There is a Missing-Phoneme Effect in Aural Prose Comprehension

Jean Saint-Aubin

École de psychologie, Université de Moncton

Raymond M. Klein

Department of Psychology & Neuroscience, Dalhousie University

Mireille Babineau

Department of Psychology, Université du Québec à Montréal

John Christie

Department of Psychology & Neuroscience, Dalhousie University

David W. Gow

Cognitive/Behavioral Neurology Group, Massachusetts General Hospital

Correspondence to Jean Saint-Aubin:

École de psychologie

Universté de Moncton

18, avenue Antonine-Maillet

Moncton, New Brunswick

E1A 3E9, CANADA

E-mail: jean.saint-aubin@umoncton.ca

Abstract

When participants search for a target letter while reading, they make more omissions if the target letter is embedded in frequent function words than in less frequent content words. This phenomenon, called the missing-letter effect, has been considered a window on the cognitive mechanisms involved in the visual processing of written language. In the present study, one group of participants read two texts for comprehension while searching for a target letter and another group listened to the narration of the same two texts while listening for the corresponding target letter's phoneme. The ubiquitous missing-letter effect was replicated and extended to a "missing-phoneme effect". Item-based correlations between the letter and the phoneme detection tasks were high leading us to conclude that both procedures reflect cognitive processes that reading and listening have in common which are rooted in psycholinguistically driven allocation of attention.

Key words: reading; audio processing; attention; psycholinguistic processes; letter search

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Fifty years ago, Corcoran (1966) made a stunning discovery: When asked to read a text for comprehension while searching for a target letter, fluent readers miss a disproportionate number of *e*s in *the* compared to other words. This finding has since been generalized to various words and languages (Arabic, Chinese, Dutch, English, French, German, Greek, & Hebrew) in studies that repeatedly find that readers miss a disproportionate number of target letters in function than in content words (for reviews, see Healy, 1994; Klein & Saint-Aubin, 2016). A famous demonstration was provided when Read's (1983) participants were asked to search for *f*s in the following sentence: FINISHED FILES ARE THE RESULT OF YEARS OF SCIENTIFIC STUDY COMBINED WITH THE EXPERIENCE OF YEARS. Even though there are 6 occurrences of the letter *f*, between 85% and 90% of adult readers detect only 3 *f*s when they read the sentence for the first time, missing those in the frequent function word *of*. This phenomenon was coined by Healy, the missing-letter effect and is formally defined as the higher omission rate for target letters embedded in function than in content words and in frequent than in rare words (for reviews of the earlier work see Healy, 1994; Koriat & Greenberg, 1994). It is worth noting that in previous missing-letter effect studies, the contribution of word function has been isolated by contrasting function and content words of the same frequency (e.g., *at* vs. *it*), and the contribution of word frequency has also been isolated by contrasting content words of various frequencies (e.g., *thought–thicket*) (e.g., Roy-Charland & Saint-Aubin, 2006). However, because function words are intrinsically more frequent than content words, in most studies in the missing-letter effect literature, word frequency and word function co-vary.

For five decades, this missing-letter effect has been used as a window illuminating a wide range of cognitive factors involved in reading, including visual factors such as eye movement patterns (e.g., Greenberg, Inhoff & Weger, 2006; Saint-Aubin & Klein, 2001) and letter position within a word (Assink & Knuijt, 2000; Guérard, Saint-Aubin, Poirier, & Demetriou, 2012); lexical and syntactic factors such as word frequency (e.g., Minkoff & Raney, 2000; Moravcsik & Healy, 1995; Roy-Charland & Saint-Aubin, 2006) and word function (e.g., Koriat & Greenberg, 1991; Saint-Aubin & Poirier, 1997); and reading specific factors such as text familiarity (Greenberg & Tai, 2001; Saint-Aubin, Roy-Charland, & Klein, 2007), reading skills and reading development (e.g., Cunningham, Healy, Kanengiser, Chizzick, & Willitts, 1988; Drewnowski, 1981; Saint-Aubin & Klein, 2008; Saint-Aubin, Klein, & Landry, 2005).

Surprisingly, even if it is well accepted that reading relies heavily on auditory processing, the auditory analog of the missing-letter effect has not been investigated. Our simple objective was to determine if a similar "missing-phoneme effect" would be observed when participants are listening to a passage presented aurally while simultaneously listening for a target phoneme[1]. Although this empirical project was conceived before we developed our attentional disengagement (AD, Roy-Charland, Saint-Aubin, Klein & Lawrence, 2007) account of the missing-letter effect, we now recognize that it might be viewed as a test of that account. According to the AD model, omission rates are higher the earlier attention disengages from a lexical item (lemma) containing the target letter. Attentional disengagement is assumed to depend critically on cognitive and psycholinguistic factors that would be operating in a relatively parallel manner whether one were reading or listening. On this view, a missing-phoneme effect should be observed and ought to behave much like the missing-letter effect. Alternatively, it is difficult to see how purely visual accounts of the missing-letter effect would predict a missing-phoneme effect (see, e.g., Greenberg, Healy, Koriat, & Kreiner, 2004; Hadley & Healy, 1991). For instance, according to the parafoveal processing hypothesis, letters are more frequently missed in function than in content words, because the former are skipped more often than the latter. Because visual acuity is lower for skipped words, it would be harder to detect a target letter embedded in them. Within this view, there is no a priori reason for observing an auditory equivalent to the missing-letter effect.

This standard phoneme monitoring task, pioneered by Foss (1969) has been used to explore attention and a wide variety of psycholinguistic issues (Connine & Titone, 1996). As described in more detail in the method section, two groups of Francophone participants were recruited. One group searched for target letters in the standard paper-and-pencil version of the task. They read two carefully constructed French passages for meaning while crossing off all of the target letters. The other group listened to narrated versions of the same passages for meaning while signaling with a key-press whenever they heard the target phoneme. The key dependent variable was how often each critical occurrence of the target (letter/phoneme) was missed.

Method

Participants

Ninety-six unpaid undergraduate students (66 women, 30 men; 48 in each detection task) from Université de Moncton took part. It is worth noting that this sample size is typical of studies in the missing-letter effect literature. All participants were native-French speakers.

Materials

Two prose passages were presented to participants. The *des* text and the *pour-cour* text used by Saint-Aubin, Klein, and Roy-Charland (2003, Experiment 1 and 5, respectively). Using two different passages like those we selected for this study helps increase the generalizability of the results. With multiple presentations of a single function word (*des*, plural indefinite article) and fewer presentations of different content words, the *des* passage is more typical of normal speech and normal text with a high rate of repetition of a few function words and a low rate of repetition of multiple content words. However, in this situation, frequency of occurrences within the text is necessarily confounded with word function. With the same number of repetitions of a single function word (*pour,* preposition meaning for) and a single content word (*cour*, noun meaning yard), the *pour-cour* text is less natural, but it overcomes the confound by having the function and the content words repeating equally often.

The *des* and the *pour-cour* texts were composed of 593 and 809 words and the target letters *d* and *r*, respectively. In the critical words, the target letter *d* was always associated to the phoneme /d/ and the target letter *r* was always associated to the phoneme /ʁ/. The *des* text contained 24 instances of the French plural indefinite article *des*, with a frequency count of 10,629 occurrences per million, and 24 instances of three-letter control content words beginning with the letter *d*, with an average frequency count of 454 occurrences per million (*dis* [say], *dit* [says], *dix* [ten], *don* [gift or donation], *dos* [back], *duc* [duke], *duo* [duet], *due* [due], *dur* [hard]) (New, Pallier, Brysbaert, & Ferrand, 2004). The 24 occurrences of the control content words were composed of nine different words for which there were between one and four occurrences. The *pour-cour* text contained 16 occurrences of the preposition *pour* (for), with a frequency count of 6,200, and 16 occurrences of the noun *cour* (yard), with a frequency of 105 occurrences per million (New et al., 2004). In addition, the target *d* was embedded in 14 nontest words for the *des* text and the target letter *r* was embedded in 49 nontest words for the *pour-cour* text.

For each text, each word containing the target letter and phoneme, be it critical or not, was separated from the previous and the following word containing a target by at least four filler words without the target letter or target phoneme. The test words were not included in the first and the last sentence of the text, they were never at the beginning or the end of a sentence, and they were never adjacent to a punctuation mark. Furthermore, in the *pour-cour* text, each sentence with the function word *pour* was matched with a sentence including the content word *cour*, in the following fashion. In each sentence of a pair, the word preceding the target word held the same number of letters and belonged to the same syntactic category (function or content word). The same pairing procedure was applied to the word following the target word.

The texts were recorded in a professional studio by a professional radio reporter from Radio-Canada, the Canadian French public radio. The narrator was instructed to read the texts in a neutral manner and no information was provided about the purpose of the experiment. The recording of the *des* text lasted 3 min 11 sec and the recording of the *pour-cour* text lasted 5 min 6 sec. Overall, in the critical texts, a minimum of 929 ms separated the onset of each target phoneme. While in the letter detection task, adults participants rarely need practice with the task, pilot testing revealed the need for some practice with the less familiar phoneme monitoring task. Consequently, in addition to the two experimental texts, three practice sentences and one practice text were recorded. Each practice sentence was composed of one and only one word with the target phoneme. A different target phoneme was used per practice sentence (/k/, /l/, & /t/). The recording of each practice sentence lasted between 3 and 5 sec. For the practice text, participants searched for the target phoneme /a/ that was embedded in 31 words. The recording lasted 2 min 22 sec.

Procedure

Participants took part individually in a private room, in one session lasting approximately 15 min. In the letter detection task, participants received a stapled package with an instruction sheet in front of it. The experimenter read the instructions aloud, while the participant read them silently. The instructions encouraged the participants to read the texts for comprehension at their normal reading speed. They were told that whenever they came across a target letter (either in upper- or lower-case) they were to circle it. They were also warned not to slow down their reading speed to detect all target letters, and not to backtrack to circle a letter they had missed. Participants were also warned that they would read two texts with a different target letter for each text and that after each text, they would have to answer five multiple-choice comprehension questions. This procedure was used to promote reading for comprehension. To familiarize participants with this task, they were asked to read the instruction sheet again and to circle all *t*s.

In the phoneme monitoring task, instructions were presented on the computer screen. The experimenter read the instructions aloud, while the participant read them silently. After reading the instructions, the participant pressed the spacebar and a blank screen appeared. The experimenter then said the target phoneme and asked the participant to repeat it to ensure proper perception of the phoneme. If the participant produced the wrong phoneme, the experimenter repeated it and asked the participant to produce it again. After successful production of the phoneme by the participant, s/he pressed the spacebar and the narration of the first sentence began. Presentation of the three practice sentences, of the practice text and of the two critical texts was always self-initiated by pressing the spacebar. Participants were asked to click a mouse immediately when they heard a target phoneme, and were encouraged to respond as quickly and accurately as possible as both speed and accuracy were being measured.

Methods of analysis

Error results are presented first, followed by response latencies for the phoneme monitoring task, and correlations between the two tasks. As it is usually the case in the letter detection task, only omissions were included as errors because with the paper and pencil procedure participants never circle a wrong letter and for the phoneme monitoring task, it is impossible to attribute a false alarm to a particular presented phoneme.

For both texts in the listening paradigm, target phonemes were considered detected when the response occurred during the first 929 ms after the onset of the word. This criterion was chosen because, for the auditory recordings, it was the shortest interval before the onset of another word in which the critical phoneme was embedded. Consequently, it is the longest possible interval during which a response could unambiguously be attributed to the critical target-containing word. A similar criterion has been applied in the past with the rapid serial visual presentation procedure and with eye movement monitoring (see, e.g., Healy, Oliver & McNamara, 1987; Roy-Charland et al., 2007; Saint-Aubin & Klein, 2001; Saint-Aubin, Kenny, & Roy-Charland, 2010).

Result

Omission rates for the reading and listening tasks for the two passages and word classes are shown in Figure 1 accompanied by the effects with 95% confidence intervals. Detailed information can be found in Table S1 and S2 in the Supplemental Material available online. As seen from the figure, the missing-letter effect (in the reading task: greater omissions for targets in function than in content words) in both passages is strong and positive. The primary and novel finding is that this is also true for the missing-phoneme effect for both passages. It is also notable that the missing phoneme-effect is substantially larger than the missing-letter effect in both passages.

With the listening task, it was also possible to compute response latencies between the onset of the word presentation and the button press indicating a detection. It should be noted that the analyses are based on 46 of 48 participants for the *des* text, because two participants made no detections on the function words *des* and on 35 of the 48 participants for the *pour/cour* text because 13 participants made no detections on the function word *pour*. As we expected (see e.g., Saint-Aubin et al., 2003), results showed that participants took longer to detect a phoneme in the function word *des* (M = 622 ms) than in control words (M = 564 ms), $t(45) = 5.60$, Cohen's d for repeated-measures = 0.84, $p < .0001$, 95% CI of the difference [36.93, 78.38], and in the function word *pour* (M = 674 ms), than in the content word *cour* (M = 523 ms), $t(34) = 6.02$, d = 1.04, $p < .0001$, 95% CI of the difference [99.63, 201.31][2]. Two kinds of further analyses were conducted to increase our confidence in the similarity of these two effects.

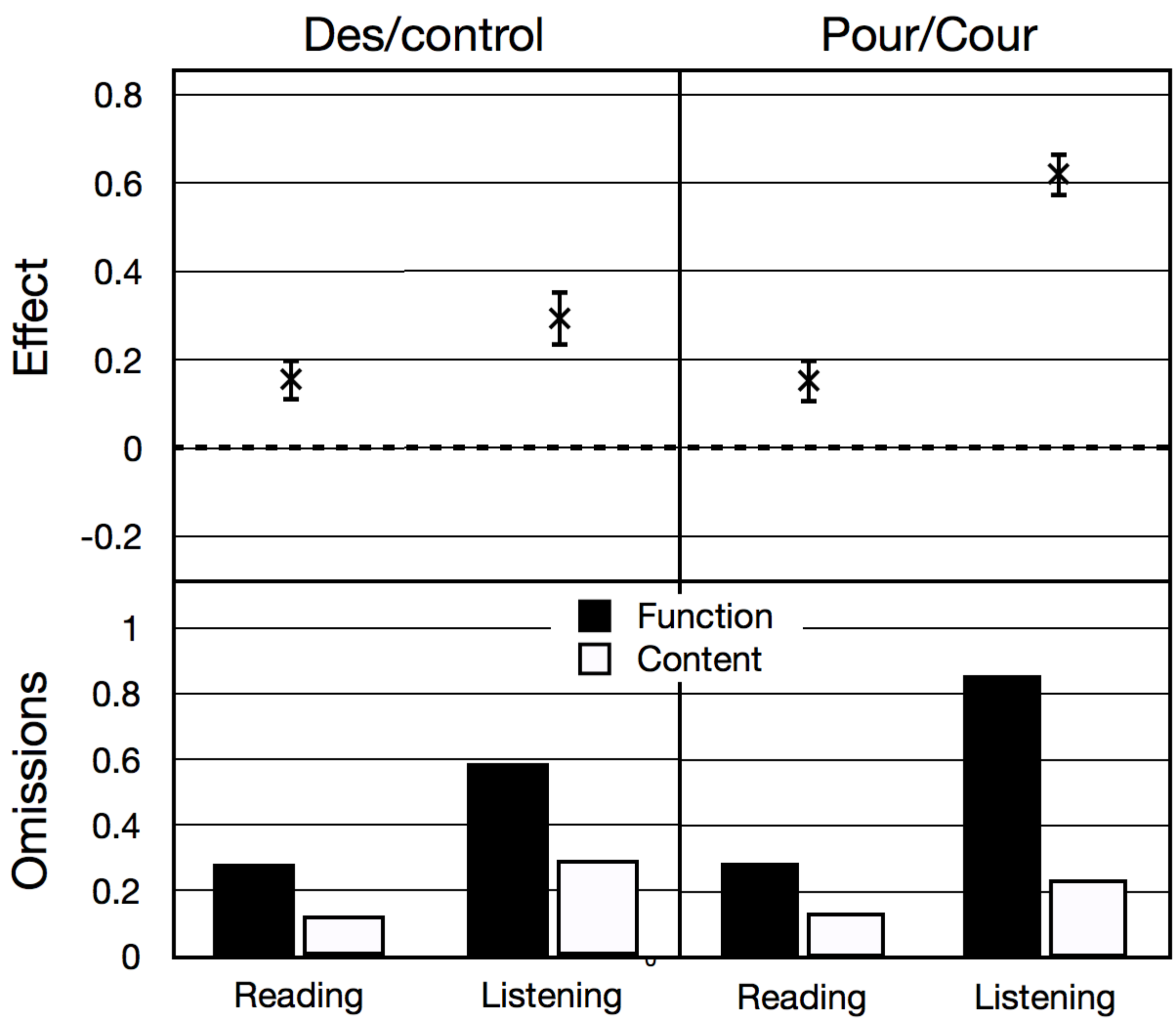

Figure 1.

Omission rates for targets (letters and phonemes) embedded in critical function words (black bars) and control content words (white bars) as a function of task (reading versus listening) and passage (*des* versus *pour/cour*). The error bars on missing-letter and missing-phoneme effects plotted in the top panel are 95% confidence intervals calculated with a stratified bootstrap procedure.

We conducted correlational analyses of omission rates across all the items in both passages. The correlation across the reading and listening tasks was significant for both the *des* passage ($r_{46} = .60$, $p < .0001$) and for the *pour/cour* passage ($r_{30} = .74$, $p < .0001$). A scatterplot showing the data combined across tasks is presented in Figure 2.

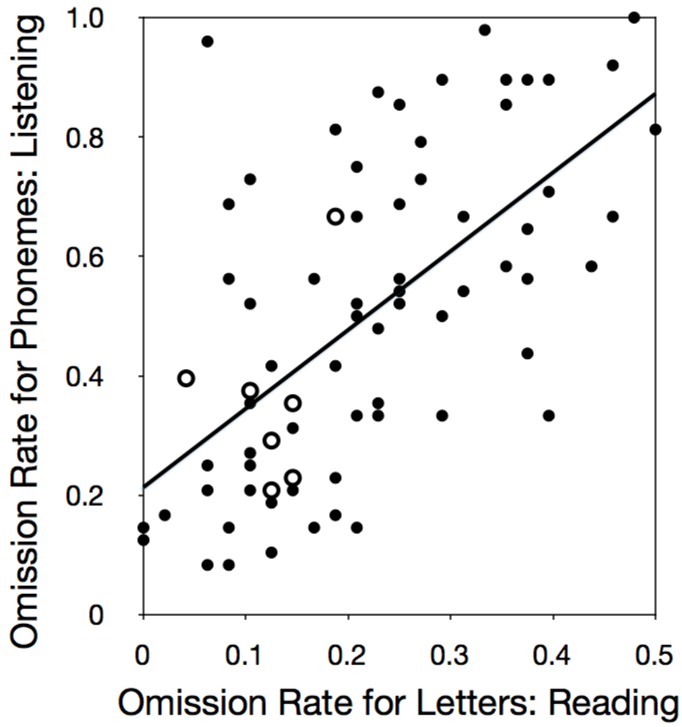

Figure 2.

Scatterplot showing omission rates from each task (with reading on the X-axis and listening on the Y-axis), for each target-containing word in both passages and the best fitting function ($r_{78} = .63$, $p < .0001$). The larger unfilled circles represent identical data from two different items.

We recognized that in a spoken passage, there might be acoustic differences between function words and content words. Because omissions might be affected by the acoustic properties of the target phonemes, we first determined whether the two classes of words differed on a variety of acoustic properties. One property on which they did differ significantly in both passages was word duration, with longer durations for content (0.319 sec) than function words (0.148 sec), $t(78) = 7.96$, Cohen's $d = 2.06$, $p < .0001$, 95% CI of the difference [0.128, 0.214]. Moreover, the raw correlation between word duration and omission rate was significant ($r_{78} = -.59$, $p < .0001$). Given this finding we embarked on model comparisons to determine whether the role of the word (function vs. content) had any explanatory power over and above word duration using multi-level logistic regressions with both participants and items as random effects (Baayen, 2008) and AIC as the metric of model fit. For those unfamiliar with using AIC, only relative AIC scores matter with lower values indicating better model fit. Differences between models greater than 10 can be considered large amounts (Symonds & Moussalli, 2011). In our analysis, the comparison model contains both role and word duration as predictors. When word duration is removed, leaving only role, the AIC changed very little, reducing by 1. This suggests word duration is barely explaining variability over and above the extra complexity it adds to the model when just role is also present. Removing the role variable, leaving only word duration, raised the AIC by 46, a very substantial increase suggesting that role is a much more important explanatory variable in the model than word duration. In short, a model with role explains the omissions about equally well whether word duration is included or not, but one with only word duration is much poorer. Therefore, even though word duration has a significant effect on omissions, it does not account for our finding that phonemes of function words are missed substantially more than the phonemes of content words.

Discussion

Results of the present study are clear and straightforward: We obtained a large missing-phoneme effect in the listening task and it correlated well, on an item-by-item basis, with the missing-letter effect in the reading task. In addition to missing more phonemes in function than in content words, listeners also took longer to detect the target phoneme in the former. This pattern of response latencies, nicely replicates what has been observed in the reading domain (see e.g., Roy-Charland et al., 2007; Saint-Aubin et al., 2003).

A strictly bottom-up visual hypothesis has also been proposed to explain the missing-letter effect: the parafoveal processing hypothesis (see, e.g., Greenberg et al., 2004; Hadley & Healy, 1991). It is assumed that word form information is picked up parafoveally whereas letter identification is largely dependent upon the detailed information provided by foveation of the word. Within this view, the high rate of skipping function words can be due to their orthographic properties alone (Angele & Rayner, 2013; Angele, Laishley, Rayner, & Liversedge, 2014) or in conjunction with psycholinguistic information about the syntax and semantics of the passage one is reading (Koriat & Greenberg, 1991). By the preceding assumption, detecting a target letter would be difficult if the word was skipped. Hence, by this hypothesis, a missing-letter effect is generated by the higher probability of skipping rather than fixating function words in reading (Carpenter & Just, 1983; Gauthier, O'Regan, & Le Gargasson, 2000; O'Regan, 1979). The similar results we have generated here when participants were listening to a passage while searching for a phoneme, in conjunction with previous results we obtained in the reading domain, encourage us to reject the parafoveal processing hypotheses (Roy-Charland et al., 2007; Saint-Aubin et al., 2003).

The missing-letter and missing-phoneme effects appear to have the same cause: Less attention is devoted to function than to content words for a passage to be understood. Because function words are more predictable (Drieghe, Rayner, & Pollatsek, 2005; Roy-Charland et al., 2007), their meanings are primed before the word is encountered. This implies that when attention is allocated to function words, the reader has a head start in processing them semantically. Attention, whether operating within the visual or auditory modality (Klein & Lawrence, 2011), disengages from them sooner than from content words (Roy-Charland et al., 2007). Although not tested here, our model also assumes that attention is disengaged faster from frequent words compared to rare words. It is further assumed that information about the physical (visual or acoustic) properties of words accumulates when attention is engaged on them. Consequently, faster attention disengagement means that physical information needed for the detection tasks is less accurately represented. Detections are assumed to be based on quality or strength of representation of the physical properties of each target and these representations are assumed to decay once the target-containing lemma is disengaged from. In this attentional disengagement model, more strongly activated target representations will generate a higher percentage of hits and faster detection reaction times (see Roy-Charland et al., 2007, for a more complete presentation of this model and how it predicts the reaction time disadvantage for targets embedded in function words).

The remarkable similarity across the two domains would not come as a surprise for researchers considering that reading was built upon listening processes. As a matter of fact, the results observed here are a logical extension of the ideas put forward by Koriat and Greenberg when they developed their structural account aimed at explaining the missing-letter effect.

> It is our thesis that the processes underlying the comprehension of both spoken and written messages recapitulate the general architecture of speech production: The extraction of structure precedes and paves the way for the extraction of meaning. Essentially, both the listener and the reader strive to quickly establish a rudimentary

> frame-and-slot organization of the phrase or the sentence into which incoming units can be placed. (Koriat & Greenberg, 1994, p.346)

Having demonstrated the presence of a missing-phoneme effect in listening and its similarity to the missing-letter effect in reading, the current study opens the door to researchers to further explore the relationship between reading and listening.

Footnotes

[1]It is worth noting that in two previous studies, participants listened to a short narration while being required to write down all words containing a target letter (Schneider, Healy, Ericsson, & Bourne, 1989; Schneider, Healy, & Gesi, 1991). Results of this letter detection task were mixed with a missing-letter effect restricted to some letters and to participants who reported using a visual search based on a mental image. However, because phoneme and not letters are present in auditory passages this odd task requires phonological to orthographic conversion and therefore is not suitable for answering our question whether there is a missing-phoneme while listening to a passage.

[2]When the response latencies were modelled using linear mixed effects regression with both participant and item random effects while the predicted response latencies were slightly different from those reported here, the effect of word role remained highly significant.

Author Contributions

All authors made a significant contribution to the study. J. Saint-Aubin was involved at all stages of the project. R. M. Klein developed the study concept and contributed with J. Saint-Aubin to the study design. Testing, data collection and data coding were performed by M. Babineau under the supervision of J. Saint-Aubin. Audio analyses were planned by D. Gow, and performed by M. Babineau under the supervision of D. Gow. Statistical analyses were computed by J. Christie and J. Saint-Aubin. J. Saint-Aubin and R. M. Klein wrote the manuscript, and D. Gow and M. Babineau provided critical revisions. All authors approved the final version of the manuscript for submission.

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Supplemental material

Table S1

Omission rate as a function of role, text, and task, as well as correlations between omission rate for function and content words, effect size and confidence intervals as a function of text and task.

	Word Role				
Condition	Content	Function	*r*	Effect	CI of effect
Des text					
Reading	.125 (.120)	.282 (.227)	.61	.156	0.106, 0.207
Listening	.295 (.166)	.588 (.231)	.38	.293	0.229, 0.359
Pour / Cour text					
Reading	.137 (.137)	.289 (.241)	.62	.152	0.100, 0.204
listening	.237 (.164)	.857 (.134)	.25	.620	0.566, 0.672

Note: Standard errors are provided in parentheses.

Table S2

Summary of multi-level logistic regressions computed on omissions with both participants and items as random effects.

	Word Role			
Condition	Content	Function	Effect	CI of effect
Des text				
Reading	-2.357	-1.244	1.113 (0.292)	0.513, 1.630
Listening	-1.029	0.465	1.494 (0.256)	0.993, 1.906
Pour / Cour text				
Reading	-2.011	-1.170	0.841 (0.241)	0.403, 1.362
listening	-1.256	2.159	3.415 (0.311)	2.636, 3.763

Note: Standard errors are provided in parentheses.