was consistently obtained across all four function prefixes, but only when the prefix was in the initial position. When it occupied the second, third, or fourth positions, there was no sign of a missing-letter effect whatsoever.

One unexpected feature of the results of Experiment 2 is that not only did the missing-letter effect disappear for function letters occupying later positions but that for these positions there was, in fact, a function advantage: Letter detection was easier for letters representing function morphemes than for those that were part of the stem of a content word.

The pronounced function disadvantage for the first function morpheme is consistent with the proposition that leading functors play a more significant role in the on-line extraction of phrase structure than do the functors that follow. Apparently, readers monitor function morphemes to anchor local frames, and once a first function unit is marked, the subsequent function morphemes are, perhaps, treated as if they were part of the content constituent that follows. Thus, the pattern of letter detection errors observed in Experiments 1 and 2 is compatible with the assumption that the missing-letter effect reflects the on-line extraction of structural frames on the basis of a shallow analysis at the early stages of text processing.

Alternatively, the failure to find a function disadvantage beyond the first function morpheme may be due to a process whereby a multiprefix string is parsed into its constituent morphemes. This might be similar to the process of prefix stripping described by Taft and Forster (1975; see also Lima, 1987; Taft, 1979). In this process, a polymorphemic word (e.g., *reheat*) is recognized after it has been decomposed into its constituent morphemes and after the prefix part has been stripped away. They found, for example, that nonwords that could be decomposed into a prefix and a stem part (e.g., *besist*) took longer to classify as nonwords than strings that could not be so decomposed (e.g., *bescue*). It might be argued that a similar decomposition process occurs with regard to multiprefix Hebrew words. Assuming that decomposition requires additional processing, it may be expected to increase the availability of the function letters, particularly those occupying later positions. We postpone consideration of this process until the General Discussion, after we have reported on two additional experiments that have some bearing on the relevance of prefix stripping to the missing-letter phenomenon. In particular, Experiments 3 and 4 examined whether the diminishing disadvantage across positions would also arise in function *word* sequences, in which prefix stripping was obviously not an issue.

Experiment 3

The aim of Experiment 3 was to examine whether the interactive pattern observed in Experiments 1 and 2 would also be obtained for Hebrew function *words*. Replicating that pattern with function words rather than function prefixes would help to reject the prefix-stripping explanation of the effects obtained in Experiment 1. Elsewhere, we have shown a function disadvantage for Hebrew function words (Koriat & Greenberg, 1991; Koriat et al., 1991) when they were not embedded in function word sequences. Specifically, does the function disadvantage observed with words also disappear when these functors take up residence in the latter positions of a functor sequence, as it did for function prefixes?

It is unfortunate that there are not as many common function-word sequences in Hebrew as there are function-prefix sequences. For example, the morphemes *THE* and *AND* can only be expressed as prefix letters. Moreover, *FROM* can be expressed as a function word rather than as a prefix only when it is followed by *THE*. Thus, Experiment 3 used only two function words, *BETOCH* (*IN* or *INSIDE*, with the first letter, *B*, used as the target letter) and *EL* (*TO*, with the second letter, *L*, used as the target letter). These words were presented either in isolation (i.e., with no adjacent function words) or preceded by either the function words *RK* (*ONLY*) or *GM* (*ALSO*).

Method

Subjects. Twenty-four University of Haifa students whose native language was Hebrew participated in the study, 3 for course credit and 21 for monetary payment.

Design. The design of Experiment 3 called for six conditions representing all combinations of two factors, target letter (*B* or *L*) and type of sentence (content word, single functor, or double functor).

Stimulus materials. A total of 72 Hebrew sentences were constructed, representing 24 sets of three matched sentences each: 12 sets for the target letter *B*, and 12 for the target letter *L*. One sentence in each set included a critical functor (*BETOCH* or *EL*) that was neither preceded nor followed by another functor (single-functor sentence). The second sentence also included that same functor, but it was preceded by another functor (double-functor sentence). The third sentence contained a critical content word (content sentence). The three sentences were matched for the number of words and the ordinal position of the critical word. The critical content word contained the same number of letters as the corresponding function word, with the target letter occupying the same position as it did in the function word. For example, the content word corresponding to *EL* could be *SL* (*basket*). The number of words in a sentence varied from 9 to 14 words. There was only one critical word in each sentence and it contained only one target letter. Within an experimental sentence, target letters appeared in noncritical words as well, but never in the word immediately preceding or following the critical string.

In the double-functor sentences, the critical string *BETOCH* (spelled as a four-letter word, like *BTOC*) or *EL* were each preceded in half of the sentences by the functor *RK* (meaning *JUST* or *ONLY*, and pronounced *RAK*) and in the remaining sentences by *GM* (meaning *ALSO*, and pronounced as *GAM*). Thus, there were four types of double functors: *GM BTOC* (*ALSO IN*), *RK BTOC* (*ONLY IN*), *GM EL* (*ALSO TO*) and *RK EL* (*ONLY TO*).

All 36 sentences representing a particular target letter were printed on two pages. The order of the sentences was random, except that matched sentences never appeared in succession. Each page contained exactly half of the sentences corresponding to each of the sentence types. A page appeared as one long paragraph of continuous text composed of unrelated sentences, with a period at the end of each sentence. The critical string never appeared at the beginning or end of a sentence or a line. Two warm-up sentences were added at the beginning of each page, so that altogether there were 20 sentences on a page.

Procedure. The procedure was the same as in Experiment 2. The booklets contained five pages, one practice and four experimental pages. The experimental pages alternated between *B* and *L* targets, with half the subjects beginning with a *B* target page, and half with an *L* target page; their order was counterbalanced across subjects.

Results

Table 4 presents the means and standard errors of the percentages of omission errors for the three types of critical sentences for the two target letters.

A two-way ANOVA, Sentence Type × Target Letter, yielded significant effects for sentence type, $F(2, 46) = 6.66$, $p < .005$, and for the interaction $F(2, 46) = 5.63$, $p < .01$. Note that the results differed for the two target letters. Whereas the results for the letter *B* disclosed the typical function disadvantage in the comparison between the content and the single-functor sentences, there was no indication of such an effect for the letter *L*. Critically, however, for both target letters, detection improved when the function words in which they were embedded were preceded by other function words.

To confirm these impressions, two separate analyses were conducted. The first focused on the contrast between content sentences and single-functor sentences. A Sentence Type × Target Letter ANOVA for this comparison yielded significant effects for sentence type, $F(1, 23) = 9.04$, $p < .01$, and for the interaction, $F(1, 23) = 6.38$, $p < .05$. The difference between the two types of sentences was significant only for the letter *B*, $F(1, 23) = 12.23$, $p < .005$, but not for the letter *L* ($F < 1$).

The second analysis contrasted the two types of function sentences. A Sentence Type × Target Letter ANOVA for this comparison yielded significant effects for sentence type, $F(1, 23) = 9.88$, $p < .005$, and for target letter, $F(1, 23) = 4.74$, $p < .05$, but not for the interaction, $F(1, 23) = 1.72$, *ns*. One-way ANOVAs, however, indicated that the difference between the two types of sentences was significant only for the letter *B*, $F(1, 23) = 9.20$, $p < .01$, but not for the letter *L*, $F(1, 23) = 1.40$, *ns*.

Note that although the reduction in error rate for function words from the first to the second position was consistent with the results of Experiment 2, there was little evidence for a function-advantage effect for the double-functor sentences. Thus, error rate for these sentences still exceeded that of the content words for the letter *B*, $F(1, 23) = 5.66$, $p < .05$, whereas for the letter *L*, the weak function-advantage effect was not significant, $F(1, 23) = 1.72$, *ns*.

Table 4
Means and Standard Errors for Percentages of Omission Errors by Sentence Type and Target Letter (Experiment 3)

Sentence type	B		L		All	
	M	*SE*	*M*	*SE*	*M*	*SE*
Content	8.0	2.5	13.2	3.2	10.6	2.5
Single functor	23.6	5.8	12.8	3.2	18.2	3.9
Double functor	15.3	4.3	9.7	2.2	12.5	3.0
All	15.6	3.9	11.9	2.3	13.8	3.0

Discussion

The results obtained with function words were not as clear as those found for function prefixes in Experiments 1 and 2. Indeed, there was a marked difference between the two function words, with the results for one of them, *EL*, failing even to replicate the typical function disadvantage in single-functor sentences. The reason for this failure is not clear because such an effect had been demonstrated for *EL* in a previous experiment (Koriat et al., 1991, Experiment 1). Nevertheless, despite the variability in letter detection across the two function words tested here, there was a trend indicating improved detection for both words when they were preceded by other functors. Placing a functor in front of the critical functor, however, did not eliminate or reverse the function disadvantage, as it did with the prefixes. Thus, these findings were not entirely consistent with the prefix results, but they did replicate a reduction in detection errors for morphemes appearing later in functor sequences.

Experiment 4

All experiments reported thus far concerned Hebrew. Experiment 4 attempted to extend the results of the previous experiments to English functors. English affords more opportunities than Hebrew for studying the effects of ordinal position for phrases that include a sequence of function words (e.g., *AND FROM THE*). In our previous work (e.g., Koriat et al., 1991), we observed that single function morphemes in Hebrew and English produce similar effects on letter detection. In Experiment 4, we explored whether comparable results are also obtained with multiple function words.

Experiment 4 included two parts. The first part focused on the five prepositions *FOR*, *FROM*, *OF*, *IN*, and *ON*. Each of these could appear in one of four types of sentences: as the only functor (e.g., *FOR*), as the first of two functors (e.g., *FOR THE*), as the second of two functors (e.g., *AND FOR*), or as the second of three functors (e.g., *AND FOR THE*). Thus, in two of these types of sentences, the preposition appeared alone or initiated a double-functor phrase, whereas in the remaining sentences it appeared in the second position of multifunctor sequences (double- and triple-functor frames).

The second part of Experiment 4 concerned the definite article *THE*. It was important to include *THE* in Experiment 4 because it has been the most extensively researched functor in the context of the missing-letter effect and also because of the distinctive linguistic properties of this functor as compared with others (see Gernsbacher & Robertson, 1991; Greenberg et al., in press). In the second part of Experiment 4, *THE* appeared in three types of phrases: those where it was the only functor (*THE*), those where it was the second of two functors (*FOR THE*), and those where it was the third among three functors (*AND FOR THE*). Note that in the design for *THE*, the size of the function sequence and the ordinal position of *THE* were confounded, as was the case for the Hebrew stimuli in Experiment 1. As in Hebrew, the definite article cannot appear before other functors in a function sequence.

Method

Subjects. Twenty-four University of Haifa students whose native language was English participated in the experiment. They were paid for their participation.

Design. The design of Experiment 4 called for an unbalanced representation of five factors: target letter (*F*, *N*, or *T*), functor (*FOR*, *FROM*, *OF*, *IN*, *ON*, or *THE*; obviously this factor was embedded in the target-letter factor), type of sentence (content or function), size of the critical frame (1, 2, or 3 words), and position of the critical word within that frame (first, second, or third).

Stimulus materials. The first part focused on the prepositional functors *FOR*, *FROM*, *IN*, *OF*, and *ON*. This part included 10 sets of six matched sentences each. Each set was constructed as follows (see Table 5). One sentence included the critical functor, neither preceded nor followed by another functor (single functor). Two sentences contained a double-functor word frame (double functor), where in one case the critical functor was preceded by the word *AND* (e.g., *AND FROM now* . . .), whereas in the other it was followed by the word *THE* (e.g., *FROM THE moment* . . .). The fourth sentence in a set contained a triple-functor frame (triple functor) with the same critical word now inserted between the words *AND* and *THE* (e.g., *AND FROM THE day* . . .). Note that in those cases where the target letter was *N*, the word *AND* that preceded the critical functors *ON* and *IN* was replaced by *BUT* (to avoid repetition of the target letter in the word adjacent to the critical preposition). Finally, each set included two additional content sentences in which the critical word was a content word of the same length as the corresponding critical preposition and which contained the target letter in the same position as did the preposition (e.g., if the critical preposition was *FOR*, the corresponding content word could be *FOG*). Six such sets of sentences were constructed for the target letter *F*, two of them around the preposition *FOR*, two around *FROM*, and two around *OF*. Four additional sets were constructed for the target letter *N*, two of them around the preposition *ON*, and two around the preposition *IN*.

Part 2 of Experiment 4 focused on the definite article *THE*. This part included 10 sets of four matched sentences each. These were constructed as follows (see Table 6): One sentence included the critical functor *THE*, neither preceded nor followed by another functor (single functor). In two sentences, *THE* was preceded by either one (double functor) or two (triple functor) other functors. The functor immediately preceding *THE* was equally often *FOR*, *FROM*, *OF*, *IN*, and *ON*, in both the double- and triple-functor sentences. In the triple-functor sentences, the first functor was always *AND*. In the fourth, content sentences, the critical word was a three-letter content word that began with *T* (e.g., *TRY*).

In both parts of Experiment 4, the sentences included in a set were matched for number of words and for the location of the critical word within the sentence. Sentences contained between 12 and 18 words each and included only one critical word each. Within an experimental sentence, target letters appeared in noncritical words as well, but never in the word immediately preceding or following the critical string.

Altogether, there were 100 experimental sentences, 36 for the target letter *F*, 24 for *N*, and 40 for *T*. Sentences for each target letter were divided equally across the two pages devoted to that letter. For the target letter *F*, one page contained all 6 sentences from one set constructed around *FOR*, around *FROM*, and around *OF*, whereas the second page contained those 6 sentences associated with the other sets of *FOR*, *FROM*, and *OF*, yielding 18 experimental sentences per page. In a similar manner, each of the two pages for *N* displayed all 6 sentences from one of the *IN* and *ON* sets, providing 12 different experimental sentences per page. Finally, each page assigned to *T* contained a complete set of 4 sentences from one of the two sets constructed around each of the five preceding functors, thereby yielding 20 different experimental sentences per page. The order of the sentences within a page was random, except that sentences that belonged to the same set never appeared consecutively. A page appeared as one long paragraph of continuous text composed of unrelated sentences. The critical word never appeared at the beginning or end of a line. Each subject's booklet contained six experimental pages (two for each target letter) and two pages of instruction and practice.

Table 5
Functor Sequences Used in Part 1 of Experiment 4

		Target letter for prepositions (*FOR*, *FROM*, *OF*, *ON*, and *IN*)				
Size	Position	F	F	F	N	N
1	1	for	from	of	on	in
2	1	for the	from the	of the	on the	in the
2	2	and for	and from	and of	but on	but in
3	2	and for the	and from the	and of the	but on the	but in the

Table 6
Functor Sequences Used in Part 2 of Experiment 4

Size	Position	Target letter for definite article (*THE*)				
		T	T	T	T	T
1	1	the	the	the	the	the
2	2	for the	from the	of the	on the	in the
3	3	and for the	and from the	and of the	and of the	and in the

Procedure. The procedure was the same as in Experiment 2. The six experimental pages were arranged in two blocks of three successive pages, wherein each page in a block was devoted to a different target letter. For each subject, the sequence of the target-letter assignment was the same across the two blocks, but the order of the three target letters within each block was counterbalanced across all subjects.

Results

We shall begin with the results of Part 1, which included the five prepositions *FOR, FROM, OF, IN,* and *ON*. Note that each of these could appear either in the first (or only) position or in the second position of a sequence. Table 7 (top panel) presents mean percentages of omission errors for first-position and second-position prepositions and for their matched content words.

The results revealed systematic differences in error rates between the five prepositions, which can be explained partly in terms of differences in the detectability of different target letters (more errors for *N* than for *F*) and word length (somewhat more errors for the shorter words). Across all prepositions, however, the following pattern did emerge: Rates of detection errors were smallest for content words, largest for first-position prepositions, and intermediate for second-position prepositions.

Consider first the comparison between content words and first-position prepositions. A two-way ANOVA, Preposition (*FOR, FROM, OF, IN,* or *ON*) × Syntactic Class yielded significant effects for syntactic class, $F(1, 23) = 106.74, p < .0001$; preposition, $F(4, 92) = 18.89, p < .0001$; and the interaction, $F(4, 92) = 7.35, p < .0001$. Note (Table 7) that the function disadvantage was consistently revealed for each of the five prepositions ($p < .005$, in each case) and that the interaction portrayed only differences in the magnitude of the disadvantage across the various prepositions.

Table 7
Means and Standard Errors of Percentages of Omission Errors for Content; First-Function and Second-Function Sentences for the Five Prepositions FOR, FROM, IN, OF, and ON; and for the Definite Article THE (Experiment 4)

Function word	Sentence type							
	Content		First function		Second function		Third function	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
	Prepositions							
FOR	4.2	1.9	31.3	5.7	9.4	4.5		
FROM	1.0	1.0	27.1	5.8	12.5	3.7		
IN	18.8	4.1	68.8	6.4	52.1	6.5		
OF	12.5	3.4	69.8	7.7	47.9	8.0		
ON	16.7	4.9	38.5	6.6	31.3	6.4		
All prepositions	10.6	1.8	47.1	4.5	30.6	4.1		
	Definite article							
THE	7.9	1.6	55.8	7.2	63.3	5.9	54.6	6.2

A similar ANOVA comparing first-position and second-position prepositions indicated main effects for position, $F(1, 23) = 43.67, p < .0001$, and for prepositions, $F(4, 92) = 28.09, p < .0001$, but not for the interaction ($F < 1$). Each of the prepositions exhibited improved detection when it occupied the second position in a string of two functors than when it served as the first (or only) functor. This effect was significant for the prepositions *FOR*, $F(1, 23) = 12.21, p < .005$; *FROM*, $F(1, 23) = 11.86, p < .005$; *OF*, $F(1, 23) = 8.35, p < .01$; and *IN*, $F(1, 23) = 4.97, p < .05$; but not for *ON*, $F(1, 23) = 1.21$, *ns*.

Finally, prepositions yielded more detection errors than did content words, even when they occupied the second position in a function-word ensemble. A two-way ANOVA yielded significant effects for syntactic class, $F(1, 23) = 40.51, p < .0001$; for preposition, $F(4, 92) = 19.23, p < .0001$; and for the interaction, $F(4, 92) = 5.64, p < .001$. The function disadvantage was significant for the prepositions *FROM*, $F(1, 23) = 8.31, p < .01$; *IN*, $F(1, 23) = 24.95, p < .0001$; *OF*, $F(1, 23) = 19.16, p < .001$; and *ON*, $F(1, 23) = 5.55, p < .05$; but not for *FOR*, $F(1, 23) = 1.72$, *ns*.

We also examined the effects of the size of the function ensemble. Recall that the first-position function sentences included both those in which the critical preposition was the sole function in the sentence (single) and those in which it was the first of two successive functors (double). Mean error rate for the single sentences (51.3%) was somewhat higher than for the double (42.9%) sentences, $F(1, 23) = 3.44, p < .10$.

In a similar vein, second-position function sentences included those in which the critical sequence consisted of two functors (double) and those consisting of three functors (triple). Mean error rates were 32.1% for the former and 29.2% for the latter sentences ($F < 1$).

An examination of the double-functor sentences permitted us to test the effects of the ordinal position of the functor when the size of the functor sequence was held constant. The results from these sentences indicated a significantly higher error rate when the critical preposition was first (42.9%; e.g., *FOR* in *FOR THE*) than when it was second (32.1%; e.g., *AND FOR*), $F(1, 23) = 6.49, p < .02$.

We turn now to the results for the definite article, *THE*, also presented in Table 7. Table 7 (bottom panel) presents the mean percentages of omission errors for first-, second-, and third-position occurrences of *THE*, and for its matched content words. It can be readily seen that the results for *THE* differed markedly from those of the prepositions. Recall, however, that the ordinal position of *THE* was confounded with the size of the function word ensemble. A one-way ANOVA for *THE* yielded $F(2, 46) = 2.41$, *ns*, for the comparison between the three function positions, whereas for each position, the error rate for *THE* was significantly higher than for content words: $F(1, 23) = 49.52, p < .0001$, for the first position; $F(1, 23) = 95.26, p < .0001$, for the second position; and $F(1, 23) = 66.29, p < .0001$, for the third position. Thus, although the function disadvantage for *THE* was strong, it was also apparently indifferent to the position of *THE* within a function word ensemble.

Discussion

The results of Experiment 4 exhibited a very different pattern for the prepositions and for the definite article. As far as the prepositions are concerned, a consistent pattern was observed across all five prepositions used, *FOR*, *FROM*, *OF*, *IN*, and *ON*. These functors showed a stronger function disadvantage when they assumed the role of a leading functor than when they followed another functor. This pattern was rather similar to that obtained for the Hebrew functor *BETOCH* (*IN*) in Experiment 3. Thus, although the missing-letter effect for these prepositions was significantly reduced when they were moved from the first to the second positions, it was not eliminated entirely. Note, however, that the reduced disadvantage of trailing functors here and in Experiment 3 indicates that the position of a functor is critical, regardless of whether it is a prefix or a word. Presumably, the pattern of detection errors demonstrated in Experiments 1 and 2 for prefix ensembles cannot be explained entirely in terms of the process of prefix-stripping.

The results for the definite article, in contrast, showed that letter detection for *THE* remained equally difficult regardless of its position. Note that because the size of the function ensemble was confounded with the location of *THE* within this ensemble (*THE* always occupied the last position), these results indicated that *neither* of these factors is particularly critical to the occurrence or magnitude of the function disadvantage pertaining to *THE*. The failure to achieve a position effect is problematic for the structural account of the missing-letter effect, whereas the indifference of letter detection errors in *THE* to the size of the function ensemble is inconsistent with the unitization position. This indifference to ensemble size has also been found in a recent study (Greenberg et al., in press), in which letter detection in *THE* was no more difficult when it appeared in the context of *FOR THE* than when it was not preceded by another functor. According to the unitization account, *THE* may be processed in terms of supraword units when it is placed in the context of a frequent two-word frame such as *FOR THE*, *IN THE*, and so on. However, our data on *THE* provided little support for the unitization position, asserting instead that detection errors in *THE* are not sensitive to where or even whether *THE* appears in a functor sequence.

General Discussion

This study focused on letter detection errors in function morphemes that appear consecutively in connected text. Though such functor sequences are quite frequent, their processing has not been given much attention. We reasoned that if letter detection errors are indeed symptomatic of the process of extracting phrase structure during reading, then perhaps some insight into this process can be gained from the study of error detection patterns in these sequences.

In particular, the motivation for studying such error patterns derived from several observations suggesting that the extraction of phrase structure is based on a fast, shallow analysis that uses a variety of cues to arrive at a tentative frame that can guide further processing. This analysis takes advantage of parafoveal preview and is most sensitive to the immediate, local context (see Koriat & Greenberg, 1991). Apparently, unlike a speaker, who may be able to plan an involved structure of utterances to be spoken (see Bock, 1990), readers as well as listeners must derive structural information on-line, using the cues that are immediately available. The most reliable cues for syntactic structure are function units, and these are monitored early in reading. If the establishment of phrase structure also follows the immediacy principle (see Just & Carpenter, 1987), then the first function unit identified ought to play the main role in defining a tentative frame, although this frame may be modified at a later time. We proposed that it is the early, tentative frames that are responsible for the greater difficulty in detecting letters in function than in content morphemes. Therefore, we expected that it would be the leading functor, the one likely to anchor phrase structure, which will evidence the highest proportion of omission errors.

The results were generally in line with this prediction. However, the pattern of detection errors differed markedly across the different function morphemes investigated, preventing any simple conclusions. Thus, the interpretations of the results considered here must be speculative at this point. Unfortunately, because of the general lack of research that is directly pertinent to the processing of functor ensembles, there are not many independent data that we could benefit from in specifying or supporting these interpretations.

The most consistent empirical conclusion that emerged from this series of experiments is that the position of a functor within a functor ensemble exerts a pervasive effect on letter detection errors. Except for the word *THE*, which proved to be immune to this effect, for all other functors included in the present study, there was a trend indicating poorer letter detection for leading than for trailing functors, although the size of this "leading-functor effect" differed greatly across experiments. Thus, in Experiment 1 the prefix representing the definite article in Hebrew evidenced a clear function disadvantage when appearing as the first and only functor but revealed no such effect when it was the second, the third, or the fourth functor in a multiprefix unit. This pattern was remarkably similar across both words and nonwords. Because the definite article is always the last in a series of prefixes, Experiment 2 was set up to determine whether the critical factor responsible for the error detection pattern in Experiment 1 was the size of the prefix ensemble (one prefix or more than one) or the relative position of the prefix (leading vs. trailing). The results indicated that it was the latter that was important: For all four function units included in Experiment 2, the function disadvantage was entirely confined to the leading functor. Thus, in both Experiments 1 and 2, it appeared that although a single function prefix produces a pronounced missing-letter effect, this effect can be entirely eliminated by placing another function prefix in front of it. However, unlike in Experiment 1, the results of Experiment 2 suggested *better* letter detection in trailing functors than in their content controls. This function advantage was noticeable for three of the four functors studied.

The results for the function words in Experiments 3 and 4 differed markedly from those of the function prefixes, but here, too, there was a trend suggesting relatively more omission errors for the leading functor. Thus, both of the Hebrew function words used in Experiment 3 indicated improved letter detection when the critical function word was preceded by another functor than when it was not. This very pattern was also consistently found for all five English prepositions used in Experiment 4 (although it was significant for only four of them). Note that in Experiments 3 and 4, although the missing-letter effect for a given functor was reduced by placing another functor in front of it, it was not totally eliminated as in Experiments 1 and 2.

In sum, although the results were complicated by several interactions, the overall pattern of a stronger function disadvantage for leading than for following functors was pervasive enough to merit its own discussion before the interactions are tackled. How can this pattern be interpreted? According to the structural account, rate of omission errors is inordinately high in function morphemes not because such morphemes are predictable and therefore skipped over during reading (as claimed by the redundancy account). Rather, it is precisely because of the critical role played by such morphemes in the establishment of phrase structure that they are lost during text processing. Thus, the higher error rate observed for leading functors ought to reflect their greater contribution to the structural frames that are tentatively considered. Assuming an on-line frame-extraction process (see Kimball, 1973) that works according to the immediacy strategy suggested by Just and Carpenter (1987), the first functor encountered ought to shoulder most of the burden of phrase organization and consequently be the most likely to be lost.

If this interpretation is correct, then the leading-functor effect observed in our study should shed some light on the nature of the tentative structural frames entertained during reading. Presumably, leading functors play a special role in defining a rudimentary structure, with the more subtle boundaries within this structure being less important. Apparently, the immediacy of on-line processing does not permit the construction of hierachically embedded structures. Because the trailing functors generally mark less useful boundaries, they may not be called on to set structure until much later in processing. Assuming that these trailing functors are brought into play relatively late in processing, it follows that they will be available for letter detection longer than the initial functors. In essence, therefore, the structural model implies that the first functor in is also the first functor out, and the earlier out the greater the rate of detection errors. Needless to say, these propositions are speculative at this point, and further research is badly needed.

How would the unitization and attentional-redundancy positions handle the leading-functor effect? According to the unitization account, as formulated by Healy and Drewnowski (e.g., Drewnowski & Healy, 1980; Healy, 1976; Healy & Drewnowski, 1983), highly frequent words, such as *THE*, tend to conceal their letters because they allow access to their whole-word unitized representation. Furthermore, such words are usually embedded in frequently occurring word sequences, such as *ON THE*, *FROM THE*, and so on, which are themselves unitized. This is why manipulations that disrupt phrase unitization (e.g., inserting asterisks between adjacent function words, as in *FOR**THE*; see Healy, Conboy, & Drewnowski, 1987) improve letter detection in function words. This line of reasoning would lead to the prediction that letter detection in *THE* should be higher when *THE* is preceded by other functors than when it is not. This prediction, however, was not borne out by the results of Experiment 4, nor by those of the recent study by Greenberg et al. (in press). This failure suggests that the improved letter detection in *THE*, resulting from the scrambling of text (see Drewnowski & Healy, 1977, 1980), cannot be explained in terms of the disruption of phrase-level unitization. Furthermore, the results for some of the other functors included in our study evidenced just the opposite trend: Letter detection was more difficult when a functor appeared alone than when it was preceded by another functor.

However, the recent modification of the unitization account advanced by Hadley and Healy (1991) can, perhaps, accommodate the leading-functor effect. According to their "parafoveal-processing hypothesis," the missing-letter effect depends on the identification of familiar words in the parafovea on the basis of their whole-word representations. Such identification allows readers to skip foveal processing. However, if familiar words are fixated, the missing-letter effect would be eliminated. This revision of the unitization account may explain the leading-functor effect by assuming that once the leading functor is identified in the parafovea and skipped over, the next functor is likely to be fixated, consequently revealing its letters (A. F. Healy, personal communication, February 1992).

Although the revised unitization model can accommodate the leading-functor effect for function words, it may have difficulty handling the results for the prefix Hebrew letters without additional assumptions. It is clear that parafoveal previewing of only an initial single-letter morpheme seems highly unlikely. Moreover, the recent study by Greenberg et al. (in press) indicated that manipulations of sentence structure can have differential effects on each of the two words in the familiar sequence *FOR THE*. These results cannot be readily explained by the parafoveal processing hypothesis. Of course, the other findings reported in our previous articles also argue against the unitization model as a general account of the missing-letter effect (Greenberg & Koriat, 1991; Koriat & Greenberg, 1991; Koriat et al., 1991).

The attentional-redundancy approach, on the other hand, predicts that letter detection should be more difficult the more expected a particular word is. Assuming functor sequences are more familiar than other sequences (see Umeda & Kahn, 1982), then functors appearing later in such sequences should, perhaps, engender more errors than those appearing earlier. This, of course, was not the case. At the very least, functors should be no less predictable when appearing within a function ensemble than when they are not preceded by another functor. Furthermore, it is unclear how the redundancy position would handle the prefix findings. Finally, other research has demonstrated that even when previous context is held fairly constant, letter detection can vary with post-target word structure (Greenberg & Koriat, 1991).

We turn next to examination of some of the interactions observed in our study. The leading-functor effect was complicated by three interactive patterns that do not follow clearly from the structural model's assumptions. First, although the leading-functor effect was obtained across both function prefixes and function words, it was more pronounced in the case of prefixes. Thus, function words continued to produce some function disadvantage even when appearing in other than the initial position (Experiments 3 and 4), whereas for prefixes the disadvantage disappeared entirely (Experiment 1) or was even reversed (Experiment 2) for later positions. Note that this interactive pattern cannot be attributed to differences between the languages used here, Hebrew and English, because the pattern was evident when comparing Hebrew function prefixes (Experiments 1 and 2) and Hebrew function words (Experiment 3).

One explanation for the difference between function prefixes and function words is in terms of the process of prefix stripping (see Lima, 1987; Taft, 1979; Taft & Forster, 1975), which occurs for the former but not for the latter. As our previous results have suggested (Koriat & Greenberg, 1991; Koriat et al., 1991), the function disadvantage that is found for Hebrew function prefixes must follow successful parsing of a letter string into its component stem and prefix. No doubt, the complexity of parsing should require more processing than does identifying functors in word form. Parsing and prefix stripping must rely on a morphological analysis of the word or the contextual constraints, or both. Moreover, when a string begins with several functors, there may be a tendency for readers to look for a stem prematurely, that is, identification of an initial prefix may inhibit or discourage them from searching for additional prefixes. Thus, subsequent prefixes may, in fact, be highlighted as readers attempt to sort out the boundary between functor prefix (or prefixes) and stem, and this additional processing may produce their advantage over other letters.

However, although the added processing associated with prefixes may explain the enhanced letter detection in function prefixes, it cannot explain the leading-functor effect itself. This effect was obtained for both function prefixes and function words. Furthermore, if the improved letter detection for trailing prefixes were solely due to prefix stripping, then letter detection for function prefixes should have improved systematically with increasing ensemble size, which was not the case. Thus, it would appear that although prefix stripping may account for part of the difference between words and prefixes, it may be how stripping ties into the process of frame extraction that is important.

A second interaction that poses a challenge concerns *THE*, which unlike all other functors represented in this study, produced a high level of omission errors that was entirely indifferent to position. Perhaps this interactive pattern reflects the difference in the reliability of *THE* and other functors in specifying the nature of a syntactic constituent. As Just and Carpenter (1987) commented, "The function word's information about the nature of a constituent is less reliable than its information about segmentation. This is because some function words can be used in more than one sense, and each sense is associated with a different constituent" (p. 39). Thus, unlike other functors, which carry ambiguous structural information (i.e., the phrase that follows is not fully predictable), *THE* carries clear structural information: It always starts a noun phrase. In fact, some of the other functors do not even reliably begin new constituents, and letter detection in these functors shifts with their roles and locations within a constituent. For example, letter detection in *FOR* was better when it ended a clause than when it began a prepositional phrase (see Greenberg & Koriat, 1991; Greenberg et al., in press). In contrast, *THE*'s status is unchanged by context, so that whatever on-line manipulations may confront the readers when they find other functors, the appearance of *THE* ought to lead to an immediate sense that a noun phrase was beginning. Thus, *THE* permits readers early and reliable access to structure, regardless of the complexity of the larger frame in which *THE* and its associated words are buried. It may also be the case that the frames led by *THE* are the most elementary structures, and so *THE* is easily dismissed. Perhaps, because of *THE*'s informative value, it is routinely identified early (and, presumably, discarded early) in the process of extracting structure.

This interpretation, however, encounters the difficulty that although *THE* continued to exhibit a strong disadvantage across positions, *H* (the Hebrew counterpart in prefix form) did show a declining disadvantage from the initial to the subsequent positions. However, a comparison of the results for the *H* prefix (Experiment 1) with those found for the other four prefixes in Experiment 2 (*IN*, *TO*, *FROM*, *THAT*) disclosed a third interaction still: Although for the former prefix the function disadvantage was simply washed out for positions other than the first, the latter prefix functors, in fact, showed a function *advantage* for these positions. That is, the size of the leading-functor effect was less pronounced for the definite article in Hebrew than for the other functors.

One might view the weak effect for *H* in the later positions to have resulted from its competing qualities of form (prefix) and function (definite article). Perhaps, the effect found with *H* underscored both the uncertainty associated with it being a late prefix on one hand, and on the other, its value as a reliable functor providing immediate specification of a constituent (see earlier). These countervailing forces may have yielded an effect that was relatively weak, as compared with the function advantage of other function prefixes and the consistently strong disadvantage of the word *THE*. It is also worth noting that, unlike the other prefixes tested here, *H* was the only prefix that does not have an alternative word form in Hebrew. In addition, in Hebrew there is no prefix or word used to represent the indefinite article in English, *A*. Thus, alternatively, the letter detection trend found for *H* may have resulted from its particularly unique status among the Hebrew prefixes used.

In sum, although the leading-functor effect is consistent with the structural model, the interactive patterns observed require an additional assumption to accommodate the differences between various types of functors and certainly functor forms. Although our interpretation of these interactions is in line with the spirit of our earlier arguments, they are admittedly speculative and post hoc, and their acceptance must await additional, independent evidence. On the whole, the results suggest two conclusions. First, the missing-letter effect does not seem to be strictly tied to specific characteristics of the words themselves, for instance, their frequency, familiarity, or even their status as open- or closed-class words. Rather, it is sensitive to subtle variations that apparently have to do with their specific role in helping to define a preliminary, gross organization for the phrase. This conclusion is consistent with the recent results of Greenberg and Koriat (1991) and Greenberg et al. (in press), in which letter detection for the same functor was found to vary greatly with the status of that functor within the phrase.

Second, the results seem to stress the importance of distinguishing between different types of functors. Indeed, there has been some discussion in the literature that suggests that various categories of functors have different roles in resolving text and produce different patterns of results on dependent measures of reading (e.g., see Aaronson & Ferres, 1983). Some researchers have taken special note of *THE*'s value in syntactic organization (e.g., see Gernsbacher & Robertson's, 1991, discussion of *THE* in signaling referential coherence). A model that attributes the missing-letter effect to the structural role played by functors in text must take into account the differences in the way these functors perform their roles.

References

Aaronson, D., & Ferres, S. (1983). Lexical categories and reading tasks. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 675–699.

Besner, D. (1989). On the role of outline shape and word-specific visual pattern in the identification of function words: None. *The Quarterly Journal of Experimental Psychology, 41,* 91–105.

Bock, K. (1990). Structure in language: Creating form in talk. *American Psychologist, 45,* 1221–1236.

Carpenter, P., & Just, M. (1983). What your eyes do while your mind is reading. In K. Rayner (Ed.), *Eye movements in reading* (pp. 275–307). New York: Academic Press.

Corcoran, D. W. J. (1966). An acoustic factor in letter cancellation. *Nature, 210,* 658.

Drewnowski, A., & Healy, A. F. (1977). Detection errors on *the* and *and*: Evidence for reading units larger than the word. *Memory & Cognition, 5,* 636–647.

Drewnowski, A., & Healy, A. F. (1980). Missing *-ing* in reading: Letter detection errors on word endings. *Journal of Verbal Learning and Verbal Behavior, 19,* 247–262.

Forster, K. I., & Ryder, L. A. (1971). Perceiving the structure and meaning of sentences. *Journal of Verbal Learning and Verbal Behavior, 10,* 285–296.

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 104–115.

Garrett, M. F. (1980). Levels of processing in sentence production. In B. Butterworth (Ed.), *Language production* (Vol. 1, pp. 177–220). San Diego, CA: Academic Press.

Gee, J. P., & Grosjean, F. (1983). Performance structures: A psycholinguistic and linguistic appraisal. *Cognitive Psychology, 15,* 411–458.

Gernsbacher, M. A., & Robertson, R. R. W. (1991, November). The definite article *the* facilitates the process of mapping. Paper presented at the 32nd Annual Meeting of the Psychonomic Society, San Francisco.

Greenberg, S. N., & Koriat, A. (1991). The missing-letter effect for common function words depends on their linguistic function in the phrase. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 1049–1059.

Greenberg, S. N., Koriat, A., & Shapiro, A. (in press). The effects of syntactic structure on letter detection in adjacent function words. *Memory & Cognition.*

Hadley, J. A., & Healy, A. F. (1991). When are reading units larger than the letter? Refinement of the unitization reading model. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 1062–1073.

Healy, A. F. (1976). Detection errors on the word THE: Evidence for reading units larger than letters. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 235–242.

Healy, A. F., Conboy, G. L., & Drewnowski, A. (1987). Characterizing the processing units of reading: Effects of intra- and interword spaces in a letter detection task. In B. K. Britton & S. M. Glynn (Eds.), *Executive control processes in reading* (pp. 279–296). Hillsdale, NJ: Erlbaum.

Healy, A. F., & Drewnowski, A. (1983). Investigating the boundaries of reading units: Letter detection in misspelled words. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 413–426.

Healy, A. F., Oliver, W. L., & McNamara, T. P. (1987). Detecting letters in continuous text: Effects of display size. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 279–290.

Just, M. A., & Carpenter, P. A. (1987). *The psychology of reading and language comprehension.* Needham Heights, MA: Allyn & Bacon.

Kimball, J. P. (1973). Seven principles of surface structure parsing in natural language. *Cognition, 2,* 15–47.

Koriat, A. (1984). Reading without vowels: Lexical access in Hebrew. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 227–242). Hillsdale, NJ: Erlbaum.

Koriat, A., & Greenberg, S. N. (1991). Syntactic control of letter detection: Evidence from English and Hebrew nonwords. *Jour-*

nal of Experimental Psychology: Learning, Memory, and Cognition, 17, 1033–1048.

Koriat, A., Greenberg, S. N., & Goldshmid, Y. (1991). The missing-letter effect in Hebrew: Word frequency or word function? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 66–80.

Krueger, L. E. (1989). Detection of intraword and interword letter repetition: A test of the word unitization hypothesis. *Memory & Cognition, 17,* 48–57.

Lima, S. D. (1987). Morphological analysis in sentence reading. *Journal of Memory and Language, 26,* 84–99.

O'Regan, J. K. (1979). Saccade size control in reading: Evidence for the linguistic control hypothesis. *Perception and Psychophysics, 17,* 578–586.

Rayner, K. (1977). Visual attention in reading: Eye movements reflect cognitive processes. *Memory & Cognition, 9,* 443–448.

Rayner, K., & Pollatsek, A. (1989). *The psychology of reading.* Englewood Cliffs, NJ: Prentice-Hall.

Schindler, R. M. (1978). The effects of prose context on visual search for letters. *Memory & Cognition, 6,* 124–130.

Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory & Cognition, 7,* 263–272.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior, 14,* 638–647.

Umeda, N., & Kahn, D. (1982). Frequency of occurrence of two- and three-word sequences in English. *Journal of the Acoustical Society of America, 72,* 2031–2033.

Received December 24, 1991
Revision received April 6, 1992
Accepted April 7, 1992 ■

Low Publication Prices for APA Members and Affiliates

Keeping You Up-to-Date: All APA members (Fellows; Members; Associates, and Student Affiliates) receive–as part of their annual dues–subscriptions to the *American Psychologist* and *APA Monitor.*

High School Teacher and International Affiliates receive subscriptions to the *APA Monitor,* and they can subscribe to the *American Psychologist* at a significantly reduced rate.

In addition, all members and affiliates are eligible for savings of up to 60% (plus a journal credit) on all other APA journals, as well as significant discounts on subscriptions from cooperating societies and publishers (e.g., the American Association for Counseling and Development, Academic Press, and Human Sciences Press).

Essential Resources: APA members and affiliates receive special rates for purchases of APA books, including the *Publication Manual of the APA,* the *Master Lectures,* and *Journals in Psychology: A Resource Listing for Authors.*

Other Benefits of Membership: Membership in APA also provides eligibility for low-cost insurance plans covering life, income protection, office overhead, accident protection, health care, hospital indemnity, professional liability, research/academic professional liability, student/school liability, and student health.

For more information, write to American Psychological Association, Membership Services, 750 First Street, NE, Washington, DC 20002-4242, USA