The Impact of Letter Detection on Eye Movement Patterns During Reading: Reconsidering Lexical Analysis in Connected Text as a Function of Task

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The impact of letter detection on eye movement patterns during reading: Reconsidering lexical analysis in connected text as a function of task

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Abstract

A comparison was made between reading tasks performed with and without the additional requirement of detecting target letters. At issue was whether eye movement measures are affected by the additional requirement of detection. Global comparisons showed robust effects of task type with longer fixations and fewer word skippings when letter detection was required. Detailed analyses of target words, however, further showed that reading with and without letter detection yielded virtually identical effects of word class and text predictability for word-skipping rate and similar effects for different word viewing duration measures. The overall oculomotor pattern suggested that detection does not substantially shift normal reading movements in response to lexical cues and thereby indicated that detection tasks are informative about word and specifically word class processing in normal reading.

To evaluate processes that contribute to reading, scholars have used a variety of tasks. Often these tasks tested reading-related component skills outside of a reading context. Specifically, word identification has often been examined with tasks that require a discriminating response to an individually presented letter string, as occurs in word-naming and item classification tasks (see Rayner & Pollatsek, 1989). Another approach has been to examine word recognition processes under relatively natural task conditions by monitoring the influence of specific word properties on responses when words are embedded in sentence or passage contexts and when the primary task consists of sentence or passage comprehension (Rayner, Raney, & Pollatsek, 1995).

One such reading task, the letter detection task, requires readers to detect all occurrences of a specific target letter in words during reading, and in many cases to answer questions regarding passage content (e.g., Healy, 1976; Koriat, Greenberg, & Goldshmid, 1991; Moravcsik & Healy, 1995). The methodological advantages of this task are that it is easily administered, that it can be applied to groups, and that it has reasonable ecological validity in that subjects perform the detection task while reading off pages for meaning. The obvious disadvantage is that the secondary task could influence the primary linguistic task, which involves word recognition and sentence comprehension. Nearly three decades of research with the letter detection task is

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predicated on the assumption that letter detection leaves linguistic processing relatively intact. The addition of a secondary letter detection task is likely to increase overall task demands, however, which could impede the success with which the primary linguistic task is completed.

Research with the letter detection task has yielded a wealth of empirical data that show a wide range of linguistic effects on the frequency with which target letters are missed in a word (also known as the missing letter effect, MLE). The MLE is significantly higher for function words than for content words (Koriat & Greenberg, 1994), and it increases with the predictability of sentence context and frequency of word occurrence (Healy, 1994). The modulation of the MLE by linguistic information is of theoretical significance in that it reveals dynamic interplay of letter-, word-, and context-level processes. The distinctively higher MLE for function words, in particular, reveals the unique role of these words in reading. According to the structure-building hypothesis (Greenberg, Healy, Koriat, & Kreiner, 2004), function words are used early during sentence processing to determine the boundaries of structural units. They recede in the background of processing thereafter and are less accessible for letter search while word and sentence meanings are in progress. The structure-building hypothesis can also explain why some properties of function words, such as their location in a previously read sentence, are difficult to recall (Inhoff & Weger, 2005).

Word recognition during reading can also be studied without the addition of a secondary task. Eye movements, which are part of normal reading, have been measured and analysed as a function of specific word properties. The results have shown that the time spent viewing words during reading is a function of their linguistic properties (Rayner & Pollatsek, 1989; Rayner et al., 1995). Word-viewing durations increased, for instance, with decreases in contextual constraint (Balota, Pollatsek, & Rayner, 1985) and with decreases in the frequency of occurrence of to-be-identified words, and they are particularly short for (high-frequency) function words (Inhoff & Weger, 2005).

Eye movements during reading with and without a secondary letter detection task have been examined to determine whether the addition of the secondary task influences reading. If this is the case, then this should be expressed in a significantly altered eye movement pattern when the secondary task is added. Vitu, O'Regan, Inhoff, and Topolski (1995; also Inhoff, Topolski, Vitu, & O'Regan, 1993) showed that several oculomotor parameters were influenced by the addition of the secondary task. Eye movements (saccades) were smaller, and the following viewing times (fixations) were longer when letter detection was added. Skips over a word were less likely, and multiple fixations on a word were more probable when letter detection was required. The data did not reveal, however, whether these effects of the secondary task on eye movements were accompanied by a different usage of available linguistic information for word recognition and sentence comprehension in the letter detection condition.

Rayner and Fischer's (1996) study was more diagnostic in that respect. It examined eye movement patterns in a reading task and a word detection task for passages that contained high- and low-frequency words. Although the reported analyses did not include a direct comparison of eye movement patterns in these two tasks, skipping rates appeared to be considerably higher, and the duration of the first fixation on words appeared to be lower in the detection task. Critically, separate analyses of the reading and detection tasks revealed more word skipping and shorter word-viewing durations for high-frequency words than for low-frequency words in reading. By contrast, word frequency did not influence eye movements in the detection task. Rayner and Raney (1996) also examined eye movements during passage reading and word search in which readers were encouraged to scan without considering meaning. The frequency of selected target words affected word-viewing durations in the reading but not in the detection task, and global measures showed longer fixation times in the reading task. Together, these two studies indicated that word identification differs in reading and search tasks. In contrast, Saint-Aubin and Klein (2001) found evidence that even with a detection task the linguistic status of three-letter words (function vs. content) still affected where the eye moves, but they collected no data on when the eye moved. Moreover, they did not contrast eye movement patterns during reading with and without detection.

Rayner and Fischer's (1996; Rayner & Raney, 1996) reading and search tasks required the finding of a specific target word. Only in the normal reading condition, however, was there a check for comprehension. It may be the case that information usage differed when detection was performed for its own sake from when it was performed in conjunction with reading. Searching for letters in words, as is typical in letter detection studies, may encourage sublexical and full lexical analysis; word search, by contrast, could involve a search for visual form (Rayner & Fischer; Rayner & Raney). Searching for "zebra", as required by Rayner and Fischer, could have invoked a surface-feature-oriented processing of words, in particular because the target word "zebra" started with the relatively rare letter, "z". Shorter mean viewing durations in the word search task than in the reading task suggested that word processing there could have been form driven. In fact, Rayner and Raney's participants were encouraged to scan the text quickly in the word search as compared to reading for meaning in the read-only task, thus confounding the presence of a secondary task (Oliver, Healy, & Mross, 2005). Saint-Aubin, Klein, and Roy-Charland (2003) did observe common patterns for both word and letter search tasks; however, in their work subjects were always required to read for comprehension. In contrast, the comparison of the reading task with and without a secondary letter detection task revealed longer viewing durations and fewer skips when a letter was to be detected (Inhoff et al., 1993; Vitu et al., 1995).

The main goal of the current study was to examine whether the addition of the often-used secondary letter detection task influences the linguistic processing of text. As in all earlier comparisons of reading and search tasks, we first examined global oculomotor parameters, but then importantly these same oculomotor responses to specific target words were also assessed. This involved comparisons of different word classes, of function and content words, under different levels of contextual familiarity. Following Rayner and Fischer's (1996) suggestions, we manipulated task type between subjects to maximize the task type effects, and we manipulated word class and contextual constraint within subjects to maximize the experimental power of these variables. If the added search task attenuated the use of linguistic information, as occurred in Rayner and Fischer, then word class and context effects should be attenuated or nonexistent when letter detection is added to the primary task of reading. Alternatively, the addition of a secondary letter detection task may leave word recognition intact, thus leaving word class and contextual effects undiminished. In both conditions subjects were instructed to read at normal rates and for comprehension.

METHOD

Participants

A total of 57 native English-speaking students from Binghamton received experimental course credit for participating. Of these, 27 experienced the reading task, and 30 performed reading plus letter detection.

Design and materials

Familiar texts were taken from popular children's material including highly recognizable nursery rhymes, song verses, and movie jingles. A total of 40 familiar verses were collected from which 40 more matching "unfamiliar" verses were derived. A total of 18 verses from each set (familiar and unfamiliar) were included in the experimental portion of the study. One verse from each set was used to begin and one to close the presentation, and neither of these verses was included in the scored text. Furthermore, six verses were altered to create half familiar and half unfamiliar verses, which were also distributed among the experimental phrases. Finally, five other familiar and five derived unfamiliar verses were set aside as practice. Note, although some familiar verses were used in the practice, warm-up, and closing verses, others were used to simply generate the unfamiliar verses for the same purposes.

The 18 experimental verses for each condition contained designated potential target content and function words that contained the letter t. Target words were neither preceded nor followed by another word containing the target letter t, and target words never appeared as the first word in a sentence. In total, within the familiar and unfamiliar verses there were 25 *the*, 8 *to* function target words, and 9 three-letter, 7 four-letter, and 5 five-to-six-letter content words.

Unfamiliar and familiar verses were matched for word length and contained the same selected target words at the same verse location. Further, the grammatical structure surrounding the target words was held constant for familiar and the derived unfamiliar counterpart. Verses contained 11–48 words, with an average of 23 words appearing in 1–4 sentences. Finally, the number of appearances of *t* was matched for the familiar and derived unfamiliar verses. Examples of familiar and derived unfamiliar verses with target words underlined appear below.

1. Jack and Jill *went* up *the* hill to fe*t*ch a pail of wa*t*er.
2. Amy and John *went* by *the* lake to ca*t*ch a fish for la*t*er.

All participants knew the familiar reading material, as determined by posttest presentation of these verses.

Note that the texts for the study met the criteria of being familiar (and derived unfamiliar) to allow an assessment of eye movements in response to global linguistic properties. More importantly, Greenberg and Tai (2001) had obtained a highly significant MLE for the unfamiliar set (16%) and a diminished MLE for the familiar set (7%) establishing the function/content word contrast. It was important to use text for which an MLE was established since it is difficult to assess detection patterns for computer-displayed text when target letters appear frequently in a line of text, given delays between gazes and recorded responses. Traditional letter detection studies use such passages, in part, to discourage readers from simply searching for single target words on a line (a strategy that could compromise fluid reading).

Apparatus

All sentences were displayed in black on a grey background on a 21-in. Liyama Vision Master 510 monitor with 28-mm dot pitch with a resolution of 1,028 × 720 pixels. All text was shown in a Courier-type font, so that each character occupied the same horizontal area of text with a maximum of 12 horizontal pixels per character. The distance between readers' eyes and the monitor was set at approximately 85 cm but head movements were not restrained, and the distance was somewhat variable. At a typical distance of 85 cm, each letter of text subtended approximately 0.44 degrees of visual angle laterally.

Eye movements were recorded via an Eyelink video-based pupil-tracking system. Viewing was binocular but eye movements were recorded from the right eye only. A high-speed video camera was used for recording, which was positioned underneath the monitored eye and held in place by head-mounted gear. The system has a relative spatial resolution of 15 minutes of arc. Its output was linear over the vertical and horizontal ranges of the display. Fixation locations were sampled every 4 ms, and these raw data were used to determine the different measures of oculomotor activity during reading.

Procedure

The head of each participant was not restrained but its position was recorded by a head-mounted camera registering body movements online. A two-dimensional 9-point calibration of the eye-tracking system began the experiment. During calibration, initiated by the reader, a sequence of markers requiring fixation appeared in random near the top, middle, or bottom of the screen on the left, centre, or right sides. Subsequently, a validation routine determined the stability and accuracy of the initial calibration. Successful calibration was followed by the presentation of a fixation marker, consisting of a plus sign shown on the left side of the screen. A second pressing of the space bar replaced the fixation marker with a line of text that remained visible until the sentence was read, which was signalled by a second space bar press. This self-paced sentence-reading procedure was used throughout.

In the reading task, participants read 10 practice verses—half familiar and half unfamiliar. Subsequently, the participants read 18 experimental familiar, 18 unfamiliar, and 6 hybrid verses arranged in random order. Each verse appeared by itself on the screen. Participants were informed in advance that questions about the verses would occasionally be asked during the session. Two matched lists were constructed so that a familiar verse on one list was replaced with a matched unfamiliar verse on the other. In the reading plus letter detection task, participants were also asked to read verses for comprehension and to detect the occurrence of each letter "t" that they signalled by pressing the space bar with their left hand.

Oculomotor measures, data selection, and data analyses

Three viewing duration measures were computed, consisting of the duration of the first fixation on a fixated word, the cumulated viewing duration on a word before another word was fixated (gaze duration), and total time, which consisted of a word's gaze durations and the time spent rereading it in case the word was fixated more than once. Only those cases were included in which the eyes landed on a word, and in which the saccade to the next word that followed progressed in word order. In addition, we computed the relative frequency with which a word was skipped in the two tasks. Two types of analysis were performed: a global analysis, which considered all words of a verse, and word-specific analysis, which included selected function and content words that occurred in contextually familiar and unfamiliar verses in which embedded target letters appeared. Between-group *t* tests were applied to global comparisons of oculomotor variables. Word-specific data were analysed using analyses of variance (ANOVAs) with the between-subjects factor reading task (without and with letter detection) and the within-subjects factors word class (function vs. content), and contextual familiarity (high vs. low). Detection performance was not analysed as the materials do not lend themselves to an unequivocal determination of which word is being responded to at the moment of a bar press.

RESULTS

Global analyses

A total of 9,222 words were fixated in the reading task, and 17,898 were fixated in the reading plus letter detection task. In harmony with Vitu et al. (1995) and Inhoff et al. (1993), but not with Rayner and Fischer (1996), first fixations on words were significantly shorter in the reading task, 225 ms, than the reading plus letter search task, 265 ms, $t(57) = 4.51$, $p < .01$. Even larger differences emerged for the other two viewing durations measures—gaze and total time—which were also shorter in the reading task, 271 ms and 297 ms, respectively, than in reading plus letter detection, 349 ms and 417 ms, $t(57) = 4.96$, and $t(57) = 6.22$, both $p < .01$. The addition of the secondary letter detection task also influenced eye movements. Skipping rate was considerably higher without than with the secondary task, 40% and 27%, respectively, $t(57) = 7.31$, $p < .01$. All four oculomotor measures thus converged, indicating that the addition of a secondary letter search task increased task demands and also influenced spatial aspects of eye movements. These findings were consistent with the view that the reading plus letter search did not result in relatively superficial text processing. On the other hand, the increase in task demands could have influenced linguistic processing of constituent target words.

Word-specific analyses of eye movement measures

Skipping rate—Skipping rate as a function of word class, contextual familiarity, and task type, are shown in Table 1 for the reading task and for the reading plus letter detection task. Skip rate was much higher when reading without than with a letter detection task (47% and 27%, respectively), $F(1, 57) = 56.29$, $MSE = 0.04$, $p < .01$, which also conforms to the results of the global analysis. Skipping rates were also relatively sensitive to the experimental manipulations. Relatively short function words were skipped much more often than content words, 47% and 27%, respectively, $F(1, 57) = 237.36$, $MSE = 1.05$, $p < .01$, and skipping was marginally more common when verse context was familiar than when it was unfamiliar, 38% and 36%, respectively, $F(1, 57) = 3.42$, $MSE = 0.01$, $p < .07$. Critically, neither word class effect nor the familiarity effect was influenced by the presence of the secondary task, $F(1, 57) \sim 1$ and $F(1, 57) < 1$, respectively.

Viewing duration analyses—First fixation durations, gaze durations, and total time are also shown in Table 1 as a function of word class and verse familiarity.

All three viewing measures yielded longer durations when reading with than when reading without a letter detection task, $F(1, 57) = 19.70$, $MSE = 119{,}960$, $p < .01$, $F(1, 57) = 27.42$, $MSE = 16{,}193$, $p < .01$, and $F(1, 57) = 38.55$, $MSE = 23{,}759$, $p < .01$, for first fixation, gaze, and total time, respectively. First fixation durations revealed an effect of word class, $F(1, 57) = 7.63$, $MSE = 1{,}029$, $p < .01$, and a marginal effect of text familiarity, $F(1, 57) = 3.26$, $MSE = 1{,}355$, $p < .08$. Importantly neither factor interacted with experimental task, $F(1, 57) \sim 1.0$, and $F(1, 57) < 1.0$, for word class and familiarity, respectively.

Gaze durations and total time yielded a converging effect pattern. Both data sets revealed robust word class effects, $F(1, 57) = 26.00$, $MSE = 2{,}910$, $p < .01$, and $F(1, 57) = 27.45$, $MSE = 4{,}262$, $p < .01$, for gaze and total time, respectively. The theoretically important interactions of word class with task approached significance for gaze, $F(1, 57) = 3.58$, $MSE = 2{,}910$, $p < .07$, and reached significance for total time, $F(1, 57) = 5.40$, $MSE = 4{,}262$, $p < .05$, with differences between word classes somewhat more dramatic with detection than without. However, subsequent analyses that evaluated the word class effect indicated it to be significant both with detection, $F(1, 30) = 17.51$, $MSE = 4{,}278$, $p < .01$, and without detection, $F(1, 27) = 10.25$, $MSE = 1{,}391$, $p < .01$ for gaze, and with detection, $F(1, 30) = 21.52$, $MSE = 1{,}957$, $p < .01$, and without detection, $F(1, 27) = 2{,}366$, $p = .01$, for total time. No interaction was found with passage context.

DISCUSSION

The primary concern was whether adding the secondary task of letter detection to reading alters substantially the nature of processing function and content words. In as much as the function and content word contrast (MLE) reflects lexical analysis, measures of processing that focus especially on when to move the eye (see Rayner & Pollatsek, 1989), ought to have less impact in the detection plus reading than in the reading-only task.

Whereas such an outcome would be of interest, a more challenging result for current theorizing would be one that shows the differences between the word classes to only materialize or materialize differently as a result of the addition of a secondary detection task. The latter outcome would be of concern since the unitization model (Healy, 1994), the structural model

(Koriat & Greenberg, 1994), and more recently the GO model (Greenberg, Healy, Koriat, & Kreiner, 2004) offer explanations of how differential processing of these word classes specifically supports fluent reading.

The present work demonstrated that both where and when eyes move are appreciably altered by adding a detection task—that is, there were fewer skips and more time devoted to target words than for those same words in the reading-only condition. Clearly, these findings indicate that readers operate more deliberately in response to the added requirement of detection. Importantly, though, the reading plus detection task showed no signs of altering movement patterns around the two classes of words or in response to text familiarity. Where the eye moved (specifically skipping patterns) with respect to word classes or text was not changed. When the eye moved provided a more mixed picture, but also not one that is problematic. First gazes showed a word class and a marginal text familiarity effect, but no interaction with task. However, more encompassing measures of processing times showed word class effects and interactions of type with task. These interactions suggest that detection enhanced lexical discrimination, in contrast to earlier work that found that detection eliminated lexical-based differences in duration measures (Rayner & Fischer, 1996; and Rayner & Raney, 1996). Apparently, letter detection as required in studies typically investigating the MLE does not inhibit lexical analysis relative to reading only, although other types of searches and instructions do.

The enhanced differences would appear to pose a problem for generalizing from a reading plus detection task to a pure reading task, since when the eye moves showed a greater word class difference when detection was involved. However, upon further inspection it is clear that although the differences between word classes were accentuated with added detection, such differences were quite strong as well when the same target words were simply read. Thus, adding detection did not disclose differences that had not been already clearly established in reading without detection.

Finding that first fixations between function and content words did not change by adding detection, but that measures potentially capturing further processing did—that is, gaze and particularly total time—suggests that the MLE may reflect, in part, later word processing including postlexical analysis (see Schmauder, Morris, & Poyner, 2000). The notion of a strong role of late processing is compatible with the structural assumption articulated in the GO model's interpretation of the MLE (Greenberg et al., 2004).

Recently, Oliver et al. (2005) explored the effect that letter detection has compared to pure reading. They replicated the MLE using computer-generated displays and button-pressing responses akin to that used in an eye movement tracking environment. Comprehension was marginally reduced by the addition of detection to reading, and similar to here detection slowed reading. Comparison of the reading plus detection task with other forms of detection task indicated that slowed reading reflected target searching and not changes in comprehension. Although the present observations are compatible with those findings, they are even more diagnostic in that they further revealed that the eye movement patterns suggestive of the differential processing of function and content words are relatively consistent whether or not detection is involved.

The finding that the eye movement data revealed an impact of task and yet demonstrated consistent differences between function and content words across tasks bolsters the proposition that word-processing patterns observed in the standard letter detection tests are informative about reading in general. Whereas the present study indicates that the addition of detection is not altering the way a reader handles familiar and unfamiliar text or classes of words, other linguistic factors could interact with task requirements. The present findings should not be construed as arguing that all forms of lexical analysis in reading remain unchanged by the addition of detection.

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Table 1

Oculomotor responses when reading target words with and without letter detection in familiar and unfamiliar verse contexts

	Reading only				Reading plus detection			
	Familiar		Unfamiliar		Familiar		Unfamiliar	
Measures	**Function**	**Content**	**Function**	**Content**	**Function**	**Content**	**Function**	**Content**
Skipping	0.58 (0.02)	0.38 (0.03)	0.57 (0.03)	0.35 (0.04)	0.38 (0.02)	0.19 (0.03)	0.34 (0.02)	0.17 (0.02)
FFD	209 (9.9)	223 (8.8)	221 (9.6)	239 (8.5)	262 (9.5)	271 (8.4)	267 (9.1)	274 (8.1)
GD	221 (11.6)	246 (16.7)	233 (12.5)	254 (17.4)	295 (11.0)	350 (15.8)	306 (11.9)	350 (16.5)
TT	234 (14.8)	265 (19.8)	251 (14.5)	269 (21.0)	345 (14.1)	417 (18.8)	350 (13.8)	406 (20.0)

Note: Skipping denotes the relative frequency (in percentages) with which saccades move over a word without fixating it; FFD, GD, and TT denote the duration (in ms) of the first fixation duration, the gaze duration, and the total time, respectively, on a word (standard errors in parentheses).