Atten Percept Psychophys (2013) 75:407–414
DOI 10.3758/s13414-013-0442-0

A further examination of the lexical-processing stages hypothesized by the E-Z Reader model

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Published online: 1 March 2013

Abstract Participants' eye movements were monitored while they read sentences in which high- and low-frequency target words were presented normally (i.e., the normal condition) or with either reduced stimulus quality (i.e., the faint condition) or alternating lower- and uppercase letters (i.e., the case-alternated condition). Both the stimulus quality and case alternation manipulations interacted with word frequency for the gaze duration measure, such that the magnitude of word frequency effects was increased relative to the normal condition. However, stimulus quality (but not case alternation) interacted with word frequency for the early fixation time measures (i.e., first fixation, single fixation), whereas case alternation (but not stimulus quality) interacted with word frequency for the later fixation time measures (i.e., total time, go-past time). We interpret this pattern of results as evidence that stimulus quality influences an earlier stage of lexical processing than does case alternation, and we discuss the implications of our results for models of eye movement control during reading.

Keywords Reading · Eye movements · Case alternation · Stimulus quality · Lexical processing · Word frequency

Over the past three decades, the study of eye movement control during reading has been the focus of extensive empirical and theoretical efforts (for reviews, see Rayner, 1998, 2009) that have resulted in the introduction of a variety of sophisticated models, including Mr. Chips (Legge, Klitz, & Tjan, 1997), E-Z Reader (Reichle, Pollatsek, Fisher, & Rayner, 1998), EMMA (Salvucci, 2001), competition-interaction (Yang & McConkie, 2001), SWIFT (Engbert, Longtin, & Kliegl, 2002), Glenmore (Reilly & Radach, 2003), SERIF (McDonald, Carpenter, & Shillcock, 2005), and SHARE (Feng, 2006). These models incorporate various assumptions and generate unique predictions that have inspired empirical tests.

Of particular relevance to the present study, Reingold and Rayner (2006) tested the central assumption of the influential E-Z Reader model (Reichle, 2011; Reichle et al., 1998; Reichle, Pollatsek, & Rayner, 2012) that word identification reflects two separate stages of lexical processing. Specifically, the E-Z Reader model assumes that the initiation of the programming of a saccade to the next word (word$_{n+1}$) occurs prior to the completion of lexical access to the fixated word (word$_n$). Saccadic programming is postulated to be driven by the output of an early lexical-processing stage (L_1), which indicates that lexical access to word$_n$ is imminent. Lexical processing of word$_n$ is then completed during a subsequent stage of lexical processing (L_2), and the conclusion of this stage causes covert attention to shift to word$_{n+1}$. During the interval of time between this attention shift and the launch of the word$_n$-to-word$_{n+1}$ saccade, parafoveal processing of word$_{n+1}$ is initiated. The duration of this interval, referred to as the *parafoveal preview*, is expected to determine the magnitude of any processing benefit when word$_{n+1}$ is later fixated (with longer preview resulting in shorter fixations on word$_{n+1}$). Importantly, as was argued by Reingold (2003), the E-Z Reader model predicts that experimental manipulations that disrupt L_1 but not L_2 should influence the processing difficulty of word$_n$ without affecting the processing of word$_{n+1}$, whereas manipulations that impact L_2 should impact word$_{n+1}$ fixation times. To test this prediction, Reingold and Rayner contrasted a stimulus quality manipulation (i.e., reducing visual contrast; henceforth also referred to as the *faint* condition) that was expected to produce a rapid influence on lexical processing (e.g., Besner & Roberts, 2003; Borowsky & Besner, 1993; Braet & Humphreys, 2006a, 2006b, 2007; White & Staub, 2012) with a case alternation manipulation (e.g., tAbLe) that was expected to produce a later influence on lexical processing (e.g., Braet & Humphreys, 2006a, 2006b, 2007; Herdman, Chernecki, &

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Norris, 1999; Mayall, Humphreys, & Olson, 1997; but see Lien, Allen, & Crawford, 2012). Consistent with the E-Z Reader model, the stimulus quality manipulation produced longer fixation times on $word_n$, but largely did not affect the processing of $word_{n+1}$. In contrast, even though the case alternation manipulation produced a smaller effect than did stimulus quality on fixation times on $word_n$, the case alternation manipulation produced a robust effect on fixation times on $word_{n+1}$. This pattern of results, which was later replicated and extended (Wang & Inhoff, 2010; see also Drieghe, 2008), is consistent with the critical assumption of the E-Z Reader model concerning the two stages of lexical processing.

Recently, White and Staub (2012) used ex-Gaussian modeling of fixation duration distributions and provided strong evidence that the stimulus quality manipulation produces a rapid influence on fixation durations. However, on the basis of these findings, White and Staub suggested that it is unclear whether the locus of this effect was an early lexical-processing stage, as proposed by Reingold and Rayner (2006), or an even earlier, prelexical visual-processing stage. The main goal of the present study was to disentangle these alternative interpretations. To accomplish this goal, we incorporated a word frequency manipulation (i.e., high- vs. low-frequency target words) that had not been included in the previous investigations (i.e., Reingold & Rayner, 2006; Wang & Inhoff, 2010; White & Staub, 2012), in order to test for interactions between word frequency and stimulus quality. According to the additive-factors logic (Sternberg, 1969), two variables that interact are interpreted as exerting their influences on a common stage of processing, and two variables that instead produce additive effects are interpreted as affecting different stages of processing. Applying this logic to the present study, given that word frequency effects (i.e., longer fixation times on low- than on high-frequency words) are considered to be a marker of lexical processing (e.g., Rayner, 1998; Reingold, Reichle, Glaholt, & Sheridan, 2012), an interaction between stimulus quality and word frequency would support Reingold and Rayner's assumption that stimulus quality affects lexical processing. However, if the two variables were to produce additive effects, then such a pattern would support the interpretation that stimulus quality effects are primarily prelexical.

Similar to the present study, single-word recognition studies have also tested for interactions between stimulus quality and word frequency. The results of these studies varied depending on the type of task that was employed, such that naming tasks produced interactions (e.g., O'Malley, Reynolds, & Besner, 2007; Yap & Balota, 2007), but lexical decision tasks typically did not (e.g., Becker & Killion, 1977; Stanners, Jastrzembski, & Westbrook, 1975; Yap & Balota, 2007; but see Bangert, Abrams, & Balota, 2012). However, whereas single-word recognition studies employed reaction time measures, the advantage of the present study is that eyetracking was used to provide more fine-grained time course information. Importantly, within the framework of the E-Z Reader model, word frequency is hypothesized to influence both the L_1 and the L_2 lexical stages. Specifically, reflecting an influence on L_1, word frequency effects are evident on the very first fixation on a word (*first-fixation duration*), and due to a further influence on L_2, the magnitude of these effects is larger when considering the cumulative duration of all first-pass fixations before the eyes leave the word (*gaze duration*). Thus, given that stimulus quality is believed to exert a rapid influence on fixation times, we were particularly interested in testing for interactions between stimulus quality and word frequency using early fixation time measures such as first-fixation duration and *single-fixation duration* (i.e., the first-fixation duration for trials with only one first-pass fixation).

Finally, although our main focus was on the stimulus quality manipulation, the present study also incorporated a case alternation manipulation. Like Reingold and Rayner (2006), we selected the case alternation manipulation because it was expected to influence a later stage of lexical processing, relative to the stimulus quality manipulation. This hypothesis was based on neuropsychological dissociations showing that stimulus quality impacts an early stage of processing in the occipital cortex, whereas case alternation impacts a later stage of processing in the right parietal lobe (Braet & Humphreys, 2006a, 2006b, 2007). Moreover, in further support of a late-acting effect of case alternation on word identification, Reingold, Yang, and Rayner (2010) demonstrated that case alternation and word frequency produced additive effects on early fixation time measures, but produced interactions for the gaze duration measure. In the present study, we expected to replicate these findings from Reingold et al. (2010), while simultaneously examining whether stimulus quality produces interactions with word frequency for the early fixation time measures. Overall, such interactions would support Reingold and Rayner's interpretation that stimulus quality influences early lexical processing. In contrast, the absence of such interactions would be consistent with the notion that the impact of the stimulus quality variable is limited to a prelexical visual-processing stage, as proposed by White and Staub (2012).

Method

Participants

All 72 participants were undergraduate students at the University of Toronto. The participants were all native

English speakers and were given either one course credit or $10 (Canadian)/h. All participants had normal or corrected-to-normal vision.

Materials and design

The target words consisted of 108 low-frequency (LF) nouns and 108 high-frequency (HF) nouns, which ranged in length from 5 to 9 letters (M = 6.4). The mean word frequencies were 2.9 occurrences per million for the low-frequency targets and 106.1 occurrences per million for the high-frequency targets, according to the SUBTLex corpus of American English subtitles (Brysbaert & New, 2009). A total of 108 pairs of high- and low-frequency words were created (matched on word length), and two low-constraint sentence frames were composed for each word pair, so that either word could plausibly fit into the sentences. For example, Sentences 1a and 1b below were created for the pair of words *table* and *banjo*:

1a. John decided to sell the **table**/**banjo** in the garage sale.
1b. I was told that the **table**/**banjo** was made out of expensive wood.

Target word predictability in these sentence frames was assessed by providing an additional group of 10 participants with the beginning of each sentence frame and asking them to write a word that could fit as the next word in the sentence. The average predictability was extremely low, amounting to 1.3 % for the high-frequency target words and 0.1 % for the low-frequency target words.

In addition to the word frequency manipulation, typography was manipulated such that the target words were either presented normally (i.e., the normal condition), with severely reduced contrast (i.e., the faint condition), or with alternating lowercase and capital letters (i.e., the case-alternated condition). For the case-alternated condition, the first letter of the word was always lowercase (e.g., tAbLe). For all three of the typography conditions, the sentence frames surrounding the target words were presented using normal text.

Thus, six experimental conditions resulted from crossing frequency (high vs. low) and typography (normal vs. faint vs. case alternated). Both of these variables were manipulated within participants, such that each participant was shown 36 trials in each of the six conditions. The case-alternated and faint condition trials were presented in two separate blocks. For one of these blocks, two thirds of the trials were in the faint condition, and the remaining third were in the normal condition. For the other block, two thirds of the trials were in the case-alternated condition, and the remaining third were in the normal condition. In total, participants read ten practice trials (five per block), 216 experimental trials (108 per block), and 38 filler trials (19 per block). The practice trials were always shown at the beginning of the block, and the experimental and filler trials were presented in a random order. The order of the two blocks was counterbalanced across participants, such that half of the participants were shown the faint block first, and the remaining half of the participants were shown the case-alternated block first. Each participant read any given target word or sentence frame only once, and the assignment of target words to sentence frames and conditions was counterbalanced across participants.

Apparatus and procedure

Eye movements were measured with an SR Research EyeLink 1000 system with high spatial resolution and a sampling rate of 1000 Hz. Viewing was binocular, but only the right eye was monitored. A chin-and-forehead rest was used to minimize head movements. Following calibration, the gaze position error was less than 0.5º. The sentences were displayed on a 21-in. ViewSonic monitor with a refresh rate of 150 Hz and a screen resolution of 1,024 × 768 pixels. All letters were presented in lowercase (except when capitals were appropriate). For the normal and case-alternated conditions, the text was presented in black (4.7 cd/m^2) on a white background (56 cd/m^2). For the faint condition, the text was presented in gray (33 cd/m^2) on a white background (56 cd/m^2).[1] Participants were seated 60 cm from the monitor, and 2.4 characters equalled approximately 1 deg of visual angle. All of the sentences were displayed on a single line, and the target words were located near the middle of the sentences.

Prior to the experiment, participants were told to focus on reading the sentences for comprehension. In addition, prior to the faint block, participants were informed that they would occasionally encounter words shown in a light gray color, and prior to the case-alternated block, they were informed that they would occasionally encounter words with alternating capital and lowercase letters. After reading each sentence, participants pressed a button to end the trial and proceed to the next sentence. To ensure that participants were reading for comprehension, about 15 % of the sentences were followed by multiple-choice comprehension questions. The average accuracy rate was 95.8 %.

[1] The faint condition in the present study was designed to produce less extreme degradation than in prior investigations (e.g., Reingold & Rayner, 2006; Wang & Inhoff, 2010), in order to match the overall levels of difficulty in the case-alternated and faint conditions. As is shown in Table 1, the first-fixation and single-fixation durations were approximately equal across the faint and case-alternated conditions, which suggests that the differential pattern of word frequency effects that emerged in these two conditions was not confounded with the level of difficulty.

Results

Trials were excluded from the analyses described below due to skipping of the target word (5.5 % of all trials). For the remaining trials, the following measures were used to examine processing times for the low- and high-frequency target words, in the normal, faint, and case-alternated conditions: (1) first-fixation duration (i.e., the duration of the first forward fixation on the target, regardless of the number of subsequent fixations on the target); (2) single-fixation duration (i.e., the first-fixation value for the subset of trials with only one first-pass fixation on the target); (3) gaze duration (i.e., the sum of all of the consecutive first-pass fixations on the target, prior to a saccade to another word); (4) go-past time (i.e., the sum of all fixations from the first fixation on the target up to and including the fixation prior to the reader moving past the target to a later part of the sentence); (5) total time (i.e., the sum of all fixations on the target); (6) the probability of skipping (i.e., trials with no first-pass fixation on the target, regardless of whether or not the target was fixated later in the trial); and (7) the probability of a single first-pass fixation. For each of these dependent measures, and for both of the typography manipulations (i.e., stimulus quality, case alternation), separate 2 × 2 analyses of variance (ANOVAs) were carried out on the data via both participants (F_1) and items (F_2), and with frequency (HF vs. LF) and typography (normal vs. faint or normal vs. case alternated) as independent variables. Table 1 summarizes the means and standard errors for the different measures, the significance of the frequency-by-typography interactions, and the results from planned comparisons that were carried out on the data by both participants (t_1) and items (t_2), in order to compute the magnitude and significance of the word frequency effects in the normal, faint, and case-alternated conditions.

Relative to the normal condition, both of the typography manipulations (i.e., faint, case alternated) produced longer fixation times (all Fs > 50, all ps < .001), lower skipping rates (all Fs > 14, all ps < .001), and a trend toward lower probabilities of a single fixation that was significant for all of the analyses (all Fs > 6, all ps < .05), except in the by-participants analysis for the stimulus quality manipulation [$F(1, 71) = 3.06$, $p = .085$]. In addition, all of the analyses showed significant word frequency effects, such that longer fixation times, lower skipping rates, and lower probabilities of a single fixation emerged in the low-frequency relative to the high-frequency condition (all Fs > 5, all ps < .05). Most importantly, as can be seen from Table 1, the pattern of frequency-by-typography interactions was markedly different for the stimulus quality manipulation relative to the case alternation manipulation. Specifically, for the early fixation time measures (first fixations, single fixations), the faint condition produced larger word frequency effects relative to the normal condition, whereas the case-alternated condition produced word frequency effects that were equal in magnitude to the normal condition. In contrast, the later fixation time measures (go-past time, total time) showed the opposite pattern of results, such that the faint condition produced word frequency effects that were similar in magnitude to the normal condition,[2] whereas the case-alternated condition produced larger word frequency effects relative to the normal condition. For the gaze duration measure, both the stimulus quality and case alternation manipulations produced larger word frequency effects relative to the normal condition. For the remaining measures (i.e., probability of skipping, probability of a single first-pass fixation), no significant frequency-by-typography interactions were apparent. Thus, we found a clear difference in the patterns of word frequency effects across conditions, such that the stimulus quality manipulation interacted with word frequency for the early fixation time measures, whereas the case alternation manipulation interacted with word frequency for the later fixation time measures. Overall, this pattern of results supports the hypothesis that the stimulus quality manipulation exerts its influence on an earlier stage of lexical processing than does the case alternation manipulation (Reingold & Rayner, 2006).

Discussion

In the present study, the stimulus quality and case alternation manipulations produced dramatically different patterns of interactions with word frequency effects during reading. Specifically, although both of the manipulations produced interactions with word frequency for the gaze duration measure, the stimulus quality manipulation (but not case alternation) produced interactions with word frequency for the early fixation time measures (i.e., first fixation, single fixation), and the case alternation manipulation (but not stimulus quality) produced interactions with word frequency for the later fixation time measures (i.e., total time, go-past time).

Importantly, the present findings support Reingold and Rayner (2006)'s assumption that the stimulus quality variable can influence lexical processing. This is because the stimulus quality manipulation produced interactions with

[2] Although the faint condition did not produce any significant interactions for the later measures (i.e., total time, go-past time), the means in Table 1 reveal some numerical differences in the sizes of the word frequency effects in the faint relative to the normal condition. Given that the later measures partially reflect first-pass fixations, it is not surprising to find these numerical differences. Most importantly, the size of these differences did not increase for the later measures relative to the earlier measures, which stands in contrast to the case-alternated condition, which produced strong increases in the magnitudes of the interactions for the later relative to the earlier measures.

Table 1 First-fixation, single-fixation, and gaze duration, total time and go-past time (in milliseconds); and the probabilities (proportions) of skipping and of single fixations, by typography condition and word frequency

Variable	Normal			Faint			Case Alternated			Frequency × Typography Interactions	
	HF	LF	Freq.	HF	LF	Freq.	HF	LF	Freq.	Faint	Case Alternated
First fixation	214	233	19***	237	264	27***	237	253	16***	$F_1 = 4.48, p < .05$	$F_1 < 1$
	(3.8)	(5.0)		(3.7)	(5.5)		(3.7)	(4.9)		$F_2 = 5.42, p < .05$	$F_2 < 1$
Single fixation	215	238	23***	244	278	34***	247	272	25***	$F_1 = 4.36, p < .05$	$F_1 < 1$
	(4.0)	(5.0)		(4.0)	(7.0)		(3.9)	(5.4)		$F_2 = 2.60, p = .110$	$F_2 < 1$
Gaze duration	247	303	56***	281	363	82***	307	407	100***	$F_1 = 12.86, p < .01$	$F_1 = 26.40, p < .001$
	(5.7)	(8.9)		(6.5)	(12.6)		(6.0)	(13.2)		$F_2 = 17.44, p < .001$	$F_2 = 24.99, p < .001$
Go-past time	294	377	83***	360	451	91***	387	520	133***	$F_1 < 1$	$F_1 = 18.24, p < .001$
	(8.4)	(12.3)		(9.3)	(15.6)		(10.6)	(16.9)		$F_2 < 1$	$F_2 = 15.21, p < .001$
Total time	323	422	99***	402	514	112***	430	594	164***	$F_1 = 1.28, p = .261$	$F_1 = 17.87, p < .001$
	(10.8)	(14.9)		(13.7)	(20.0)		(17.3)	(23.4)		$F_2 = 1.82, p = .180$	$F_2 = 17.63, p < .001$
Prob. of skipping	.09	.07	.02*	.06	.04	.02**	.04	.03	.01 n.s.	$F_1 < 1$	$F_1 = 1.40, p = .240$
	(.01)	(.01)		(.01)	(.01)		(.01)	(.01)		$F_2 < 1$	$F_2 = 1.43, p = .234$
Prob. of single fixation	.75	.64	.11***	.72	.62	.10***	.63	.49	.14***	$F_1 < 1$	$F_1 = 1.15, p = .287$
	(.01)	(.02)		(.02)	(.02)		(.02)	(.02)		$F_2 < 1$	$F_2 = 1.30, p = .257$

Standard errors are shown in parentheses. The means and standard errors shown are based on the by-participants analyses. For F tests, the dfs are $F_1 = (1, 71)$ and $F_2 = (1, 107)$. For t tests, the dfs are $t_1 = 71$ and $t_2 = 107$. For t tests, p values are given for t_1 if $t_1 < t_2$, or for t_2 if $t_2 < t_1$, and these are denoted as follows: $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$; n.s., $p > .1$. HF = high frequency, LF = low frequency, Freq. = word frequency effect. For the fixation time variables, Freq. = LF – HF. For the probability variables, Freq. = HF – LF.

the word frequency variable, which is a known marker of lexical processing (e.g., Rayner, 1998; Reingold et al., 2012), and Sternberg (1969)'s logic assumes that two variables that interact are influencing the same stage of processing. Nevertheless, although our findings indicate that stimulus quality affects early lexical processing, we do not rule out the possibility that stimulus quality may also affect an even earlier, prelexical stage, such as the visual-processing stage (V) in the E-Z Reader model (Reichle et al., 1998), as suggested by White and Staub (2012).

The present findings replicate single-word recognition studies that have used naming tasks to demonstrate interactions between stimulus quality and word frequency (e.g., O'Malley et al., 2007; Yap & Balota, 2007). Moreover, Bangert et al. (2012) recently tested for interactions using a lexical decision task that required continuous arm-reaching responses, so that movement trajectories could be tracked. In contrast to prior findings that lexical decision tasks do not produce stimulus quality and word frequency interactions (e.g., Becker & Killion, 1977; Stanners et al., 1975; Yap & Balota, 2007), Bangert et al. demonstrated an interactive effect during the early part of the movement trajectory, such that the stimulus quality variable affected the initial movement trajectories of high-frequency words to a greater extent than those of low-frequency words. Consequently, the single-word recognition literature provides convergent evidence for our conclusion that stimulus quality impacts lexical processing.

Similar to Bangert et al. (2012)'s approach of examining fine-grained time course information, in the present study we employed a wide range of fixation time measures. The overall pattern of results that emerged for these measures was highly consistent with the E-Z Reader model's assumption that lexical processing takes place in two stages. Specifically, the model assumes that the word frequency variable separately influences both the L_1 and L_2 lexical stages, such that word frequency effects on L_1 are primarily reflected by the first-fixation duration measure, and an additional word frequency effect on L_2 results in even stronger word frequency effects on gaze duration. This assumption of two separate word frequency influences is consistent with recent studies that have employed ex-Gaussian fitting to show that word frequency produces a shift in the distribution of fixation times, as well as an additional influence on long fixation times (Reingold et al., 2012; Staub, White, Drieghe, Hollway, & Rayner, 2010). With respect to the present findings, the E-Z Reader model can accommodate the case alternation and stimulus quality results by assuming that the stimulus quality variable primarily influences L_1, whereas the case alternation variable primarily influences L_2. More specifically, stimulus quality, but not case alternation, interacted with word frequency for the early measures (i.e., first-fixation and single-fixation durations) that primarily reflect L_1, and both manipulations produced interactions for the gaze duration measure, which is expected to reflect both L_1 and L_2 influences. Thus, taken together with previous findings (e.g., Reingold & Rayner, 2006; Reingold et al., 2010; Wang & Inhoff, 2010), our results add to the growing evidence that supports the E-Z Reader model's distinction between early and late lexical-processing stages.

In addition to reinforcing the L_1 and L_2 distinction, the present findings are consistent with the assumptions that were added to recent versions of the E-Z Reader model to explain how the L_1 and L_2 stages of lexical processing interact with postlexical integration (Reichle, Warren, & McConnell, 2009). According to the model, whenever postlexical integration of word n fails to complete prior to completion of the lexical processing of word $n + 1$ (i.e., *slow-integration failure*, as described in Fig. 2B of Reichle et al., 2009), the probability of a regressive saccade moving the eyes back to word n increases. Thus, in the present study, the case-alternated condition might have influenced regressive fixations on the target words by increasing the probability of slow-integration failure, either by slowing L_2 (and hence delaying the onset of integration) and/or by interfering with integration more directly. This account might explain why case alternation (but not stimulus quality) modulated the magnitude of word frequency effects for the later measures (i.e., total time, go-past time) that partially reflect regressive fixations.

The differential patterns of results that emerged for the case alternation and stimulus quality manipulations are also consistent with neuropsychological dissociations between these two variables. In particular, Braet and Humphreys (2006a, 2006b, 2007) demonstrated a dramatic double dissociation, such that transcranial magnetic stimulation (TMS), applied selectively to the right parietal lobe, as well as lesions in this part of the brain, disrupted the recognition of case-alternated words but did not impact the effects of contrast reduction, but the reverse pattern occurred as a result of bilateral lesions and TMS applied to the occipital cortex (i.e., a disruption to the recognition of reduced-contrast words and no impact on the effects of case alternation). As was discussed by Reingold et al. (2010), such dissociations imply that the stimulus quality manipulation primarily disrupts an early lexical-processing stage, whereas the impact of case alternation primarily involves higher-level, attentional, lexical, or postlexical processes.

More generally, the present findings reinforce the idea that word frequency effects during reading are modulated by a wide range of manipulations of the visual appearance of the text, including typography manipulations (Barnhart & Goldinger, 2010; Kolers, 1968; D. G. Paterson & Tinker, 1947; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; Sheridan & Reingold, 2012a, 2012b; Slattery & Rayner, 2010; Tinker & Paterson, 1955), visual content (e.g., K. B. Paterson, McGowan, & Jordan, 2012), and the removal of interword spaces (e.g., Rayner, Fischer, & Pollatsek, 1998; Sheridan, Rayner, & Reingold, 2013). Future studies could continue to examine the nature of interactions between visual manipulations and lexical variables such as word frequency. As has been demonstrated in the present study, interactions between visual manipulations and lexical variables have the potential to reveal information about word identification processes.

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