The influence of word function in the missing-letter effect: Further evidence from French

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When asked to detect target letters while reading continuous text, subjects miss more letters in highly common function words than in less common content words. This is known as the *missing-letter effect*. According to the structural account, the higher omission rates for frequent function words are attributable to their role in supporting the extraction of phrase structure, after which they become lost in the transition from structure to meaning. This implies that word function in and of itself should affect letter detection accuracy. This issue was examined in four experiments while controlling for a number of confounded factors associated with another influential model: the unitization account. The first experiment extended the missing-letter effect to the French language. The second showed that letter detection is influenced by slight variations in the function assumed by the same word, such as when it is used as a definite article as opposed to a pronoun. This effect was observed even when the frequency of the orthographic pattern and the syllable stress patterns were controlled. In the last two experiments, a control was added for another factor: frequency of word meaning. The results indicate that word function contributes to the missing-letter effect over and above what is contributed by frequency of word meaning.

When subjects attempt to circle a target letter while reading continuous text, omissions are far more numerous when the target is embodied in a frequent function word, such as *the, on, of, or for*, than in a less frequent content word (see, e.g., Corcoran, 1966). This well-replicated phenomenon, known as the missing-letter effect, has recently produced much empirical activity and theoretical debate. The reason for this interest is well summarized by the concluding sentence of Healy's (1994) recent review: "Thus, the letter detection task provides a window illuminating a wide range of cognitive processes involved in reading text" (p. 342).

Two main theoretical proposals, surveyed below, are linked to the missing-letter effect. Each account emphasizes different and conflicting hypotheses concerning the processes called upon in reading. Evidence concerning the role of syntactic factors in the missing-letter effect found for function words appears critical to clarifying a number of theoretical issues. The aim of the work reported herein was to produce such evidence, by taking advantage of some convenient properties of the French language.

The Unitization Account

To account for the missing-letter effect, Healy and her associates put forward a unitization account of reading processes (Drewnowski & Healy, 1977, 1980; Healy, 1976; Healy & Drewnowski, 1983). According to this framework, readers process text at several levels simultaneously, including feature, letter, syllable, word, and supra-word levels. It is assumed that when the identification of a unit at a given level is successful, processing at all lower levels is interrupted, even if it has not been completed. The missing-letter effect is seen as the by-product of a successful higher order identification, one that is completed before constituent letters have been fully processed: If letter processing is interrupted, the probability that a target letter will be missed is heightened.

In this first version of the unitization account, familiarity with a unit's visual configuration is of paramount importance. This is because familiarity with a supraletter unit is assumed to produce faster processing at that level. Consequently, the more familiar the unit, the higher the probability that its constituent letters will not be fully processed. The unitization account then easily handles the missing-letter effect found for function morphemes, given that they are among the most frequent words found in written text.

The unitization model has received impressive empirical support. For example, it has been shown that readers make more omissions when the target letter is embodied in a frequent noun than when it is embodied in a rare noun (Drewnowski & Healy, 1982; Healy, 1976). This is attributed to faster processing at the higher order word level for more familiar nouns. Thus, there is a greater proba-

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bility that these frequent nouns will be identified before their constituent letters have been fully processed, resulting in more omissions. Conversely, the size of the missing-letter effect is reduced substantially when familiarity of the orthographic pattern is destroyed. This has been demonstrated in a number of ingenious experiments. For example, inserting asterisks between each character in a prose passage has produced more improvement in letter detection for common words such as *the* and *of* than for less common words (Healy, Conboy, & Drewnowski, 1987; Schneider, Healy, & Gesi, 1991). Presumably, the asterisks impede access to reading units larger than the letter by disrupting the visual configuration of those units. This would allow more time for letter processing, resulting in better target letter detection, especially for highly familiar visual units such as frequent words. Similarly, the missing-letter effect is smaller when the familiarity of visual shapes is reduced by the use of alternating type case (Drewnowski & Healy, 1977), misspelled target words (Healy, 1980; Healy & Drewnowski, 1983; Healy, Fendrich, & Proctor, 1990), or words with scrambled letters (Healy, 1976).

The Structural Account

Koriat and Greenberg (1991; Greenberg & Koriat, 1991; Koriat, Greenberg, & Goldshmid, 1991) have challenged the prominence of visual familiarity in producing the missing-letter effect. They point out that even if one does obtain a missing-letter effect when letter detection accuracy for frequent nouns is contrasted with that for rare nouns, the most marked effects have been observed when highly common function words are contrasted with content words. However, even if function words are the most frequent words in English, they also assume a special role in sentences. Consequently, the missing-letter effect could be attributable to word function, to word frequency, or to both. In fact, Koriat and Greenberg have demonstrated in a number of studies, surveyed below, that word function may be the critical factor.

On the basis of their work with the letter detection task Koriat and Greenberg (1991, 1993, 1994) have argued that structural organization overrides perceptual organization (e.g., unitization) in producing the missing-letter effect. They have proposed what has come to be known as the structural account of reading processes. Central to this account is the structural precedence hypothesis: In reading, there is an active on-line integration of structure and meaning whereby a shift in dominance occurs from structure-supporting units to meaning-laden elements (Koriat & Greenberg, 1994). According to this framework, early in text processing, readers try to establish a tentative structural frame of the sentence, on the basis of a rapid and shallow analysis. This skeletal structure allows the integration of more semantically informative units into a meaningful representation. Prominent function cues such as articles, prepositions, conjunctions, and affixes would be particularly useful during the first phase of this analysis. Once they have been used to build

this structural frame, they recede into the background as the meaning of the text unfolds. According to this structural view, this figure-ground process leads to a greater omission rate for function words in the letter detection task. Target letter identification would be more difficult for structural units pushed into the background than for semantically informative content words that stand in the foreground. In this account, then, letter detection is thought to reflect postlexical processing, in contrast to the unitization account, in which letter detection proceeds in parallel with processing at all other levels.

This proposal has been supported by the results of several experiments, in which the main strategy has involved varying the grammatical role of a functor while controlling for other factors such as the familiarity of its visual configuration (see Koriat & Greenberg, 1994, for a review). In one series of experiments, Koriat et al. (1991) contrasted two kinds of Hebrew phrases carrying the same meaning. In Hebrew, several function words can appear as highly frequent words or as single-letter prefixes appended to word stems. In contrast with matched content words, prefixed content words, as a whole, have a less frequent visual configuration. Despite this, letter detection was poorer for function prefixes than for matched content words. In addition, in prefixed content words, the letter detection disadvantage was restricted to the prefixed letter.

However, Healy (1994) has offered a compelling alternative interpretation of these results, based on the unitization account: She points out that according to the unitization account, the visual familiarity of the morpheme affix rather than the frequency of the entire orthographic pattern could well be the critical factor (see also Drewnowski & Healy, 1980).

In another series of experiments, Koriat and Greenberg (1991) placed nonwords in either a content or a function role. In English, more omissions were observed when nonwords were placed in a function than a content slot. Koriat and Greenberg made a similar demonstration with Hebrew materials. Once more, even if these results support the structural account, Healy (1994) has offered an alternative interpretation based on the unitization account. She argues that the English nonwords that were used can be seen as misspellings of a highly frequent function word (e.g., *fol* and *fom* for *for*). Thus, they would entail omission rates comparable to those found for usual function words, albeit somewhat diminished, given the reduction in visual familiarity caused by misspellings (Healy & Drewnowski, 1983). She also suggests that results with Hebrew nonwords can be accommodated within the unitization account, by considering the morpheme affix as the relevant unit instead of the entire orthographic string, as was previously argued by Drewnowski and Healy (1980).

Greenberg, Koriat, and Shapiro (1992) ran a third series of experiments in which they took advantage of English function words that could assume different syntactic roles. For example, they used the high-frequency two-word sequence *for the*. It was used as part of either

one phrase (e.g., *He was looking for the book in his room*), or two different phrases (e.g., *The book he was looking for the night of the party*). They reported fewer omissions of the letter *f* when *for the* was part of two different phrases. Other findings included the decline in the number of omissions when a function word assumed a content role (e.g., *for* in *for or against*, or *on* in *the on switch*) (Greenberg & Koriati, 1991; Moravcsik & Healy, 1995). The original unitization account has difficulty accounting for these effects, because the orthographic pattern of the studied words was constant; yet the number of omissions was found to vary with grammatical function. Therefore, visual familiarity with the orthographic configuration cannot be the only active factor.

There are, however, two problems with the structural account of these findings. Both relate to the confounding of grammatical function with another factor, and both are associated with alternative interpretations of the reported results.

Prosodic stress patterns. First of all, in most if not all of these studies, the prosodic stress pattern was not constant for the words used in function and content roles (e.g., *for better or worse*, vs. *...are you for or against*). It follows that the smaller number of omissions for the target letter embodied in the content word could be due to the fact that this word is more heavily stressed (Greenberg & Koriati, 1991). Drewnowski and Healy (1982) and Goldman and Healy (1985) have shown that target letters are detected more readily when they are part of a stressed syllable.

Frequency of word meaning and the processing time hypothesis. As Moravcsik and Healy (1995) have pointed out, when function words assume a content role, they also assume a less frequent meaning. For example, the use of *for* in *for or against* is associated with a much less frequent meaning than that which accompanies its usual function role. Hence, although the familiarity of the visual pattern cannot account for differences in omission rates, familiarity of meaning could be the important factor. In Moravcsik and Healy's recent series of experiments, frequency of word meaning was associated with a large missing-letter effect: the higher the familiarity of a word's meaning, the more likely subjects were to miss a target letter within. This is an important finding, because in all the studies in which a function word had been used in a content role, its meaning was less familiar than when it assumed its usual function role.

Healy (1994) and Moravcsik and Healy (1995) have proposed a revised version of the unitization framework in order to account for these effects and for those of a number of other factors. In particular, Moravcsik and Healy (1995) have developed the *processing time hypothesis*. According to this hypothesis, the visual processing of letters continues until a late stage of semantic/syntactic accessing, implying that letter detection will be under the influence of the speed with which this stage is completed. Moreover, it is thought that a number

of factors can reduce the processing time of a morpheme, including the familiarity of its meaning, its visual configuration, or its phonology. Any factor that reduces a unit's processing time will heighten the probability that an embodied target letter will be missed.

To summarize, we are left with two compelling and conflicting hypotheses that can account for the missing-letter effect found for function words. One is the unitization account, including the processing time hypothesis, described above. Alternatively, there is the structural account. Within the latter, the role of structural cues, such as function words, is of central concern. This framework insists on the particular nature of the high rate of omissions found for these words in the letter detection task. This is thought to reveal the precedence of structural analysis in relation to the extraction of meaning. However, there is an alternative account of some of the main findings that appear to support this view. One possibility involves the change in prosodic stress pattern that very often accompanies the use of a function word in a content role. A further possibility is stressed by the processing time hypothesis: Familiarity of word meaning can be viewed as a major determinant of the missing-letter effect found for function words.

In the experiments reported here, we pursued a number of objectives related to these conflicting accounts. First, in Experiment 1, we extended the basic missing-letter effect, obtaining it in the French language. In Experiment 2, we manipulated the grammatical role of a function word while prosodic stress pattern was held constant. Finally, in Experiments 3 and 4, we examined the influence of word function, while also controlling for frequency of meaning.

EXPERIMENT 1

Method

Subjects. Seventy-five students (48 females, 27 males) attending a local college volunteered to participate in this experiment. French was the first language of all of the participants.

Materials. Twenty critical sentences were constructed. Half of them contained the preposition *dans* (in), with a frequency count of 9,316, whereas the other half contained the verb *dire* (to say), with a frequency of 2,530, per million (according to Baudot, 1992). The following restrictions were applied to the composition of critical sentences. Each sentence with the preposition *dans* was matched with a sentence involving the verb *dire*. Each of these sentences contained approximately the same number of words, had a similar structure, and in each one, the critical word occupied about the same location in the text. To illustrate implementation of these restrictions, two pairs of matched content and function word sentences are presented in Table 1. An examination of this table reveals that for both pairs, the critical content word *dire* and its corresponding function word *dans* occupy the same ordinal position within their respective sentences, and they are both preceded by a verb and followed by a function word. In addition, within the full text, the critical words were never placed at the beginning or at the end of a sentence or a line, and the target letter *d* was never embodied in the words immediately preceding or following the critical word.

Table 1
Two Pairs of Matched Critical Sentences Used in Experiment 1, and Their English Translation

Sentence	Description
Original Sentences in French	
First Pair	
Function word <i>dans</i>	La neige tiède, revenant à l'état liquide, s'écoule <i>dans</i> les rues.
Matched content word <i>dire</i>	L'écureuil, gambadant sur notre terrasse, semble <i>dire</i> sa joie.
Second Pair	
Function word <i>dans</i>	Une vie frénétique s'installe <i>dans</i> mon petit quartier.
Matched content word <i>dire</i>	Une muse soudaine nous fait <i>dire</i> des paroles inspirées.
English Translations*	
First Pair	
Function word <i>dans</i>	The melting snow, returning to its liquid state, is trickling in the street.
Matched content word <i>dire</i>	The squirrel capering about our terrace, seems to say its joy.
Second pair	
Function word <i>dans</i>	A frenetic activity is settling into my small neighborhood.
Matched content word <i>dire</i>	A sudden muse made us say inspired words.

*Note that the meaning of the French sentences could be much more elegantly conveyed in English than what is found here. However, we strove to maintain the sentence structure so that the translations would serve their illustrative purpose.

The critical sentences were included in a story about the springtime, 52 sentences long. The text was a long one-and-a-half spaced paragraph, and it occupied a single page. The text was typed in Times 12-point font produced by a laser printer. Critical sentences were separated by at least one filler sentence. The first and last sentences of the text were also fillers. These filler sentences contained the target letter *d*, but neither *dans* nor *dire* was included.

An instruction sheet was stapled in front of the text. The instructions encouraged the subjects to read the text for comprehension at their normal reading speed. They were told that whenever they came across a *d* (either upper- or lowercase) they were to circle it. They were also warned not to slow down their reading speed to detect all the *ds*, and not to backtrack in order to circle a *d* that they had missed. To familiarize the subjects with this task, they were asked to read the instruction sheet again and to circle all *ts*.

Procedure. The subjects were tested in three groups of about 25 individuals each. The experimenter read the instructions aloud, while the subjects read them silently. Before the subjects started practice on the instruction sheet, they were told to wait until they had received the appropriate signal before proceeding to the next page. When all subjects had finished practice, the experimenter gave the signal to turn the page. The letter *d* appeared at the top of the text to remind the subjects which letter they had to circle.

Results and Discussion

The mean percentage of omission errors for both the critical and the other words in the text holding the target letter *d* are presented in Table 2, as a function of their syntactic status. These percentages were calculated for each subject, and for each condition, by dividing the number of omissions by the appropriate number of occurrences. There were 10 occurrences for each critical word (*dans/dire*), and, respectively, 36 and 22 occurrences for the other content and function words. The 36 occurrences of content words were divided up in the following way: 12 occurrences of adjectives (e.g., *dur* [hard], *chaud* [warm]), 13 occurrences of verbs (e.g., *dort* [sleeps], *entends* [hears]), 9 occurrences of nouns (e.g., *dimension* [size], *monde* [world]), and 2 occurrences of adverbs (*délicieusement* [delightfully] and *soudainement* [suddenly]). For the function words it is harder to provide a unique translation, given that the English equivalent depends on their particular grammatical function in the sen-

tence. However, from the 22 occurrences of function words, there were 9 occurrences of *de* (of) as a preposition and 3 of its contracted form *d'*, 2 occurrences of *de* (the) as an article and one of its contracted form *d'*, 5 occurrences of *des* (the) as an indefinite article indicating plural, and 2 occurrences of *du* (the) as a partitive article.

Inspection of the first section from the top of Table 2 reveals more omissions of the target letter for function than for content words, either for words from the critical pool or for the other words containing the target letter. Separate analyses of variance (ANOVAs) were conducted for each word pool, since the appropriate methodological controls were only implemented for the critical words.

For critical words, a repeated measures ANOVA with word type as the only factor confirmed that there were significantly more omissions for *dans* than for *dire* [$F(1,74) = 103.66, p < .0001$]. For the remaining words, the results were essentially the same, with significantly more omissions for function words [$F(1,74) = 61.45, p < .0001$].

These results show the same pattern of omissions with French as had previously been observed with English and Hebrew material. They further illustrate the phenomenon's ubiquity. Whatever reading processes produce this particular pattern of omissions, they appear to be common to a number of languages.

EXPERIMENT 2

In this experiment, the grammatical function of the critical word was manipulated while we controlled for a number of other factors—namely, visual familiarity, phonology and prosodic stress. Two uses of a high-frequency word (*les*) were compared. In both cases, it assumed a function role. Its use as the plural definite article was contrasted with its use as a pronoun (*them*), referring to an entity or content phrase. In the latter case, it assumes a more content-like role and carries more meaning. According to the structural model of reading processes, it should be associated with less omissions when assuming a content role. Within this model, it is

Table 2
Means and Standard Errors for Percentages of Omission Errors for Each Experiment,
Word Function, and Target Letter, and for the Difference Between Function and Content Word

Conditions	Word Function					
	Function Word		Content Word		Difference	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Experiment 1						
Critical words (<i>dans/dire</i>)	51.20	3.28	21.87	2.32	29.33	2.88
Other words	48.61	2.68	26.41	1.78	22.20	2.83
Experiment 2						
Letter <i>l</i> in word <i>les</i>	15.46	1.76	8.45	1.36	7.01	1.23
Experiment 3						
Letter <i>o</i> in word <i>or</i>	2.03	1.10	0.29	0.29	1.74	1.07
Letter <i>r</i> in word <i>or</i>	11.56	2.07	5.94	1.41	5.63	2.10
Overall	6.63	1.26	3.01	0.76	3.61	1.16
Experiment 4						
Letter <i>u</i> in word <i>outré</i>	2.40	1.33	5.60	2.17	-3.20	2.22
Letter <i>t</i> in word <i>outré</i>	44.55	6.16	36.36	6.79	8.18	4.30
Overall	22.13	4.27	20.00	4.04	2.13	2.45

Note—The word *les* was placed in the function word column when it was used as the plural definite article, and in the content word column when it was used as a pronoun.

assumed that given its greater contribution to the meaning of the text when used as a pronoun, *les* should not be pushed into the background as easily as other units supporting phrase structure. According to the unitization account, previous experiments in which a critical word was used in both function and content roles can be criticized for two reasons. First of all, the unitization account can account for the uncovered effects with the help of the processing time hypothesis and by assuming that letter detection is continued until a late stage of semantic/syntactic processing. If a word has a less frequent meaning when it is used as a content word, access to its meaning will be slowed, increasing the time available for target letter identification. Second, and perhaps more basically, in most of the relevant studies, word function was confounded with prosodic stress. Experiment 2 was designed to control for the latter confound, whereas Experiments 3 and 4 addressed the frequency of word meaning hypothesis. Hence, in this experiment the prosodic stress pattern was held constant for both usages of *les*, contrary to most, if not all, previous studies in which a word assumed both a function and a content role (see Koriart & Greenberg, 1991, concerning the confounding of prosodic stress in previous studies).

Method

Subjects. Ninety-seven students (61 females, 36 males) from a local college volunteered to participate in this experiment. French was the first language for all of the subjects. None had participated in the previous experiment.

Materials. Twenty critical sentences were assembled. In half of them the word *les* stood for the plural definite article, with a frequency count of 19,230, whereas in the other half it was used as a pronoun (*them*), with a frequency of 980, per million (according to Baudot, 1992). These two different usages of *les* are highly familiar: Out of a total of 21,684 words found in Baudot's norms, the definite article *les* occupies the 8th position; the pronoun *les* is 94th. The word *les* only appeared once in the critical sentences, and it was never embodied in the other sentences. The critical sentences were in-

cluded in a story about waking-up in the morning, 52 sentences long. All the other restrictions in the text construction were the same as those used in Experiment 1.

Procedure. The instructions, procedure, and practice were similar to those of Experiment 1 except for the following changes. The subjects were tested in four groups of about 25 individuals each instead of three groups, and the target letter was now *l*.

Results and Discussion

As shown in the second section from the top of Table 2, there were more omissions of the target letter *l* when the word *les* stood for the plural definite article than when it stood for a pronoun. A repeated measures ANOVA confirmed that this difference was statistically reliable [$F(1,96) = 32.61, p < .0001$].

Experiment 2 yielded results very similar to those of the previous experiment, with better target letter detection for the word assuming a more content-like role, as when *les* was used as a pronoun. This effect cannot be attributed to differential familiarity with the visual configuration of the critical word, or to variations in phonology or prosodic stress patterns. However, in this experiment as in previous studies, word function and frequency of meaning were confounded. Therefore, the lower omission rate found for *les* when it stood as a pronoun can be attributed to either or both. According to the structural account, it would be attributed to its more content-like role as a pronoun: As the meaning of the text unfolds, it will be left in the foreground, whereas when strictly assuming a function role as a definite article, it would be pushed into the background.

According to the processing time hypothesis, the better target detection for the pronoun is attributable to its less frequent meaning in that role. Consequently, it would be processed more slowly at the late semantic/syntactic level, leaving more time for letter analyses. Indeed, Moravcsik and Healy (1995) have recently reported a finding that indicates that frequency of meaning could be the po-

tent factor. They compared two uses of the word *it*. In one case—the more common one—*it* carried more meaning, referring to an object or entity. In the less frequent case, *it* was used as a dummy with no reference to an object (e.g., in *it was raining*). Hence, contrary to the situation in Experiment 2, the more content-laden function word had a higher frequency. Also, contrary to the present findings, results showed more omissions for this use of the word, suggesting that frequency of word meaning was the important factor, instead of word function.

Before addressing the issue of the possible independent contribution of word function to letter detection accuracy, an unforeseen result will be discussed. The overall omission rate in Experiment 2, for both usages of *les* (about 12%), was only one third of that found in Experiment 1 for the two critical words (about 37%). Although this is a comparison between two distinct experiments, the fact that subjects were drawn from the same population, and that materials were assembled according to the same rules, makes it a surprising result.

According to the structural account, using the same word in a function and a more content-like role could explain the lower omission rate found in Experiment 2. In fact, whereas in Experiment 1 the structural role of target words was revealed by both lexical and contextual factors—in French the word *dans* (*in*) is always used as a preposition, and the word *dire* (*to say*) as a verb—in Experiment 2, it was *only* disclosed by contextual factors. Perhaps this may have delayed the processing of *les* relative to that of the critical words in Experiment 1. Thus *les* would have stayed longer in the foreground, resulting in improved letter detection (Koriat & Greenberg, 1991, 1996).

The processing time hypothesis can also account for the lower omission rate found in Experiment 2. The argument would be that there were fewer omissions for target letter *l* than for *d*, because the former was processed faster at the letter level. Such an argument has already been put forward by Schneider and Healy (1993), who observed more omissions for the target letter *t* than for the target letter *o*. They argued that the difference in the number of omissions between *o* and *t* might be attributable to their visual properties. More specifically, as a visual pattern, letters have qualities over and above those that can be specified by their feature-based analysis. According to the Gestalt principles of organization, some letters could be said to have more “goodness” of pattern than others (Garner & Clement, 1963). Schneider and Healy (1993) have suggested that letters with better Gestalt goodness of pattern could be identified more rapidly at the letter level of analysis. In that study, they argued that in the font that they used, the letter *o* was perfectly symmetrical and regular, but the letter *t* was not. Consequently, the letter *o* would possess more goodness of pattern, and this would account for the smaller number of omissions that it produced. To test this hypothesis, they used an unusual font. By contrast with their usual font, the letter *o* became less symmetrical and regular,

whereas the letter *t* became more symmetrical and regular. As predicted, the use of this unusual font increased number omissions for the target letter *o*, but decreased it for the target letter *t*. (We thank Alice Healy for pointing out this interpretation during the review process.)

The same argument can be applied to the present study. In fact, in Times font, the letter *l* is more regular, symmetrical—though not perfectly so, because of serifs—and continuous than the letter *d*. Consequently, the letter *l* should be processed faster than the letter *d*, and fewer omissions should be observed with the former. Indeed, this is exactly what was found.

EXPERIMENT 3

The main aim of Experiment 3 was to clarify the influence of word function on target detection accuracy. This is important, because it is a central assumption of the structural account. In the previous experiment, more omissions were reported when the critical word was used in a function role rather than a more content-like role. Although suggesting a contribution of word function to target detection, these results do not allow such a claim, given that frequency of word meaning was a confounding factor. Clearly, if the role of word function is to be assessed adequately, the frequency of word meaning must be held constant while word function is varied. In other words, what is needed is a function word that is used equally often in a function and in a content role. Conveniently, it was possible to find a French word that met this criterion.

According to the structural account, readers should miss more target letters when the critical word assumes a function role than when it assumes a content role. However, given that frequency of word meaning is constant, the processing time hypothesis predicts an equivalent number of omissions for both uses of the word.

As a subsidiary aim, a more direct test of the letter processing speed hypothesis, invoked to account for the lower omission rate in Experiment 2 than in Experiment 1, was implemented. More precisely, subjects were searching either for the target letter *o* or for the target letter *r*. According to the processing time hypothesis, more omissions for the target letter *r* than for the target letter *o* were anticipated: The letter *o*, displayed in Times font, has more symmetry, redundancy, and continuity than does the letter *r*. Readers should thus process the letter *o* faster, and fewer omissions should be found.

Method

Subjects. Eighty-three students (69 females, 14 males) attending a psychology class at Laval University volunteered to participate in this experiment. French was the first language for all the subjects, and none of them had ever participated in a letter detection experiment.

Materials. Sixteen critical sentences were constructed. In eight of them, the word *or* was used as a conjunction¹, having a frequency of 174 per million according to Baudot (1992); in the other eight, it was used as a noun (meaning *gold*), with a frequency count of 155. These sentences were included in a 1.5-page double-spaced pas-

sage about a boy meeting a girl. The word *or* was never preceded by an article with an apostrophe, as in *l'or*, nor by a punctuation mark, and the target letters *o* and *r* were never embodied in the words immediately preceding or following it. It should be noted that according to punctuation rules, *or*, as a conjunction, should be preceded by a comma, or preferably by a strong punctuation mark—namely, a period or a semicolon (Grevisse, 1986, Rule 1039). Moreover, it is often followed by a pause (e.g., when one is reading aloud), which is translated by a comma in written text (Grevisse, 1986, Rule 1039). There is no such requirement when it is used as a noun. The missing punctuation could have been perceived as unusual, attracting the readers' attention, or the usual pause could allow more time for processing constituent letters. Consequently, our omission of punctuation marks around *or* may have contributed to better target detection for the critical word in its function role, contrary to what would be expected on the basis of the structural account. All the other restrictions in the text construction were similar to those used in the previous experiments.

Procedure. The procedure was the same as in the previous experiments, but with the following differences. The subjects were tested in a single group, and instead of all searching for the same target letter, 43 searched for the target letter *o*, whereas 40 searched for the target letter *r*. The texts with either *o* or *r* as a target letter were shuffled and randomly distributed to the subjects. In addition, to encourage reading for comprehension, subjects were told that their understanding of the prose passage would be tested. Accordingly, they answered three multiple-choice questions about the text after completing the letter detection task.

Results and Discussion

Mean percentage of omissions and standard errors for both target letters, for both uses of *or* are displayed in the third section from the top of Table 2. Overall, subjects made more omissions when *or* was used as a conjunction rather than a noun. This effect appeared stronger for the target letter *r* than for *o*. There were very few omissions with *o* (overall, 1.16%), pointing to the possibility of a ceiling effect. The results were analyzed with a mixed-design ANOVA, with target letter as the between-subjects factor and word function as the repeated factor. There was an effect of the target letter [$F(1,81) = 25.21$, $p < .0001$] and of word function [$F(1,81) = 10.22$, $p < .005$], but the interaction did not reach significance [$F(1,81) = 2.84$].

These results showed a clear effect of word function on letter detection accuracy, with frequency of word meaning controlled. More specifically, as predicted by the structural account, there were more omissions when *or* assumed a function role than when it assumed a content role (Koriat & Greenberg, 1994). To our knowledge, this is the first demonstration of the effect of word function, unconfounded by frequency of word meaning. However, although this seems unlikely, there is the possibility that the slight difference in frequency of use could explain the reported effect. If such was the case, these results would no longer be a problem for the processing time hypothesis stating that more omissions should be observed when a word is used in its more frequent meaning.

The present results also showed a strong main effect of target letter, which did not interact with word function. As predicted by the processing time hypothesis, the letter *o* with better Gestalt goodness of pattern was also missed

less frequently. This is in line with the reported difference in detection accuracy between the target letter *d* in Experiment 1 and the target letter *i* in Experiment 2, and also with the previous findings of Schneider and Healy (1993).

EXPERIMENT 4

Given the theoretical significance of the word function effect found in the previous experiment and the possibility of attributing this effect to frequency of word meaning, it seemed important to replicate this finding with additional methodological controls. More specifically, we attempted to replicate our findings with another word. In fact, unlike in the previous experiment, the frequency of meaning of the target word used here was slightly higher when it assumed a content role than when it assumed a function role. According to the structural account, there would be more omissions when the target word assumed a function role. However, the processing time hypothesis predicted either no difference or more omissions for the content word, because of its slightly more frequent use.

A further test of the letter processing speed hypothesis was also possible by contrasting detection accuracy for two target letters: *u* and *t*. Upon examination, the letter *u* appears to have a better Gestalt goodness of pattern with more continuity than that exhibited by the letter *t*. Consequently, on the basis of processing time hypothesis, more omissions were anticipated for the target letter *t*, both when the target word assumed a content role and when it assumed a function role.

Method

Subjects. Forty-seven students (43 females, 4 males) attending an introductory psychological course at Laval University volunteered to participate in this experiment. French was the first language for all the subjects, and none of them had ever participated in a letter detection experiment.

Materials and Procedure. Ten critical sentences were constructed. In 5 of them, the word *outré* was used as a preposition (*beyond*), with a frequency count of 26, whereas in the remaining 5 it was used as an adverb (*moreover*), with a frequency of 124, per million (according to Baudot). These sentences were included in a 1.5-page double-spaced passage about someone looking for a new apartment. The target letters *u* and *t* were never embodied in the words immediately preceding or following the critical word. All the other restrictions in the text construction were the same as those used in the previous experiments. The procedure was also the same as in Experiment 3, except that 25 subjects searched for the target letter *u*, whereas 22 searched for the target letter *t*.

Results and Discussion

The last section at the bottom of Table 2 presents the mean percentage of omissions and standard errors for both target letters, for the two functions of *outré*. Overall, subjects made slightly more omissions when *outré* was used as a preposition than as an adverb. This effect seems attributable to the target letter *t*. For the target letter *u*, the effect was smaller, and in the opposite direction. The significance of these trends was tested with a mixed-design ANOVA with target letter as the between-

subjects factor, and syntactic role as the repeated one. There was an effect of target letter [$F(1,45) = 37.84, p < .0001$] and a significant interaction [$F(1,45) = 5.95, p < .025$], but the main effect of word function did not reach a significance [$F(1,45) = 1.14$]. Simple main effects revealed the influence of word function for the target letter *t* [$F(1,45) = 5.78, p < .025$], but not for the target letter *u* [$F(1,45) = 1.00$].

The results of Experiment 4 yielded a very similar pattern to that found in Experiment 3. In both cases, there was a strong effect of target letter with fewer omissions for the letter with better Gestalt goodness of pattern. This is exactly what was predicted by the processing time hypothesis, and it emphasized the need to account for the influence of the visual properties of letters in reading.

For word function, contrary to Experiment 3, overall it was impossible to observe a main effect of this factor. However, and importantly, there was a significant interaction between word function and target letter. More specifically, word function did not influence letter detection accuracy for the target letter *u*, although the non-significant trend was in the direction predicted by the processing time hypothesis, with more omissions for the more familiar usage. This effect seems attributable to a ceiling effect, given that when both uses of *outré* are considered together, there was only a mean 4% omission rate. Analyses of individual scores revealed that on a total of 10 occurrences of the critical word (5 instances as a function word and 5 instances as a content one), 18 subjects made 0 omissions, 4 subjects made 1 omission, and 3 subjects made 2 omissions. This is potentially attributable to *u*'s Gestalt goodness of pattern. Consequently no theoretical conclusions should be based on the sole basis of the nonsignificant effect of word function for the target letter *u*. For the target letter *t*, the effect of word function was significant, with more omissions when the critical word assumed a function role. This effect was found even though the word *outré* has a more frequent meaning as a content word. These results support the predictions of the structural account and cannot be anticipated on the basis of the frequency of word meaning. Therefore, it can be argued that although frequency of meaning appears to be an important factor in target detection (see Moravcsik & Healy, 1995), word function also plays a significant role.

GENERAL DISCUSSION

In the present study, we examined the influence of word function on letter detection accuracy, for subjects reading a prose passage. Results of all four experiments are straightforward and easy to summarize. Overall, our findings indicate that word function is a significant determinant of letter detection performance, over and above the effects of visual familiarity, phonology, prosodic stress pattern, and frequency of word meaning. The first experiment, in which target letter detection was compared for a function word and a common content word, showed a higher omission rate for the function word. The

same pattern was found in Experiment 2: When the same word was used as a definite article or as a more content-laden pronoun, the former use produced more omissions. Experiment 3 also showed more omissions when the critical word assumed a function role instead of a content role, even though frequency of word meaning was almost identical for both usages. However, there was a slight difference in frequency of word meaning, with a more frequent usage in the function role. A further test of the word function effect was implemented in the fourth experiment with the additional control of using a word having a higher frequency in a content than in a function role. Results showed that letter detection was worse when the word assumed a function as opposed to a content role for the target letter *t*, but not for the target letter *u*. Finally, there was an effect of target letter in the last two experiments. Letter detection was easier for target letters with better Gestalt goodness of pattern. We now turn to the theoretical implications of these findings.

According to the processing time hypothesis, in a letter detection task, omissions occur as a result of incomplete processing of the target letters. Subjects, having completed higher level processing, move on to the next part of the text too quickly to allow an adequate analysis at the letter level. Consequently, on the one hand, whatever *decreases* the time needed to fully process a letter increases letter detection accuracy (Schneider & Healy, 1993). On the other hand, whatever *increases* the time a reader spends processing a word increases letter detection accuracy (Moravcsik & Healy, 1995). In this account, familiarity with a word increases processing speed at the word level. Hence, letter detection errors are predicted to co-vary with the familiarity of a word's features, use, and meaning.

This proposal easily accounts for the effects of the visual properties of target letters on omission rate. The overall superior detection rate in Experiment 2 as compared with Experiment 1 could be attributed to the better Gestalt goodness of pattern for the letter *l* in the former compared with the letter *d* in the latter. The same argument applied to the better detection of the letter *o* compared with the letter *r* in Experiment 3, and the letter *u* compared with the letter *t* in Experiment 4. More precisely, it has been suggested that letters with better Gestalt goodness of pattern can be identified faster at the letter level of analysis (Schneider & Healy, 1993). Consequently, the probability is higher that these letters would be fully processed, before the reader moves to the next segment of the text.

The processing time hypothesis can also account for the word function effect found in the first three experiments, although the explanation is more convincing for the first two. In Experiment 1, the word assuming a function role had a higher frequency than did the word assuming the content role. Therefore, the lower omission rate for the content word could be attributable to its lower frequency, since frequency of usage influences word identification speed. In Experiment 2, even if the same word was used in a function and in a content-like role, its

use as a function word was more usual. Consequently, its less familiar usage as a content-laden word would imply slower processing, entailing more time for letter detection. The same was true for the third experiment, where again letter detection accuracy was worse when the critical word assumed a function instead of a content role. However, in this case, more caution is needed in attributing the decreased detection accuracy to more familiar use as a function word. In fact, the difference in frequency of meaning for both uses was very small. This casts some doubts on the role of frequency of meaning as the factor responsible for the important difference in detection accuracy.

The processing time hypothesis has more difficulty accounting for the results of Experiment 4. In this experiment, the same word was used in a function and in a content role, but unlike in Experiment 3, it had a higher frequency of meaning as a content word. Despite this, the target letter *t* was missed more often when the critical word assumed a function role. If the familiarity of a word's meaning was the sole potent factor, the opposite should have been observed, with more omissions when the target word assumed a content role.

Although familiarity of word meaning cannot account for the present results, the processing time hypothesis might still provide a satisfactory explanation. In fact, Moravcsik and Healy (1995) suggested that lexical access time includes the time to process word meaning. It would then be possible to assume that readers spent more time processing the critical word when it assumed a content role instead of a function role. This would be attributable to the target word's more rich or complex meaning in a content role. The argument could easily be understood, for example, by assuming that in English the word *the* has less meaning or a simpler meaning than does a usual content word. However, there are some problems in applying such an argument here. For one, it is difficult to see why readers would spend more time processing the meaning of the critical word *outré* when it assumed a content role (*moreover*) rather than a function role (*beyond*). The application of such an argument would require an independent measure of meaning complexity or richness which is lacking at the present moment (at least in French). Moreover, any difference in meaning would have to be determined on the basis of the word's syntactic or grammatical function. This then implies that function would have to be at least tentatively extracted before meaning. In other words, one way in which more time could be spent processing the word *outré*—or any other word that could assume both a content and a function role—occupying a content role, would be for readers to extract sufficient syntactic or structural information from the phrase, sentence, or local context to tentatively attribute content roles to such instances. This suggestion, however, is essentially what the structural account insists on: The extraction of structure precedes and supports the analysis of meaning.

In sum, in its current form, the processing time hypothesis can account for the effects of target letters in all experiments and for the effects of word function obtained in Experiments 1 and 2. However, in our view, this explanation is not a satisfactory account of the word function effect obtained in the third and fourth experiments. We now turn to the alternative interpretation—namely, the structural account.

In contrast with the processing time hypothesis, the structural account permits a straightforward interpretation of the word function effect found in the four experiments reported here. Koriat and Greenberg (1991, 1993, 1994, 1996) have proposed that in processing text, readers first attempt to establish a tentative frame of the phrase or sentence and then use that frame to support the integration of semantically informative units into a meaningful representation. As the meaning of the text unfolds, the prominent function cues, used to build the frame, recede to the background. Thus, it would be more difficult to detect a letter in words assuming a function role. However, if function words assume a content role, they would contribute less to the structural frame, and consequently they should remain in the foreground, producing fewer omissions. More specifically, Koriat and Greenberg (1994) have suggested the following:

...the structural account assumes a hierarchical organization with a dominance shift from structure to meaning and places the missing-letter effect at a *post-access* [*italics theirs*] stage, after the phrase has been parsed into its constituent morphemes, and after the function morphemes have been interpreted in their structure-supporting role. (p. 348)

This proposal elegantly accounts for the main results of the present experiments, since in all cases the higher omission rates were found when words assumed such a structure-supporting role.

The structural account can also account for the overall difference in omission rate between Experiments 1 and 2—using, respectively, the target letters *d* and *l*—by drawing attention to differences in methodology. In fact, the critical words used in Experiment 1 have only one possible meaning in French—as either function or content words—whereas in Experiment 2, the same words assumed both function and more content-laden roles. Consequently, in Experiment 1, both contextual and lexical factors might have revealed the structural role of target words, whereas in Experiment 2, readers could only rely on contextual factors (Koriat & Greenberg, 1991, 1996). This would allow a faster identification of their structural role in the former, leaving them for a shorter period of time in the foreground. More omissions should be observed as a result.

However, in its present form, the structural account cannot explain the target letter effect found in the last two experiments. Koriat and his collaborators have also observed on some occasions an effect of target letter on detection accuracy, but they did not find systematic variations requiring a specific explanation (Koriat & Green-

berg, 1996). Nonetheless, the hypothesis suggested by Healy and her associates that the visual properties of letters may influence their identification speed, which in turn would influence detection accuracy, does not seem incompatible with the structural account. In fact, it could be argued that words supporting the structural frame of the sentence stay more briefly in the foreground than words providing more meaning, but for both types of words some letters would be easier to detect than others.

The need to incorporate new elements into the structural account in order to encompass a larger range of phenomena, including target letter effects, is also evidenced by Healy's (1994) and Moravcsik and Healy's (1995) comments. They argued that the unitization account and the processing time hypothesis can account for most if not all of the effects uncovered with the letter detection task, as well as for other related phenomena, whereas the structural account is less comprehensive. For example, their proposals can easily account for the higher rate of omissions found for more common content words than for less common content words, while the structural account is silent on these matters. On the other hand, the structural account can successfully account for the influence of word function, while the processing time hypothesis has more difficulties accounting for this. In our view, an integration of the processing time hypothesis and the structural account would provide the most compelling framework, given the explanatory power of familiarity.

In their discussion of possible mechanisms underlying the proposed dominance shift from structure to meaning, Koriat and Greenberg (1994) discuss one possibility that encompasses familiarity. This proposal has the advantage of integrating familiarity, while insisting on the hypothesis of structural precedence that the present results support. Basically, the proposal is that the coding of structure depends on fast, conceptually driven processing that is aided by the familiarity of morphemes, syntactic structure, and contextual constraints. Such an account simultaneously insists on bottom-up, familiarity driven processes and top-down or conceptually driven structure extraction. It appears reasonable to argue that function morphemes are typically integrated into familiar phrase structures: phrase structure is, relative to phrase content, far more familiar and redundant. Given this familiarity, an evolving structural frame can be thought of as creating expectancies with respect to an upcoming contributor to the structure (including, but not limited to, function words; Koriat & Greenberg, 1994). These expectancies will promote faster processing and will leave the reader with less time available for letter detection in the structure-supporting units. Once this process is sufficiently advanced, the reader can turn to the interpretation of meaningful units. There is ample evidence to support the hypothesis that familiarity aids in the extraction of meaning (Moravcsik & Healy, 1995). This would in turn create a situation in which target detection is more swiftly taken care of, producing errors

(see Healy, 1994, for a discussion of the missing-letter effect as a speed-accuracy tradeoff). Although this is a speculative account, it could prove to be a productive framework. Together with the work of Koriat and Greenberg, as well as that of Healy and co-workers, it points toward the investigation of the effects of syntactic factors and contextual constraints, within the letter detection task.

CONCLUSION

In sum, the results of this study demonstrate a contribution of word function that is not confounded with prosodic stress, frequency of orthographic pattern, or frequency of meaning. Although the processing time hypothesis can account for some of the reported findings, it cannot, in its current form, explain how word function affects letter detection performance independently of familiarity. On the other hand, the structural account can account for the findings of the four experiments in a straightforward manner. However, it has some difficulties explaining other findings. An account in which both structural precedence and familiarity play important roles in the reading process would provide the most comprehensive explanation of the type of phenomena discussed here.

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NOTE

1. According to *Collins Robert* (1987), there is no direct translation of this conjunction. English equivalents could include *however* or *whereas*.

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**38th Annual Meeting of the Psychonomic Society
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The 38th Annual Meeting of the Psychonomic Society will be held in Philadelphia, Pennsylvania, at the Marriott Hotel. Registration will begin on Thursday evening, November 20. A poster session will be held on Thursday evening; spoken sessions will begin on the morning of Friday, November 21. Sessions will continue through noon on Sunday, November 23.

Programs and hotel reservation cards will be mailed to members and associates in September. Additional programs will be available at the meeting registration desk for \$10.00.

For further information, please contact the Secretary-Treasurer of the Society: Roger L. Meilgren, Department of Psychology, Box 19528, University of Texas, Arlington, TX 76019-0528 (phone: 817-272-2775; fax: 817-272-2364; e-mail: mellgren@uta.edu).