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Syntactic Control of Letter Detection: Evidence From English and Hebrew Nonwords

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According to the unitization account, letters are more often missed in function words (e.g., *the*) than in less common content words because their higher familiarity allows access to their whole-word representations. The present study, however, replicated this pattern with nonwords. For both Hebrew and English, nonwords produced more detection errors when placed in function slots than in content slots. A similar effect was found for Hebrew prefix nonwords, where the initial letter could be interpreted as a function morpheme or as part of the stem. The results were seen as support for a structural model in which function morphemes are initially utilized to define the structural frame of a phrase but recede into the background as meaning is uncovered. Several interactive patterns illuminated the details of frame extraction.

One of the most extensively replicated findings in reading research is that very common function words, such as *the*, *and*, and *of*, tend to conceal their constituent letters (e.g., Corcoran, 1966; Drewnowski & Healy, 1977; Healy, 1976; Healy, Oliver, & McNamara, 1987; Proctor & Healy, 1985; Read, 1983). Thus, when readers search for the letter *t* in running text, they are more likely to miss it in *the* than in less common words, such as *rather*, that contain the same letter string. This phenomenon, termed by Healy (1976) the *missing-letter effect*, served as the basis for a unitization model of reading (see Drewnowski & Healy, 1980; Healy & Drewnowski, 1983). According to this model, readers process text at several levels of analysis in parallel. When a familiar unit is encountered, it affords fast access to the corresponding unitized representation, thus bypassing access to its lower level, constituent units. Hence, *the* has a higher rate of omissions because its familiar orthographic pattern allows direct activation of its unitized whole-word representation, thereby preempting access to its constituent letters.

Several findings are consistent with the unitization model. For example, typographic variations that presumably impede access to whole-word representations were found to reduce the size of the missing-letter effect substantially. Thus, destroying the familiar visual shape of *the* by alternating type case (e.g., Drewnowski & Healy, 1977) or by inserting asterisks or blank spaces between characters in continuous text (Healy, Conboy, & Drewnowski, 1987) improved letter detection for *the* relative to other, less common words. Also, the introduction of misspellings was found to reduce or eliminate the *the* disadvantage (e.g., Healy, 1980; Healy & Drewnowski, 1983; Healy, Fendrich, & Proctor, 1990). These results support a strong version of the unitization account that stresses the familiarity of the visual pattern as such: Familiar orthographic patterns enjoy fast activation of their corresponding unitized representations, so that for these patterns, access to the whole-word entry wins the race over letter-mediated access.

Other findings, however, indicated that the missing-letter effect is also sensitive to linguistic context: Although omission errors on *the* remained inordinately high even when presented in a scrambled word passage, scrambling did reduce the size of the missing-letter effect (Drewnowski & Healy, 1977, 1980; Healy, 1976). In particular, where scrambling destroyed local context (e.g., *the* plus verb), letter detection for *the* was much better than when scrambling retained local context (*the* plus noun). This effect led Drewnowski and Healy (1977) to introduce the notion of phrase unitization. They proposed that familiar phrases may be processed in terms of supraword units that consist either of short syntactic phrases or of word frames such as *on the* __ and *from the* __ (see Healy, Conboy, & Drewnowski, 1987).

Although the missing-letter effect was obtained in comparing letter detection for common and rare nouns (e.g., Healy, 1976), the most dramatic effects have been found with the most frequent words, *the* and *and*. These words are not only highly familiar, but they also assume a specific role in text, and it is not clear that their disadvantage derives from their higher frequency rather than from their linguistic status as function words. For example, subjects may invest little attention in function words because of their greater predictability and redundancy in text (see, e.g., Corcoran, 1966; Krueger, 1989; Schindler, 1978).

Because frequency and function are highly confounded in English, with function words being among the most common

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words (see Haber & Schindler, 1981), a recent study by Koriat, Greenberg, and Goldshmid (1991) undertook to disentangle orthographic frequency and linguistic function by taking advantage of some of the properties of Hebrew. In Hebrew, the function morphemes appear either as very frequent short single words (*el dn*, to Dan), or as single letters prefixed to content words (*ldn*). Although these prefix words were not more frequent, as whole-word patterns, than matched content words, they engendered significantly more detection errors, which suggests that the missing-letter effect depends on morphemic function rather than on orthographic frequency. Furthermore, the difficulty in detecting letters in the prefix words was found to be confined to the letter representing the function prefix and did not extend to the letters belonging to the word stem. This suggests that the missing-letter effect for the Hebrew prefix words is not due to unitization of the word as a whole and that it occurs at a relatively late stage, after the parsing of the word into its constituent morphemes. Additional results suggested that the inordinately high proportion of errors for both Hebrew function prefixes and English function words is also not due to a greater unitization at the phrase level. Finally, results obtained with Hebrew ambiguous words (e.g., *smr*) indicated that where prior context favors interpretation of these words as prefix-plus-stem combinations (*that mister*. . .), omission errors are greater than where context favored their interpretation as unprefixed content words (*kept*). Thus, apparently, the missing-letter effect does not depend entirely upon the frequency of the perceptual unit.

Taken together, these results suggested that the missing-letter effect for common function morphemes is due in some large part to their linguistic role in text rather than to their greater unitization as familiar orthographic patterns. Furthermore, the results suggested that this effect is not due to the perceptual processes leading up to and including lexical access, but occurs at a postlexical, postparsing stage, where accessed representations are integrated into an overall meaning schema (see Rayner & Frazier, 1989). According to a tentative account sketched by Koriat et al. (1991), the missing-letter effect reflects a shift in attention from structure to meaning: In extracting the meaning of text, a sentence frame is constructed, and successive elements are integrated into it. Function units serve as the cornerstones in the construction of this frame, but they fade into the background as the focus shifts from the sentence's structure to its substantive significance.

To push this argument to the extreme, one should be able to demonstrate a missing-letter effect even for a Lewis Carroll, jaberwocky-type sentence, such as *He claked the blonty pinock on dra pnoocked crums*. Although such sentences are composed mostly of nonwords and therefore cannot allow the extraction of articulate meaning representations, they do convey some information regarding the overall syntactic frame of the sentence (see Carr, Brown, & Charalambous, 1989; Epstein, 1961). If the missing-letter effect reflects the transition from structure to meaning, then perhaps it should be found for nonwords as well, with nonwords that support the syntactic frame of the sentence yielding an inordinately large proportion of errors. Thus, in the experiments to be reported below, we sought to determine whether the syntactic structure of a sentence is sufficient to promote a missing-letter effect. In addition, we also explored the effects of several variables in an attempt to uncover the possible contribution of semantic, lexical, and visual factors to the construction of structural frames during reading.

The prediction of a missing-letter effect for nonwords, however, is tempered by findings from studies investigating the effects of misspelling on letter detection (e.g., Healy, 1980; Healy & Drewnowski, 1983; Healy et al., 1990; Proctor & Healy, 1985). In these studies, subjects searching for the letter *t* in passages that contained some misspellings were found to make significantly more errors on *the* than on other correctly spelled words. This effect, however, was reduced or entirely eliminated by the introduction of misspelling (e.g., *thd*). These results clearly suggest that the greater proportion of errors observed for *the* is because of its familiarity rather than because of its role within the structural frame of the phrase.

Despite this discouraging evidence, however, there are two reasons why we explored our idea further. First, most of the misspelling studies have focused on *the*. However, this word is probably less informative regarding the overall structural frame of the sentence than other function words. Therefore, in our first exploratory study (Experiment 1), we chose to focus on the function word *for*. Second, previous misspelling studies were not specifically designed to compare error rates for nonwords occupying different syntactic slots and therefore did not include some of the controls that are necessary for this comparison. For example, the nonwords occupying content locations were more wordlike than those occupying function locations because they were generally longer and therefore more of their orthographic structure was preserved in the misspelling. This difference might have helped conceal a possible function-disadvantage effect for nonwords. Accordingly, the very same nonwords were used in Experiment 1 in both content and function locations.

Experiment 1

In Experiment 1 subjects searched for the letter *f* in a text that contained some nonwords. Two critical nonwords, *fom* and *fol*, were the focus. They were inserted in a passage where the text demanded a function word or where the text demanded a content word. In the function position they always replaced the word *for*, whereas in the content position they substituted for a three-letter content word beginning with *f* (e.g., *fog*). In addition to the nonword targets, the function word *for* and matched content words were also included. This procedure has two advantages. First, because the critical items are nonwords, their role in the sentence is solely determined by the semantic–syntactic context in which they appear. Second, identical items served in both function and content roles, thus the contribution of their sentential role can be assessed by directly comparing error rates for these items in the two roles. Should letter detection be difficult for the nonword in the function location, the effect can be attributed to the acquired role in the sentence. Furthermore, if a missing-letter effect is obtained for the unfamiliar nonwords, this would argue strongly against the unitization position, where this effect is seen to issue from the greater familiarity of function words.

Finally, a comparison between *fom* and *fol* allows us to evaluate the redundancy hypothesis (see Corcoran, 1966; Krueger, 1989; Proctor & Healy, 1985) that subjects skip function words in reading. If such is the case, letter detection would be equally difficult for *fom* and *fol* placed in function slots, though *fom* in lowercase is more visually similar to *for*. Evidence from Haber and Schindler (1981) and Healy and Drewnowski (1983) suggests that the visual similarity between the misspelled word and its parent word may play a role in proofreading and letter detection.

Method

Subjects. Forty Union College students were paid $1 for participating in this experiment.

Stimulus materials. Four paragraphs that contained 42 sentences each were composed. The first and last sentences in each passage were fillers where the target letter *f* did not appear. Each of the remaining 40 sentences contained one critical string. Four types of critical strings were used, each in 10 sentences: *for* (frequency = 9,489 in Kucera & Francis, 1967), a three-letter content word beginning with *f* (Mean frequency = 181.4; e.g., *fog*), *fom*, and *fol*. Each of the critical nonwords, *fom* and *fol*, was placed half the time (5 sentences) in sentence locations where the function word *for* would normally appear (e.g., *The captain called fol his crew*. . .) and half the time in locations where a content word would appear (e.g., *The ship was lost in a fol*. . .). The sentences with the four types of critical strings were distributed evenly across a passage. In addition, the critical string never appeared at the beginning or end of the sentence or line of text, and the target letter never appeared in the words immediately preceding or following the critical word. This was true for Experiment 1 as well as for all experiments reported in this article.

In addition to the critical nonwords, *fom* and *fol*, each sentence also included one nonword that did not contain an *f*. This nonword appeared at least three words apart from the critical string.

Three additional passages that met the aforementioned requirements were derived from a first passage. One passage was created by simply exchanging all instances of *fol* for *fom*, and vice versa. Another passage was generated by trading target nonwords for target words. For example, in sentences where *for* or *fog* had appeared, now either *fol* or *fom* appeared. Meanwhile, sentences that previously exhibited *fol* or *fom* now contained *for* or *fog* (or another appropriate *f*-content word). Obviously, *for* replaced nonwords in function locations, whereas an *f*-content word replaced nonwords in content locations. Finally, another passage resembled the third passage except that again the locations of *fol* and *fom* were exchanged. Thus, across all four passages, each sentence appeared twice with a target word (either *for* or an *f*-content word) in the critical location and once each with each of the two nonwords *fol* and *fom* in that target location. Each passage occupied a single page.

Procedure. Ten subjects each were randomly assigned to one of the four passages. They were instructed to read the passage normally and circle the target letter *f*. They were informed that they would encounter misspelled words and that they should treat them like any other item in the passage.

Results

Table 1 presents mean percentage of omission errors for the function and content words and for the nonwords *fom* and *fol* placed in content and function slots. These means, as well as all means to be reported in the present article, were derived by calculating percentages for each subject and then averaging across subjects.

Table 1
Means and Standard Errors of Percentage of Omission Errors for Function and Content Words and Nonwords in Experiment 1

	Function		Content	
String	*M*	*SE*	*M*	*SE*
Word	51.7	4.5	11.2	2.0
Fom	36.0	4.2	10.0	1.9
Fol	11.5	2.5	4.0	1.6

Clearly, the function-disadvantage effect is most strongly observed for the contrast between *for* and the matched *f*-content words (e.g., *fog*), $F(1, 39) = 97.70$, $p < .0001$. This result replicates the typical missing-letter effect. Of greater interest, however, is the observation that the effect also extends to nonwords, which engendered more omission errors when they appeared in function locations (23.7% across *fol* and *fom* stimuli) than when they appeared in content locations (7.0%), $F(1, 39) = 32.47$, $p < .0001$. Words produced more errors than nonwords, $F(1, 39) = 42.59$, $p < .0001$, and the size of the function-disadvantage effect was stronger for words than for nonwords, as suggested by a Lexicality (word vs. nonword) × Class (content vs. function) interaction, $F(1, 39) = 31.95$, $p < .0001$. Furthermore, a two-way analysis of variance (ANOVA) comparing the function-disadvantage effect for the two nonwords indicated that the visually similar nonword *fom* engendered both a greater rate of omissions, $F(1, 39) = 42.20$, $p < .0001$, as well as a stronger function-disadvantage effect, $F(1, 39) = 19.41$, $p < .0001$, as compared with *fol*. It should be noted, however, that the function-disadvantage effect was significant for both *fom*, $F(1, 39) = 33.63$, $p < .0001$, and *fol*, $F(1, 39) = 9.39$, $p < .005$.

Discussion

The results may be summarized as follows: (a) The usual missing-letter effect was replicated for words, with the function word *for* yielding more omission errors than its matched content words; (b) omission errors overall were less common in *f* nonwords than in *f* words; (c) most important, nonwords yielded a higher error rate when placed in function slots than when placed in content slots; and (d) the size of the function-disadvantage effect was strongest for words, being most pronounced for the comparison between *for* and its matched content words, next strongest for the visually similar nonword *fom*, and weakest for the physically distinct nonword *fol*.

What are the implications of these results concerning the unitization account of the missing-letter effect? First, the observation that the same exact letter string (*fom* or *fol*) concealed its letters to different degrees, depending on its contextual location, indicates that syntactic function affects letter detection even when orthographic frequency is kept constant. This observation is analogous to the finding from the previous study with Hebrew (Koriat et al., 1991; Experiment 4), where the initial letter of the same ambiguous word was missed more often when prior context biased interpretation of the word as a function prefix-plus-stem combination than when it biased its interpretation as an unprefixed content word. Second, the missing-letter effect was demonstrated with nonwords, whose frequency in the language is zero. In fact, omission rate was significantly higher for the nonword *fom*, when this was placed in a function slot (36.0%), than for the presumably more frequent content words (11.2%), $F(1, 39) = 45.51$, $p < .0001$. In our previous study with Hebrew, we also found an inordinately high omission rate for function prefix words, although these were presumably no more frequent than their matched content words. Here, however, we observe that the contribution of function to letter omission, in fact, beats that of frequency.

It has been observed that function words tend to conceal their misspellings better than content words of the same length and that misspellings that maintain the overall shape of the word are less likely to be detected (Haber & Schindler, 1981; Healy & Drewnowski, 1983). Perhaps, then, *fom* and *fol* produce more errors when they are mistakenly read as *for*, thereby preempting processing of their constituent letters. Indeed, Healy and Drewnowski (1983) raised the possibility that the reading units responsible for the missing-letter effect might be response units (e.g., phonological codes) rather than perceptual units. Perhaps, then, the higher omission rate for *fom* than for *fol* is proof that the missing-letter effect for these nonwords depends on their tendency to activate *for*. Experiment 2 was intended to rule out this interpretation of the results of Experiment 1 while extending the evaluation to Hebrew text.

One issue that has been avoided so far concerns the discrepancy between our results and those of previous studies investigating the effects of misspelling on letter detection in *the* and other words. We shall address this issue in Experiments 4 and 5.

Experiment 2

Experiment 2 exploited some of the characteristics of Hebrew to further explore the possibility that the missing-letter effect for function units is contingent on their role in supporting sentential structure. As was detailed in the previous report (Koriat et al., 1991), function morphemes in Hebrew appear either as very frequent short single words (*el dn*, to Dan), or as single letters prefixed to content words (*ldn*). Although these prefix words were not more frequent than matched content words, they were found to engender significantly more detection errors than their matched content words, which suggests that the missing-letter effect depends on morphemic function (Koriat et al., 1991; Experiment 1). In the present experiment we examined whether the function-disadvantage effect is found even when the prefix word is transformed into a nonword. The benefit of using Hebrew is that this transformation can be achieved while keeping intact the initial letter representing the function morpheme. In parallel, content words beginning with the same target letter were also transformed into nonwords, keeping intact their initial letters. The question, then, is whether detecting the initial letter of Hebrew nonwords is more difficult when sentential context biases interpretation towards a function prefix than as part of the stem of a content word. Note that in the Hebrew prefix nonwords used, the stem itself, as well as the entire string (prefix-plus-stem), each constituted a nonword.

Unlike Experiment 1, in which only two nonword strings (*fom* and *fol*) were used, Experiment 2 used a large variety of nonword strings that did not suggest any particularly frequent word (like *for* in Experiment 1).

Method

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

Design. There were four conditions, defined by whether the critical string was a word or a nonword (lexicality) and by whether the sentential frame favored interpretation of the initial letter of that string as a function prefix or as part of a stem (favored interpretation). As in the previous Hebrew experiments (Koriat et al., 1991), four letters served as the target letters—*b, l, m* and *s*. Each represented the initial letter of the corresponding critical string.

Stimulus materials. For each of the target letters *b, l, m* and *s*, 64 experimental sentences were formed, for a total of 256 sentences. Each sentence contained a critical word that displayed the target letter in its initial position. In half of the sentences, the critical word was an unprefixed content word, so that the initial letter was part of the stem (*stem*), whereas in the remaining half the target was a function letter prefixed to a content word (*prefix*). In half of the stem-and-prefix sentences, the critical word was replaced by a nonword that had the same initial letter and the same derivational and inflectional pattern as the parent word. However, the root morpheme was always a nonword. Thus, the syntactic frame of a sentence favored interpretation of the initial letter of the critical nonword, either as a function prefix or as part of the stem morpheme.

In addition, in each of the word sentences, one content word (other than the critical word) was transformed into a nonword, leaving intact affixes. This nonword preceded the critical word in half of the prefix and stem sentences and followed the critical word in the remaining sentences, but at least one word separated the two nonwords.

A note of explanation on the substitution scheme used to create the nonwords is in order. Most words in Hebrew consist of two discontinuous morphemes, a consonantal root and a construction pattern. The majority of Hebrew roots comprise three consonants, but some comprise four consonants. The construction pattern combines (a) a derivational and inflectional affixation (as in English, *ideal–idealization, eat–eating*), with (b) a vowel pattern of the root consonants (somewhat similar to *drive–drove* in English). Thus, in transforming words into nonwords, the consonantal root was replaced by a nonword root. An attempt was made to create a root that bears little similarity either to the parent root or to other legal Hebrew roots. Therefore, in about two thirds of the cases, a three-letter root was replaced by a four-letter root. The construction–affixation pattern of the original word was left intact, as was the initial letter in the case of the critical nonwords. We should note that vowels are normally not explicitly expressed in Hebrew unpointed orthography, so we may only presume that the nonwords were often read according to the vowel pattern of the original word because they mimicked the affixation pattern of the word they replaced (see Koriat, 1984).[1]

In addition to the 256 experimental sentences, 112 filler sentences were formed, half of which contained two nonwords, whereas the

Table 2
Means and Standard Errors of Percentage of Omission Errors for Prefix-Favored and Stem-Favored Interpretations of Initial Letter of Words and Nonwords in Experiment 2

	Words				Nonwords			
	Prefix		Stem		Prefix		Stem	
Target letter	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
b	26.8	3.3	9.9	1.8	27.7	3.4	8.2	1.5
l	13.0	1.8	9.5	1.6	6.4	1.3	2.9	0.7
m	22.9	2.8	9.5	1.6	21.9	3.0	5.3	1.0
s	9.5	2.0	2.1	0.6	6.1	1.7	1.3	0.6
All	18.1	2.0	7.7	1.1	15.5	1.9	4.4	0.7

other half contained none. These were included so that subjects would not expect a particular number of nonwords in each sentence.

The 64 experimental sentences corresponding to each target letter were distributed across four different pages in a booklet, with each page containing 16 sentences, 4 of each Lexicality × Favored Interpretation combination. Each page also included 7 filler sentences, 3 placed at the beginning of the page, and 4 evenly distributed throughout the page. In this experiment and all that follow, the order of the experimental sentences on a page was random, and a page appeared as one long paragraph of unrelated sentences, with a period at the end of each sentence.

In total, booklets contained 2 practice pages, followed by the 16 experimental pages, arranged in four blocks of 4 pages each. Within a block, 1 page was devoted to each target letter. The order of the four targets remained the same across the four blocks but was counterbalanced across subjects.

Procedure. Subjects were told to read passages at their normal reading speed but to circle the designated target letter whenever they came to it. The target letter was displayed at the top of each page. Further, subjects 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, using the target letter *cheth* (not included in the experiment).

It should be noted that the letter *m* has two different forms in Hebrew, according to whether it occupies a terminal or a nonterminal position, and subjects were told to circle only the nonterminal form.

Results

Table 2 presents mean percentage of omissions for prefix-favored and stem-favored interpretations of word and nonword strings.

A two-way ANOVA, Lexicality (words vs. nonwords) × Favored Interpretation (prefix vs. stem), yielded $F(1, 47) = 15.93$, $p < .001$, for lexicality, $F(1, 47) = 61.03$, $p < .0001$, for favored interpretation, and $F < 1$ for the interaction. The prefix interpretation induced more errors overall (16.8%) than the stem interpretation (6.1%). Omission rate was higher for words (12.9%) than for nonwords (10.0%), but the function-disadvantage effect was highly significant for both types of strings, $F(1, 47) = 52.97$, $p < .0001$, for words, and $F(1, 47) = 52.55$, $p < .0001$, for nonwords.

As in the previous study (Koriat et al., 1991), the four target letters differed markedly in mean error rate, $F(3, 141) = 35.40$, $p < .0001$, as well as in the size of the function-disadvantage effect, $F(3, 141) = 27.24$, $p < .0001$, with the letters *b* and *m* yielding more errors and a stronger function disadvantage than the letters *l* and *s*. However, the function-disadvantage effect was significant for each of the letters. Thus, two-way ANOVAs, Lexicality × Favored Interpretation, yielded significantly higher error rates for the prefix-favored interpretation for the letters *b*, $p < .0001$, *l*, $p < .005$, *m*, $p < .0001$, and *s*, $p < .001$. For all letters there was a greater difficulty in detecting target letters in words than in nonwords, but this effect reached significance only for the letters *l*, $p < .0001$, and *s*, $p < .005$. For none of the letters was the interaction significant.

An analysis of the critical word strings yielded a function disadvantage for each of the four letters, *b*, $F(1, 47) = 36.94$, $p < .0001$, *l*, $F(1, 47) = 4.64$, $p < .05$, *m*, $F(1, 47) = 39.96$, $p < .0001$, and *s*, $F(1, 47) = 15.96$, $p < .001$. It is important to note that this effect held as well for an analysis of the critical nonword strings for each of the four letters, *b*, $F(1, 47) = 55.18$, $p < .0001$, *l*, $F(1, 47) = 8.72$, $p < .005$, *m*, $F(1, 47) = 37.51$, $p < .0001$, and *s*, $F(1, 47) = 7.43$, $p < .01$.

Discussion

The results of Experiment 2 yielded unequivocal support for the hypothesis that the greater rate of omission errors observed for function morphemes in Hebrew derives from their specific role in the sentence rather than from factors that have to do with orthographic familiarity. As in the previous study (Koriat et al., 1991), percentage of omission errors was significantly higher for the initial letter of words when the letter represented a function prefix than when it was part of the stem of a content word. By itself, this result is inconsistent with the unitization account because the Hebrew prefix words as whole-word patterns are apparently no more frequent than

[1] A note on the critical content words used: In the absence of adequate frequency norms in Hebrew, some information regarding the relative frequency of these words might be gained by reference to Balgur (1968), which lists the frequency of Hebrew words in the reading materials of elementary school children on the basis of a sample of about 200,000 words. Of the critical content words used in Experiment 2 (after stripping the prefix letter, if any), 85% were listed in this corpus, and 52% of these had a frequency of 100 per million or more. Although some of the words used were not listed in the elementary school norms, none of these would be considered rare among students by any standards.

their matched content words. However, the key outcome of Experiment 2 is the additional finding that the function-disadvantage effect was obtained to the same extent with nonwords. Thus, even when the orthographic string was novel and unfamiliar, more omission errors were found when that string appeared in a sentential slot normally occupied by a function-prefix-plus-stem combination than when it appeared in a slot calling for an unprefixed content word.

These results argue against the unitization account of the missing-letter effect in terms of the greater familiarity of function words. Rather, the nonword results indicate that it is the syntactic role in text that is primarily responsible for the greater rate of omission errors found for function morphemes. Furthermore, it appears that the size of this effect is not stronger for familiar than for unfamiliar letter strings.

Taken together, the results of Experiments 1 and 2 provide further support for the proposition that the missing-letter effect is intimately linked to the overall structural frame of the sentence. Presumably, this effect is symptomatic of the process whereby elements that support the overall structural frame of a sentence or a phrase recede to the background as attention shifts from structure to meaning. The interesting result of Experiment 2 is that this effect occurs even when the function morpheme constitutes a single letter that is appended as a prefix to a word or a nonword. This result implies that the effect occurs at a rather late stage in the process, after the entire orthographic string has been parsed into its likely constituent morphemes. A similar conclusion is suggested by the finding of Drewnowski and Healy (1980) that subjects make more detection errors in the trigram *ing* when it constitutes a suffix morpheme (e.g., *walking*) than when it is part of the stem (e.g., *something*). The results of the present study further suggest that such parsing occurs even for nonwords, where each nonword is parsed into one or more legal morphemes and an illegal root. Once such parsing has taken place, the letters that support the structural frame (e.g., the prefix letters in the critical words and nonwords) tend then to recede to the background in favor of the semantically informative elements.

Finally, the nonwords in Experiment 2 were not visually similar to high-frequency Hebrew words, and so the high error rate obtained with the prefix nonwords could not arise from mistaking them for familiar words.

Experiment 3

The first aim of Experiment 3 was to extend the results of the previous experiment to Hebrew function words. Although both Experiment 1 and 2 yielded consistent support for the function-disadvantage hypothesis, the exact pattern of the results differed across the two experiments. Notably, error rate was considerably higher for *for* in Experiment 1 than for the Hebrew prefix words in Experiment 2, resulting in a significant Lexicality × Syntactic Slot interaction in Experiment 1 but not in Experiment 2. These results suggest the possibility that the relative contribution of syntactic and lexical factors differs in the two languages. Whereas syntactic status affects detection errors in both languages, lexicality appears to play an important role in English but much less so in Hebrew. In fact, in previous studies with English, even minor misspellings were found to eliminate the missing-letter effect entirely (e.g., Healy & Drewnowski, 1983), whereas in the Hebrew strings of Experiment 2, this effect appears to be entirely immune to much stronger impairment of lexicality. Thus, perhaps the determinants of the missing-letter effect differ for the two languages.

Alternatively, the discrepancy between the results of the two experiments may be attributed to the nature of the targets studied: Whereas Experiment 1 focused on function words, Experiment 2 focused on function prefixes. Function words and function prefixes differ in two ways. First, function prefixes are clearly less frequent than function words (in fact, they are less frequent than the corresponding unprefixed content words). Perhaps, then, orthographic frequency also contributes to the missing-letter effect by modulating the effects of syntactic role.

A second difference that is more pertinent to the structural account is that in the case of the Hebrew prefix strings, contextual information is critical in constraining parsing and interpretation of the initial letter as a function morpheme, and this is generally true for both prefix words and prefix nonwords (but see Experiment 4). The same also holds for the English nonwords of Experiment 1 (e.g., *fom*), whose syntactic status is revealed only by their sentential context. Such is not the case with function words, whose syntactic function may be determined on the basis of lexical information. This may explain why the function-disadvantage effect was stronger for words than for nonwords in Experiment 1 but not in Experiment 2.

Experiment 3 used the Hebrew function words corresponding to the function prefixes employed in Experiment 2. These allowed us to determine whether the discrepancy between the results of Experiments 1 and 2 is due to language differences or to the nature of the targets used. If Hebrew function words are found to produce a stronger function-disadvantage effect than their matched function nonwords, this would rule out language differences as an explanatory factor. The design was similar to that of Experiment 2, conforming to a 2 × 2, Lexicality × Favored interpretation factorial.

The second aim of Experiment 3 was to pit the effects of orthographic familiarity and syntactic function against each other. For this purpose, two conflict conditions were added. In the first, a function word in a sentence was replaced by a matched content word, whereas in the second, a content word was replaced by a function word. If word familiarity affects letter detection, function words should yield a relatively high proportion of errors even when placed in content slots. Thus, altogether, the design of Experiment 3 conformed to a 2 × 3, Syntactic Slot (content or function) × String (content word, function word, or nonword) factorial.

Method

Subjects. Thirty-six University of Haifa students whose native language was Hebrew participated in the study, 34 for pay and 2 for course credit. None had participated in Experiment 2.

Stimulus materials. Four Hebrew function words were used (see Koriat et al., 1991), *betoch, el, min,* and *asher.* In Hebrew unpointed orthography, these are spelled as *btoc*, *el*, *mn*, and *asr*, and thus contained the target letters *b*, *l*, *m*, and *s*, respectively. For each function word, 24 sentences were constructed. Twenty-four additional sentences were used in which the critical word was a content word. The critical content word consisted of the same number of letters as the corresponding function word and represented the target letter in the same position as the function word. Half of the sentences in each group were transformed into nonword sentences by replacing the critical word with a nonword. For all function words except for *btoc*, this was done by changing one and only one letter other than the target letter. In this manner, the nonword differed in only one letter from both the corresponding function word and the corresponding content word. However, the word *btoc* did not allow a sufficient number of content words to be formed by changing a single letter, and therefore in most cases the corresponding nonwords and content words differed from it in two letters. Because it was not possible to find 12 different content words (for each of the 4 function words) that satisfied the constraints described above, some of the critical content words had to be repeated across different sentences, in which case the corresponding nonword was also repeated. Each pair of sentences representing the same level of lexicality were matched for number of words and for the ordinal position of the critical string within the sentence.

To construct the conflict sentences, the following procedure was used. First, for each of the target letters, 12 function and 12 matched content sentences were composed. The function sentences contained the particular function word associated with the target letter (e.g., *btoc* for *b*), whereas the content word sentences contained a critical content word that had the same number of letters as the corresponding function words and differed from it in only one letter other than the target letter (except for the content words matched to *btoc*, which could differ by up to two letters). Also, each pair of matched function and content sentences contained the same number of words and represented the critical word in the same ordinal position. Then the critical function and content words in each pair of matched sentences were exchanged for each other, which resulted in two types of sentences, those in which a function slot is occupied by a content word and those in which a content slot is occupied by a function word.

As in Experiment 2, one content word (other than the critical word) in each of the word sentences was transformed into a nonword, leaving intact affixes. Also, there were 112 filler sentences, half of which contained two nonwords, whereas the other half contained none.

The 72 experimental sentences corresponding to each target letter were randomly distributed across three different pages in a booklet so that on each page appeared 24 experimental sentences, 4 of each of the six Slot × String sentence types. Each page also included 7 filler sentences, 3 of which were placed at the beginning of the page, whereas the remaining 4 sentences were evenly distributed throughout the page.

In total, booklets contained 1 practice page, followed by the 12 experimental pages, arranged in three blocks of 4 pages each. Within a block, 1 page was devoted to each target letter. The order of the four targets remained the same across the three blocks but was counterbalanced across subjects.

Procedure. The procedure was similar to that of Experiment 2.

Results

Table 3 presents mean percentage of errors as a function of syntactic slot (content or function) and type of string (content, function, and nonword).

A String × Slot ANOVA for the data of Table 3 yielded $F(2, 70) = 31.27$, $p < .0001$, for string, $F(1, 35) = 41.77$, $p < .0001$, for slot, and $F(2, 70) = 24.82$, $p < .0001$, for the interaction. It may be seen that the expected effect of syntactic slot was obtained for both function words and nonwords but not for content words. The highest error rate was found for function words placed in their proper location (23.1%). This rate was significantly higher than that of content words placed in their proper context (10.6%), $F(1, 35) = 37.99$, $p < .0001$, replicating the typical missing-letter effect. Placing a function word in a content slot reduced its error rate markedly (to 12.3%), $F(1, 35) = 51.35$, $p < .0001$. In contrast, the error rate for content words was low and did not differ as a function of syntactic slot, $F(1, 35) = 2.92$, *ns*. Note that the error rate for function words placed in content slots was significantly higher than that of content words placed in function slots, $F(1, 35) = 6.75$, $p < .05$.

Table 3
Means and Standard Errors of Percentage of Omission Errors as a Function of Syntactic Slot and Type of String in Experiment 3

	Content		Function		All	
String	*M*	*SE*	*M*	*SE*	*M*	*SE*
Content	10.6	1.7	8.8	1.7	9.7	1.6
Function	12.3	2.3	23.1	3.0	17.7	2.6
Nonword	6.4	1.2	10.9	1.8	8.7	1.4
All	9.8	1.6	14.3	2.0	12.0	1.8

Of particular interest are the results for nonwords. Error rates for nonwords were generally low, consistent with the previous experiments. Nevertheless, nonwords placed in function slots produced a significantly higher percentage of errors than those placed in content slots, $F(1, 35) = 15.65$, $p < .0005$. Ignoring the conflict conditions, a Lexicality × Slot ANOVA yielded $F(1, 35) = 12.81$, $p < .001$, for the interaction, indicating that the function-disadvantage effect was more pronounced for words than for nonwords.

The results reported above were obtained rather consistently across the four target letters used. Thus, the reduction in error rate for function words placed in content (as opposed to function) locations was significant for each of the target letters, *b*, $F(1, 35) = 14.91$, $p < .0005$, *l*, $F = 13.45$, $p < .001$, *m*, $F = 46.87$, $p < .0001$, and *s*, $F = 11.36$, $p < .005$. The failure to find slot effects for content words was also observed across all four target letters. Finally, the function-disadvantage effect for nonwords was noted for each of the target letters: Mean percentage of errors for nonwords placed in content and function slots, respectively, was 11.8% and 20.6% for the letter *b*, 7.9% and 11.6% for the letter *l*, 4.2% and 9.0% for the letter *m*, and 1.9% and 2.3% for the letter *s*. The effect was significant only for the letters *b*, $F(1, 35) = 11.15$, $p < .005$, and *m*, $F = 9.58$, $p < .005$, and near significant for *l*, $F = 3.51$, $p < .07$.

Discussion

The results of Experiment 3 are consistent with those of Experiments 1 and 2 in demonstrating a function-disadvantage effect for nonwords. This effect, however, was smaller than that observed in Experiment 2, which employed the same function morphemes and the same target letters. Furthermore, whereas in the two Hebrew experiments, nonwords produced fewer detection errors than words, only Experiment 3 yielded a clear Lexicality × Slot interaction (when the conflict sentences were excluded), indicating a stronger function disadvantage for words than for nonwords. This pattern is similar to that found in Experiment 1 with English. These results suggest that the discrepancy between the results of Experiments 1 and 2 does not reflect language differences but is probably due to the nature of the target stimuli used: The function-disadvantage effect is stronger for words than for nonwords only when the function morpheme constitutes an independent orthographic unit (Experiments 1 and 3) but not when it constitutes a prefix.

This pattern of results may be taken to indicate that word frequency contributes interactively to the missing-letter effect, resulting in the inordinately high proportion of errors for the very common function words in both English and Hebrew. Alternatively, it may reflect the interplay between lexical and contextual factors in helping the identification of function units and the establishment of structural frames. We shall delay discussion of these alternative interpretations to the General Discussion section.

The unique, conflict conditions included in Experiment 3 yielded unexpected results: Placing a function word in a content slot reduced error rate markedly, whereas placing a content word in a function slot had little effect. Because this pattern of results was also replicated in Experiment 5, we shall delay its discussion until the results of that experiment have been presented.

Experiment 4

The results of Experiments 1–3 here contrast with those reported earlier in studies investigating the effects of misspelling on *the* as opposed to content words (Cunningham, Healy, Kanengiser, Chizzick, & Willitts, 1988; Healy, 1980; Healy & Drewnowski, 1983; Healy et al., 1990; Proctor & Healy, 1985). To illustrate, in Healy and Drewnowski's study (1983; Experiment 1), subjects searching for the letter *t* in passages that contained some misspellings were found to make many more errors on *the* (48.9%) than on content words (7.8%). However, this effect was entirely eliminated by the introduction of misspelling, which resulted in 1.1% errors for both *the* and other misspelled words. This interactive pattern was consistently obtained across a large number of experiments. One exception is the observation of Healy and Drewnowski (1983; Experiment 2) that the *the* disadvantage did survive certain types of misspellings. Specifically, substituting *n* for *h* (in lowercase) yielded 22.9% and 7.6% detection errors in misspelled *the* and content words, respectively. A similar pattern was also found in uppercase, when *n* was substituted for *h*, and when *f* was substituted for *e*. Mostly, however, the previous results for *the* seem to differ markedly from those obtained for *for* in Experiment 1 and for the four Hebrew function prefixes and function words in Experiments 2 and 3.

Two possible explanations for this discrepancy may be offered. The first attributes the differences to the specific function words used. The present study included the function morphemes *for, to, in, from,* and *that* or *who,* as opposed to most previous letter detection experiments, which employed the common determiner *the.* As was indicated earlier, perhaps *the* is not as informative regarding the overall structural frame of the sentence or phrase as are the other function words. If such is the case, then the higher error rate observed for *the* must be caused by different processes than those underlying letter detection in the other function words studied. An alternative explanation is that because the previous misspelling studies were not designed to test the effects of syntactic slots for misspelled words, the strings occupying function and content slots were not equated on some of the potentially influential factors, such as length and overall visual similarity to the parent word.

Experiments 4 and 5 investigated these possibilities by focusing on the definite article slot in Hebrew (Experiment 4) and English (Experiment 5). The procedure was similar to that of the preceding experiments. Special care was taken to control for the number of letters in the critical strings, and in Experiment 5, also for the overall visual similarity between the nonwords and their corresponding content and function words. Experiment 4 examined the definite article in Hebrew. This has only one form: It is expressed by a single letter (*h*) that is always appended as a prefix to the defined noun. Experiment 4 was therefore similar in design to Experiment 2, using a 2 × 2, Lexicality (word vs. nonword) × Favored Interpretation (function vs. stem) factorial. The results for words will establish whether the well-replicated missing-letter effect for *the* is also obtained for the corresponding Hebrew prefix. The results for nonwords may help determine whether this effect derives from the role of the definite article in the sentence, as is apparently the case for the other function prefixes used in the previous experiments.

We should note that in addition to single-prefix words and nonwords, multiprefix words and nonwords were also employed. In Hebrew, several different morphemes can be strung together in front of a stem. In the multiprefix units, *h* (*the*) is pushed closest to the stem so that it will not always appear in the initial position. The multiprefix strings were included to test the possibility that some function morphemes (e.g., *the* in English) tend to be processed in terms of word frames that also include the preceding morpheme (see Healy, Conboy, & Drewnowski, 1987). However, the results for multiprefix strings were not salient to the present issues and will not be reported here.

Method

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

Design. The design of the experiment called for four conditions defined by 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 focus of the experiment concerned the condition in which the prefix letter *h* appeared as the initial single prefix or as the initial letter of a content word. This part included 48 sentences. In the remaining 112 matched sentences, the target letter appeared in the second, third, or fourth positions of the critical string, and when interpreted as a prefix, it was always that last prefix in an ensemble of two to four prefixes.

Stimulus materials. For the single-prefix sentences, 16 sets of four Hebrew sentences were composed, in which 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. Also, the two word sentences and the two nonword sentences in each set of four were matched for the number of words and for the ordinal position of the critical string within the sentence. Of the critical words used (after stripping the prefix, if any), 50% were listed in Balgur (1968) with a frequency of 100 or more in a million. (Thirteen percent were not listed in this corpus, though none of them was actually rare.) The critical strings in the nonword sentences were derived by using the same substitution scheme as in Experiment 2: 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 mentioned above. This 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.

For the multiprefix part of the experiment, 28 additional sets of four sentences each were constructed according to the same procedure. The only difference was that the target letter now occupied either the second, the third, or the fourth position.

The experimental sentences were assigned to four blocks containing 44 sentences each, so that each block included 11 sentences of each Lexicality × Favored Interpretation combination, 1 of every set of 4 matched sentences. Each block required two pages of text. Each page also included 3 filler sentences that were placed at the beginning of the page.

Procedure. The instructions and procedure were similar to those of Experiment 2. The order of the blocks was counterbalanced across subjects.

Results

Table 4 presents means and standard errors of percentage of omissions for prefix-favored and stem-favored interpretations of words and nonwords.

A two-way ANOVA, Lexicality (words vs. nonwords) × Favored Interpretation (prefix vs. stem) for these strings yielded $F(1, 31) = 18.94$, $p < .0001$, for lexicality, $F(1, 31) = 37.53$, $p < .0001$, for favored interpretation, and $F(1, 31) = 3.86$, $p < .10$, for the interaction. The prefix interpretation induced a higher miss rate overall (17.5%) than the stem interpretation (4.1%). Omission rate was higher for words (13.9%) than for nonwords (7.7%), but importantly, the function-disadvantage effect 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.

A further analysis proved instructive. As noted by Healy, Conboy, & Drewnowski (1987), the word *the* in English tends to appear often in the context of frequent word sequences, such as *from the* and *to the* (see Umeda & Kahn, 1982). Therefore, the occurrence of *the* can be predicted from some of its preceding words. This situation is even more acute in Hebrew, where a special, semantically redundant function word (*et*) is inserted before the definite article to signify an accusative case. Thus, *left the kibbutz* would be translated as azav *et h*kibbutz. To investigate the role of preceding words, a post hoc analysis was carried out, in which all sentences, including critical single-prefix letter strings, were classified into three categories: those where the string was preceded by *et*, those where it was preceded by some other function word (*on, in, that, all*, etc.), and those where it was preceded by other words. The number of word sentences included in each category was two, five, and nine, respectively. The respective frequencies for the nonword sentences were two, five, and eight, respectively.

Table 4
Means and Standard Errors of Percentages of Omission Errors for Prefix-Favored and Stem-Favored Interpretations of Letter H in Words and Nonwords (Experiment 4)

	Prefix		Stem	
Lexical status	*M*	*SE*	*M*	*SE*
Words	22.1	3.3	5.7	1.2
Nonwords	12.9	2.6	2.5	0.9

Table 5 presents the percentages of errors for the six types of function sentences. Although each of the six means was significantly higher than the mean for their respective stem strings (which was 5.7% for words and 2.5% for nonwords; see Table 4), the results clearly suggest that prior context interacts with lexicality in these sentences. For word stimuli, letter detection remained difficult, regardless of the type of preceding word. In contrast, the missing-letter effect for nonwords is clearly reduced in the absence of a local context that supports the prefix interpretation (i.e., other). In fact, for the *et* and function sentences, the missing-letter effect was equally pronounced for words and for nonwords. Thus, separate two-way ANOVAs, Lexicality × Favored Interpretation, for the *et* and function sentences yielded significant effects for favored interpretation, $F(1, 31) = 13.38$, $p < .001$, and $F(1, 31) = 22.85$, $p < .0001$, respectively, but no significant effects for lexicality or the interaction. In contrast, a similar ANOVA for the other sentences yielded $F(1, 31) = 34.54$, $p < .0001$, for favored interpretation, $F(1, 31) = 31.99$, $p < .0001$, for lexicality, and $F(1, 31) = 11.57$, $p < .005$, for the interaction.

Thus, when prior local context supported the prefix interpretation, there was little difference between words and nonwords in the extent of the missing-letter effect. However, in the absence of a biasing local context, prefix words produced, in fact, more detection errors than did prefix nonwords, $F(1, 31) = 18.71$, $p < .0001$. Note, however, that even the prefix nonwords in the other condition yielded a significantly higher error rate than did the respective stem nonwords, $F(1, 31) = 9.85$, $p < .005$.

Discussion

Experiment 4 yielded a pattern of results that closely matched that found in Experiment 2 (i.e., a function-disad-

Table 5
Means and Standard Errors of Percentages of Omission Errors for Prefix-Favored Interpretations of Letter H in Single-Prefix Words and Nonwords

	Preceding Word					
	Et		Function		Other	
Lexicality	*M*	*SE*	*M*	*SE*	*M*	*SE*
Words	23.4	5.9	16.9	3.5	24.7	4.0
Nonwords	18.8	5.4	16.7	4.3	8.6	2.0
All	21.1	4.0	16.8	2.7	16.6	2.5

Note. The results are presented separately, according to type of preceding word in Experiment 4.

vantage effect was found for both words and nonwords). Thus, it would seem that the sentential slot that normally houses a definite article morpheme is associated with an inordinately high proportion of errors, as are the slots normally occupying such function morphemes as *for, in, to, from,* and *that* or *who.* These results suggest that, at least for Hebrew (but see Experiment 5), similar processes are responsible for the high proportion of errors in *the* as compared with other function words. These results are in disagreement with those reported in English for detection errors in misspelled *the* as compared with other, content words, but we will delay discussing this discrepancy until the results of Experiment 5 have been reported. Additionally, because the definite article in Hebrew is represented by a prefix, the results of Experiment 4 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 interpreted as a definite article.

Some clue as to the mechanism by which lexical and syntactic factors affect letter detection is provided by the effects of prior context on the missing-letter effect. It seems that the missing-letter effect for nonwords depends to a large extent on the presence of an appropriate local context that biases interpretation of the nonword as a prefix-plus-stem combination. Such context is less critical for prefix words, for which access to lexical units can facilitate parsing. Thus, either contextual constraints or lexical factors can induce the parsing of a letter string into its constituent morphemes. Once a letter has been identified as representing a function morpheme, it becomes subject to the missing-letter effect.

Note that in the nonword sentences the grammatical class of the nonword could be inferred from its location in the sentence as a whole. Nevertheless, it was the immediately preceding context that was critical for producing the function-disadvantage effect for nonwords. Indeed, Healy, Oliver, and McNamara (1987) also found that it takes only a function word and a second related word to produce the missing-letter effect.

Experiment 5

Experiment 5 sought to extend the results of Experiment 4 to the English definite article *the.* As previously noted, the results of the present study are in disagreement with those of past work on the missing-letter effect for *the* and misspelled *the.* Experiment 5 sought to establish a missing-letter effect for misspelled *the* under conditions that impose a tighter control over string length and the overall similarity between the misspelled words and the parent words. The design of the experiment was similar to that of Experiment 3 and included six conditions representing all Slot (function and content) × String (function word, content word, and nonword) combinations. Also, like Experiment 1, Experiment 5 included a manipulation of the overall similarity between the nonwords and the respective parent words.

Method

Subjects. Forty-four Union College students participated in the study.

Design. Two target letters were used, *t* and *e.* As in Experiment 3, the design for each target letter conformed to a 3 × 2 factorial, Type of String (function word, content word, or nonword) × Syntactic Slot (function or content). The function string was always *the*, whereas the matched content words and nonwords were three-letter strings. These were placed either in a sentential slot that is normally occupied by *the* (function slot) or in a slot that is normally occupied by a matching three-letter content word (content slot). In addition, the nonwords were selected so that in half of the cases they had the same overall visual shape as the word they replaced, and in the remaining half they had a different shape.

Stimulus materials. For each target letter (*t* or *e*), 12 matched sets of six sentences were constructed, each containing one critical string. Four critical strings were used across the six sentences, the function word *the*, its yoked content word, and their matched nonwords. All critical strings contained three letters and represented the target letter in the initial position (for *t*) or in the final position (for *e*). The yoked content word differed from *the* in one or two letters, whereas each of the two matched nonwords differed from *the* and the content word by only one letter (e.g., *the–ths, two–twm*). The four words were used to build six sentences by constructing three sentences that housed the critical word *the* and three others that were constructed around the corresponding critical content word (e.g., *two*). Two of these sentences, word–content, and word–function were used in normal text form. The two conflict sentences were formed by exchanging the critical content word for *the*, and vice versa. In the two remaining sentences, the critical word was replaced by its matched nonword. Every appearance of *the* or its matched nonwords was preceded by a preposition.

Half of the sets used to derive the six sentences for each target letter employed nonwords with the same overall visual shape as their matched words (e.g., *the–ths, two–twm*), whereas in the remaining sets they had different shapes (*the–tpe, tie–tke*). Visual similarity was defined in terms of the pattern of ascenders and descenders (see Healy & Drewnowski, 1983).

In addition, 156 filler sentences were formed, one third of which contained two nonwords, one third of which contained one nonword, and one third of which contained none. These were included so that subjects would not expect exactly one nonword in each sentence.

The 72 experimental sentences corresponding to each target letter were distributed across six different pages in a booklet, so that on each page appeared 12 experimental sentences, one of each of the six sentence constructions, in both the same-shape and the different-shape conditions. On each page, 12 filler sentences alternated with 12 experimental sentences starting and ending with a filler sentence, but with 2 consecutive experimental sentences appearing somewhere midpassage.

Booklets contained 12 experimental pages, arranged in two blocks of 6 pages each. Each block was devoted to a different target letter (*t* or *e*) and was preceded by an additional page that was used for practice. The order of the two targets was counterbalanced across subjects.

Procedure. The procedure and instructions were similar to those of Experiment 1.

Results

Table 6 presents mean percentage of errors as a function of syntactic slot (content or function) and type of string (content, function [*the*], or nonword). The results are presented for both target letters, *t* and *e*.

A preliminary three-way ANOVA, String × Slot × Letter, indicated a higher percentage of errors for the target letter *e* than for the target letter *t*, $F(1, 43) = 10.73$, $p < .005$, and a somewhat stronger effect of syntactic slot for *e* than for *t*, $F(1, 43) = 7.05$, $p < .05$. Aside from these effects, however, the results for the two target letters were quite similar and will be pooled together in the following analyses. Across both target letters, very significant effects were found for string, $F(2, 86) = 209.83$, $p < .0001$, slot, $F(1, 43) = 177.07$, $p < .0001$, and their interaction, $F(2, 86) = 155.36$, $p < .0001$.

From the results of Table 6, it may be seen that the expected effects of syntactic frame were obtained for both *the* and nonwords but not for content words. The highest error rate was found for *the* placed in its proper context (67.7%), and this was significantly higher than that of content words placed in their proper context (9.2%), $F(1, 43) = 276.91$, $p < .0001$, thus replicating the typical missing-letter effect. Placing *the* in a content slot reduced error rate markedly (to 26.6%), $F(1, 43) = 242.47$, $p < .0001$, though this rate was still significantly higher than that observed for content words placed in *the* slots, $F(1, 43) = 57.83$, $p < .0001$. However, the placement of content words in the two types of slots had little effect, $F(1, 43) = 2.65$, *ns*. Taken at their face value, these results suggest that both lexical and syntactic factors influence letter detection, with the former exercising a somewhat more powerful effect.

Of greater importance are the results for nonwords. These were found to produce a markedly lower error rate, consistent with previous findings. Nevertheless, nonwords placed in *the* slots produced a significantly higher percentage of errors than those placed in content slots, $F(1, 43) = 13.52$, $p < .001$.

Recall that half of the nonwords in each slot condition had the same overall shape as the word they replaced, and half had a different shape. A two-way ANOVA, Slot (*the* vs. content) × Shape (same vs. different) indicated a higher percentage of errors for same-shape (12.3%) than for different-shape nonwords (5.4%), $F(1, 43) = 30.30$, $p < .0001$, and a Slot × Shape interaction, $F(1, 43) = 12.07$, $p < .005$. For same-shape strings, percentage of errors averaged 7.0% for content slots and 17.6% for function slots, $F(1, 43) = 16.24$, $p < .0005$. The respective means for different-shape strings were 4.7% and 6.1%, respectively, $F < 1$. Thus, the function-disadvantage effect was mainly obtained for same-shape nonwords.

Discussion

The results of Experiment 5 yielded a remarkably similar pattern to that found in Experiment 3. This was the case even though Experiment 5 focused on the definite article in English, whereas Experiment 3 was based on other function words. Most important, both experiments yielded a similar function-disadvantage effect for nonwords. Consistent with Experiments 1 and 3, the function-disadvantage effect was less pronounced for nonwords than for the corresponding words. Also, as in Experiment 1, the function-disadvantage effect for nonwords varied with the overall visual similarity between the nonwords and the respective parent words. In fact, it was obtained only for nonwords that retained the visual shape of *the*.

As for the word stimuli, these yielded an interactive pattern similar to that found in Experiment 3: Placing function words in content slots reduced error rate markedly, whereas placing content words in function slots did not increase error rate. However, error rate for function words remained higher than that typical of content words even when these were placed in slots that were syntactically inappropriate.

General Discussion

The present study examined the syntactic control of letter detection. It was proposed that function morphemes are utilized in the initial stages of text processing to define the structural frame of the phrase but recede to the background as meaning unfolds. Therefore, function units should engen-

Table 6
Means and Standard Errors of Percentage of Omission Errors as a Function of Syntactic Slot and Type of String for Target Letters T and E in Experiment 5

	T				*E*				All			
	Content		Function		Content		Function		Content		Function	
String	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Content	8.1	1.6	5.1	1.4	10.2	1.4	10.0	1.8	9.2	1.3	7.6	1.3
Function	24.6	3.4	62.7	4.5	28.6	3.7	72.7	4.3	26.6	3.0	67.7	3.9
Nonword	4.0	1.0	8.5	1.6	7.8	2.0	15.2	2.8	5.9	1.2	11.8	1.9
All	12.2	1.7	25.4	2.1	15.5	1.9	32.6	2.4	13.9	1.6	29.0	2.0

der more detection errors than content units. The evidence pertaining to the function-disadvantage hypothesis can be summarized as follows: Function words yielded a higher percentage of errors than content words when both appeared in their normal sentential locations. This was true in Experiments 1 and 5, which used the English function words *for* and *the*, and in Experiment 3, which used four different Hebrew function words. These results replicate the typical missing-letter effect, which has been amply documented in previous work. Because function words are among the most frequent words in both English and Hebrew, it is not clear how much of this effect is due to their linguistic function and how much is due to their greater familiarity. However, a similar function-disadvantage effect was also clearly observed in Experiments 2 and 4, which used Hebrew prefix words that are not necessarily of high frequency when viewed as whole-word patterns. These latter results replicated our earlier findings (Koriat et al., 1991) and suggest that independent of frequency, the syntactic role in text also affects letter detection.

This conclusion receives additional support from the finding of a function-disadvantage effect even for novel and unfamiliar nonwords. Thus, whereas in all of the five experiments the error rate was smaller for nonwords than for words, nonwords yielded consistently more errors when placed in a function slot than when placed in a content slot. This was also true for the determiner (*the*) in both English and Hebrew. Most impressive were the results of Experiments 2 and 4, which used Hebrew function prefixes: The initial letter of a nonword was more likely to be missed when context favored its interpretation as a function prefix rather than as part of the stem of a content word. These findings suggest that the effects of syntactic role occur at a postparsing stage.

The effects of syntactic location on letter detection cannot be readily explained in terms of the processes that were postulated by either the attention–redundancy account or by the unitization account of the missing-letter effect. The attention account (see, e.g., Corcoran, 1966; Schindler, 1978) places the locus of the missing-letter effect for function words at a prelexical stage, whereas sentential redundancy permits readers to skip over highly predictable orthographic units. The unitization account, in contrast (e.g., Healy & Drewnowski, 1983), ascribes that effect to lexical-access processes (i.e., to the stage at which orthographic patterns contact their internal representations). It assumes that very frequent words conceal their constituent letters because their relatively high familiarity allows rapid activation of their whole-word representations. However, the effects of syntactic role observed for nonwords in the present study appear to result from a process that takes place at a postlexical stage after some of the phrase's structure has been extracted and after the orthographic units have been parsed into their probable morphemes. These effects are consistent with the processes postulated by the structural position, at which the greater error rate for function morphemes is assumed to ensue from their role in supporting the structural frame of the sentence.

We should note that some previous findings also indicate that letter detection for the same orthographic pattern can vary, depending on its morphemic function. Abramovici (1983) noted that subjects were more accurate in locating misspellings in *was* when it had a primary function (e.g., *he was big*) than when it had an auxiliary function (e.g., *he was coming*). Also, Drewnowski and Healy (1980) found more detection errors in the trigram *ing* when it constituted a suffix morpheme than when it was part of the stem.

Although the function-disadvantage effects that were consistently observed in the present study highlight the syntactic control of letter detection, the results on the whole disclosed a complex pattern of interactions, which suggests that letter detection errors are the result of an intricate interplay between syntactic, semantic–lexical, and visual factors. These interactions are also difficult to explain in terms of a model that relegates the missing-letter effect solely to prelexical or lexical mechanisms. However, assuming that letter detection errors also reflect the structural properties of the phrase, these interactions can shed light on the processes underlying the computation of structural frames. Taken together, the results to be discussed below suggest that during the early stages of sentence processing, readers combine evidence from a variety of cues to construct a structural frame for the phrase or the sentence. This frame is then used as a scaffold to support the interpretation of individual units and their integration into an overall meaning schema. Predominant among these cues are function words and contextual constraints. The extraction of phrase structure appears to occur on the basis of a cursory and shallow visual analysis that may utilize a parafoveal preview of information (see Rayner & Pollatsek, 1989). Letter detection errors in the structure-supporting function units apparently occur later, as processing focuses on the extraction of meaning. In what follows, we shall discuss four patterns of interactions that were disclosed by the results and show how they fit into this tentative model of the establishment of structural frames.

The first interactive pattern involves the contrast between words and nonwords. Across all five experiments, words produced more detection errors than did nonwords. Moreover, although a function-disadvantage effect was observed for both kinds of strings, it was stronger for the words in Experiments 1, 3, and 5. In contrast, the two experiments that used Hebrew prefix words and nonwords (Experiments 2 and 4) revealed roughly similar function disadvantages for both types of strings.

One possible interpretation of these results is in terms of a two-factor model, in which both frequency and function contribute to the missing-letter effect: The lexicality effect reflects the contribution of orthographic frequency, whereas the function-disadvantage effect for nonwords and for prefix words and prefix nonwords must arise from their syntactic role within the phrase. Meanwhile, function words placed in function slots reveal the joint effects of function and frequency, generally yielding the highest error rates. This account explains why the function-disadvantage effect was stronger for words than for nonwords, whereas the less frequent, prefix words did not differ from prefix nonwords in this respect. Note that this account differs from that of Healy and her associates (e.g., Healy, Oliver, & McNamara, 1987), in which both the word frequency disadvantage (the higher error rate for function than for content words) and the word inferiority effect (the higher error rate for words than for nonwords) are assumed to stem from the same mechanism: the greater unitization of familiar strings.

An alternative account, however, accords better with the structural model. According to this account, the pattern of interactions noted above reflects the interplay between lexical and contextual factors in helping to identify sentence constituents that can serve to anchor phrase structure. Because function units are among the best such candidates (see Just & Carpenter, 1987), they tend to be monitored early in processing. In normal text, both lexical and contextual factors join to facilitate the identification of function words, resulting in a strong missing-letter effect for these words. In contrast, nonwords placed in function slots evidence a much smaller function disadvantage because their function is revealed only by contextual cues. Meanwhile, prefix words and their nonword counterparts are more similar to one another than simpler words and their counterparts in two ways. First, in both prefix words and prefix nonwords, the identification of the function morpheme depends on proper parsing of the string, and this parsing, too, ought to rest on contextual information. Second, in both types of strings the constituent function morpheme (the prefix) remains intact and can be singled out on the basis of local context. Such is not the case for the misspelled function words, in which the function morpheme itself is destroyed. These differences can explain why function words evidenced a higher error rate than function nonwords, whereas prefix words and prefix nonwords yielded generally similar effects.

This interpretation is supported, but also qualified, by a second pattern of interaction, namely, the differing effects of local context on letter detection in prefix words and prefix nonwords. In Experiment 4, the size of the function-disadvantage effect for Hebrew prefix nonwords was found to depend heavily on the type of preceding word. When the immediately preceding context supported an interpretation of the nonword as a prefix-plus-stem combination, the function-disadvantage effect was as strong as that observed for prefix words. In contrast, preceding neutral contexts diminished the size of the function disadvantage relative to that of words. Thus, local context appears to be less critical for prefix words than for prefix nonwords.

This interactive pattern suggests that the function-disadvantage effect for prefix words and nonwords does not arise from the prefix stripping that is assumed to occur before lexical access to the word's stem (Lima, 1987; Taft, 1979). Rather, it occurs at a postlexical stage, in which lexical cues alone or contextual constraints alone can trigger the parsing of the letter string into its morphemic function and stem constituents. Thus, even in isolation, a prefix word can often be parsed by activating the lexical entry corresponding to its constituent stem. This may explain why the function-disadvantage effect for prefix words was indifferent to the presence of supporting local context. In contrast, an isolated nonword provides no such cues to help determine whether its initial letter is part of the stem or represents an independent morpheme. Therefore, its parsing into separate units must depend heavily on local context.

These results also tentatively suggest that the interaction between lexicality and syntactic function discussed earlier is related neither to the language studied (Hebrew or English) nor to the nature of the critical unit (prefix vs. word). Rather, it seems to depend on the contribution of lexical information to the identification of function morphemes. This contribution is obviously strong when the function morpheme corresponds to a word (Experiments 1, 3, and 5). However, it is also critical when it corresponds to a prefix and local context is insufficient to assist parsing. In that case lexical activations corresponding to the stem become important (Experiment 4).

Furthermore, these results have implications regarding the size of the structural frame influencing the function-disadvantage effect. In principle, readers could infer the grammatical class of a nonword on the basis of its location within the sentence as a whole. Nevertheless, the results presented in Table 5 suggest that it was the context that immediately preceded the nonword that was crucial for the function-disadvantage effect. This is consistent with the results of Healy and her associates (Drewnowski & Healy, 1977; Healy, Oliver, & McNamara, 1987), which suggests that the effects of context on the missing-letter effect are confined to the immediate surroundings of *the*. Thus, although readers presumably establish frames at different levels of generality (story, passage, sentence, phrase), the function-disadvantage effect is most sensitive to local frames, possibly at the phrase level only.

A third interactive pattern concerns the effects of syntactic slot. Consider the conflict conditions of Experiments 3 and 5, in which function and content words were placed in syntactically inappropriate slots. The error rate for function words was dramatically reduced, whereas the error rate for content words was largely unaffected by syntactic slot. This interaction parallels that of Drewnowski and Healy (1977) that scrambling the words of a sentence improves letter detection in function words more than in content words, which suggests that function words are more sensitive to their syntactic placement than content words. They explained this result in terms of the idea that phrases surrounding function words tend to have a greater phrase-level unitization. ("The special properties of the frequent function words make them particularly likely to be joined to other words in reading" [p. 647].) However, this idea was not supported by the results with Hebrew (Koriat et al., 1991; Experiment 3), which indicated that the difficulty in detecting letters in prefix words is confined to the letter representing the function prefix and does not extend to the neighboring letters. In terms of the present theoretical formulation, function words are particularly informative regarding the phrase's structure. Therefore, subjects automatically monitor their presence and construct tentative frames around them. When these frames are consistent with contextual constraints, the missing-letter effect is strongest. However, even when function words are misplaced, they often permit themselves to be integrated into a locally plausible frame, thereby engendering a moderate missing-letter effect even when they are placed in content slots (see Experiments 3 and 5). As for content words, these are less likely to serve as initial syntactic anchors anyway (see Just & Carpenter, 1987), and so their constituent letters remain generally accessible, regardless of their location in the text.

Aside from the effect of lexical activations, however, the construction of structural frames is also guided by expectations based on the surrounding syntactic and semantic context. That is why nonwords produced a higher error rate when placed in function than in content slots. A comparison of nonwords to content words provides further insight: When placed in function slots, content words produced in fact somewhat fewer detection errors than did nonwords. This is true despite the fact that letters were detected generally better in nonwords than in words. Thus, in Experiment 3, content words placed in function slots produced 8.8% errors, compared with 10.9% for nonwords placed in the same slots, $F(1, 35) = 3.37$, $p < .08$ (see Table 3). The respective percentages for Experiment 5 were 7.6% and 11.8%, respectively, $F(1, 43) = 9.38$, $p < .005$ (see Table 6). These effects must be interpreted with caution because in both experiments there was a somewhat greater visual similarity between the content words and the function words they replaced than between the nonwords and the function words they replaced. However, if this effect is real, it may suggest that not only do readers monitor function words, but they also search for them in their expected locations in text. When a nonword that is roughly similar to the expected function word is encountered, it may be readily assimilated into the evolving frame. The assimilation is sufficient to produce a missing-letter effect for the nonword before a detailed analysis reveals the misspelling. On the other hand, when the encountered string is a content word, thus referencing a lexical entry that is incompatible with a function interpretation, it inhibits the establishment of the structural frame around it.

The idea that the function-disadvantage effect occurs following a superficial processing of text is consistent with a fourth interaction that involves the contribution of visual similarity. Both Experiments 1 and 5 indicated a stronger function-disadvantage effect for nonwords that were visually similar than those that were visually dissimilar to the words they replaced. In fact, the function-disadvantage effect was not significant for the visually dissimilar nonwords in Experiment 5. These results suggest that the establishment of structural frames takes place at a preattentive stage, where the shallow processing of text is often sufficient to form a tentative local schema. Although this schema may prove inappropriate by a more detailed analysis of the letter strings, it is sufficient to produce a function-disadvantage effect. This idea is consistent with the proposition of Healy and her associates (e.g., Healy, Oliver, & McNamara, 1987) that the pull of the sentence discourages detailed analysis of its components.

Thus, on the whole, the results can be integrated into a tentative model in which the function-disadvantage effect is seen to reveal the preliminary extraction of structural frames during reading. We posit that as readers proceed through text, they initially attempt to establish a structural frame into which they can integrate the meaning of the phrase units. Detection errors in function units result from the shift of attention from structure to meaning. The results of the present study suggest four factors that affect the computation of phrase structure. The first concerns function words. Presumably, readers monitor text for function units, attempting to use them as anchors around which to build tentative phrase-level frames. However, when this process proves inconclusive, they move forward in an attempt to uncover an appropriate frame for the sentence as a whole. Therefore, function words produced a high rate of letter detection errors when in appropriate context and somewhat less when they appeared in inappropriate syntactic slots. The second factor involves syntactic–semantic constraints imposed by context. These constraints help guide the extraction of structure by generating expectancies regarding the sentential slots where function words are likely to reside. Hence, more detection errors occur in nonwords placed in function slots than in those placed in content slots. Contextual constraints also help in parsing nonword strings into their function-plus-content constituent morphemes, generating more detection errors for the function component. The third factor relates to lexical activations (other than those corresponding to function words). Where the function morpheme is represented by a prefix, and local context is insufficient to assist parsing, readers take advantage of lexical activations corresponding to the stem. These help to single out the function morpheme, which can then serve to anchor a structural frame. Naturally, such a process cannot take place with prefix nonwords.

Finally, visual factors also play an important role. We assume that tentative frames are established before all relevant constraints have been taken into account (see Frazier, Clifton, & Randall, 1983). This construction is based on a fast-moving process that can make do with a shallow perceptual analysis. Therefore, nonwords that bear a strong visual similarity to the expected function words might serve to cue a tentative frame. In fact, a recent study suggested that the missing-letter effect for an English function word depends also on the words that follow it in text (Greenberg & Koriat, 1991). Also, eye movement studies suggest that when a reader fixates a content word that is followed by a short function word, the function word can be identified without a direct fixation (see Rayner & Pollatsek, 1989; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989). Perhaps, then, a parafoveal preview, which does not afford a high resolution, is sufficient to support the kind of structural frames that are responsible for the function-disadvantage effect.

Aside from the dominant role that function words seem to play in the derivation of structural frames (see Just & Carpenter, 1987), our results do not permit us to determine how contextual constraints, lexical activations, and visual factors are integrated into the process or whether they are consulted sequentially or in parallel. At present, the complex pattern of results observed fits rather well with the type of automatic interactive model advanced by McClelland and Rumelhart (1981; see also McClelland, St. John, & Taraban, 1989). According to such a model, the extraction of tentative structural frames is determined by a collaborative, parallel interaction between syntactic, semantic–lexical, and visual factors. On the other hand, most linguistic approaches to syntactic analysis (see Altmann, 1989; Rayner & Pollatsek, 1989) would seem to favor a more sequential, algorithmic approach, where several rules are applied in a principled manner to derive the syntactic structure of a sentence. Perhaps the automatic construction of local structural frames that occurs essentially on-line is determined by a parallel-interactive process, whereas the construction or evaluation of the more encompassing frame rests on the principled application of rules and heuristics. If such is the case, then the function-disadvantage effect would seem to arise from the former process.

Finally, although our discussion has pushed a structural account of the data, we should stress that our results and those of Healy and her associates converge in supporting the same features of the missing-letter phenomenon: that common function words have a particular status in letter detection; that they are more sensitive to contextual effects than content words, but continue to engender a relatively high error rate even when local context is disrupted; that local context, perhaps just the neighboring words, is the more decisive; and that visual factors that destroy normal orthographic patterns exert a stronger effect on function words than on content words. Altogether, this pattern of results is equally interpretable in terms of both the unitization and structural accounts. However, although Healy (1976, 1980) has demonstrated that word frequency affects detection errors even when syntactic function is controlled, the results of the present study as well as those of Koriat et al. (1991) and Greenberg and Koriat (1991) clearly indicate that syntactic function affects detection errors when orthographic frequency is controlled. Thus, perhaps letter detection errors result from different processes that occur at different stages of reading, and these processes cannot be accounted for in terms of a single model.

In conclusion, we propose that the missing-letter effect for function units is symptomatic of the structural frames that are constructed in the early stages of text processing. These frames help to guide the extraction and integration of semantic content but recede to the background as the meaning of the phrase unfolds. This proposition assumes that syntactic processing leads the way to semantic interpretation (see Forster & Ryder, 1971) and that the missing-letter effect occurs in the transition from structure to meaning. If this assumption is correct, it would seem profitable to use the letter detection task in combination with eye movement methods assumed to tap the on-line processes that occur during reading (see Rayner et al., 1989). As far as we know, this has not been done so far, possibly because of the common adherence to the unitization view that the missing-letter effect is due to orthographic frequency. Subsequent work must also address the paradox that, on the one hand, many students of reading assume that function words are particularly helpful in the early stages of sentence processing (see Altmann, 1989; Rayner & Pollatsek, 1989), whereas, on the other, some claim that these are merely skipped during reading because of their high redundancy in text (e.g., Corcoran, 1966; Schindler, 1978).

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