RUNNING HEAD: The selective reading paradigm

Attention and eye-movement control in reading: The selective reading paradigm

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Abstract

We introduced a novel paradigm for investigating covert attention and eye-movement control in reading. In 2 experiments, participants read sentence words (shown in blue color) while ignoring interleaved distractor strings (shown in orange color). Each single-line text display contained a target word and a critical distractor. Critical distractors were located just prior to the target in the text and were either words or symbol strings (e.g., @#%&). Target word availability for parafoveal processing (i.e., preview validity) was also manipulated. The results indicated much shallower processing of distractors than targets and this pattern was more pronounced for symbol than word distractors. The influences of word frequency and fixation location on first-pass fixation durations on distractors were dramatically different than the well-documented pattern obtained in normal reading. Robust preview benefits were demonstrated both when the critical distractors were fixated and when the critical distractors were skipped. Finally, with the exception of larger preview benefits that were obtained in the condition in which the target and critical distractor were identical, the magnitude of the preview effect was largely unaffected by the nature of the critical distractor. Implications of the present paradigm and findings to the study of eye-movement control in reading are discussed.

The use of eye movements to study reading has a rich history dating back over a century (see Rayner, 1998, 2009, for reviews). Readers move their eyes primarily forward in the text to encounter new words. The magnitude of the typical forward movement (*saccade*) for readers of English is about 7-9 letter spaces. High-velocity saccadic eye movements, during which vision is largely suppressed (Matin, 1974), occur at an average rate of 3-4 per second and are separated by periods during which the eyes remain relatively still (*fixations*), and perceptual information is extracted. Saccades are required in order to align the high-acuity foveal region of the retina (the central 2° of vision) with the part of the text that is being encoded by the reader. However, during each fixation, while the fixated word *(word N*) is primarily encoded using foveal vision, parafoveal vision is used to extract perceptual information from at least the next two words in the text *(word N+1* and *word N*+2). Specifically, for readers of English the encoding of useful perceptual information is confined to the *perceptual span*, an asymmetric region of the text around the fixation point, which is limited to about 3-4 letter spaces to the left and 14-15 letter spaces to the right of fixation (McConkie & Rayner, 1975). Importantly, when the area of useful orthographic information during a fixation is restricted to word *N*, word *N+1* and word *N+2*, reading rate is approximately normal, while reading rate decreases by about 10% when only Word *N* and Word *N+1* information is available and by over 30% when only Word *N* information is available (Rayner, Slattery, & Bélanger, 2010; Rayner, Well, Pollatsek, & Bertera, 1982).

As demonstrated by Miellet, O'Donnell and Sereno (2009), the size of the perceptual span is largely determined by attentional demands and not by the rapid visual acuity drop-off as a function of the distance from the fovea. Specifically, these authors reported no increase in the size of the perceptual span in an experimental condition in which they compensated for visual

acuity drop-off by magnifying the size of letters as a function of their eccentricity (i.e., their distance from fixation). Additional evidence for the important role of selective attention in determining the size and shape of the perceptual span is derived from findings that despite their proximity to the fovea, lines of text that are adjacent to the currently fixated line are not encoded (Inhoff & Briihl, 1991; Inhoff & Topolski, 1994; Pollatsek & Rayner, 1990) as well as from findings that the size and shape of the perceptual span varies dramatically across languages (for a recent review see Schotter, Angele, & Rayner, 2012). Specifically, the asymmetry in the perceptual span always favours the acquisition of information in the direction of reading as compared to the opposite direction (e.g., greater encoding from the right side than left side of fixation in English, but the reversed pattern in Hebrew; see Pollatsek, Bolozky, Well, & Rayner, 1981). In addition, the high density of information in Chinese and Japanese scripts results in substantially smaller perceptual spans (in terms of degrees of visual angle) in these languages relative to English (e.g., Ikeda & Saida, 1978; Inhoff & Liu, 1998; see also Liversedge et al., 2016), a finding that is consistent with the idea that attentional factors largely determine the size of the perceptual span (for additional evidence see Kaakinen & Hyönä, 2014).

Given the hypothesized importance of selective visual attention in determining the location of the text to be foveated (i.e., fixation location) as well as in delimiting the duration of each foveation (i.e., fixation duration), most current models of eye-movement control in reading incorporate explicit assumptions concerning the influence of the allocation of attention on various eye-movement parameters. One type of eye-movement control model in reading, which is referred to as the *Sequential Attention Shift* (*SAS*) model, assumes serial lexical processing and a tight coupling between attention and saccadic control in reading. An early version of this model was proposed by Morrison (1984; see also Just & Carpenter, 1980), and several modified

versions aimed at extending it were later introduced (e.g., Henderson & Ferreira, 1990; Henderson, 1992; Kennison & Clifton, 1995; Pollatsek & Rayner, 1990; Rayner & Pollatsek, 1989; Reichle, Pollatsek, Fisher, & Rayner, 1998). The *E-Z Reader* model (Reichle et al., 1998; for a review, see Reichle, 2011) constitutes the most prominent instantiation of the SAS model and the first formal computational model of eye-movement control in reading. In contrast to the concept of serial lexical processing that is central to SAS models, models assuming *Guidance by Attentional Gradient* (*GAG models*) postulate that attentional resources are simultaneously distributed across multiple words within the perceptual span and that lexical processing of these words occurs in parallel. Similar to the perceptual span, the attentional gradient is assumed to be asymmetrical, extending further in the direction of reading than in the opposite direction, with more efficient processing of words near the center of the gradient than in the periphery. Prominent computational models that incoporate such a proposal include *SWIFT* (Engbert, Nuthmann, Richter, & Kliegl, 2005) and *Glenmore* (Reilly & Radach, 2003).

Thus, a key differentiation between models of eye-movement control in reading concerns the manner in which covert attention mechanisms result in serial or parallel lexical processing of words within the perceptual span. Currently, the controversy surrounding this issue is far from being resolved (for recent reviews of this debate see Murray, Fischer, & Tatler, 2013; Radach & Kennedy, 2013; Schotter et al., 2012). While the present investigation was informed in part by the serial versus parallel lexical processing literature, the main goal of the present study was to develop and explore a novel approach for the study of selective attention and eye-movement control in reading. Specifically, the *selective reading paradigm* was designed for the purpose of investigating the flexibility with which readers are able to attend to and process relevant target words while ignoring irrelevant distractor words or symbol strings. Accordingly, in order to

motivate the present paradigm, we begin by briefly considering research on eye-movement control in reading within the context of the broader literature on covert visual attention. We then outline the rationale underlying the present paradigm and report results from two experiments employing this paradigm.

Covert visual attention and eye-movement control in reading

There is a substantial body of research that has suggested that eye movements are typically preceded by a covert attentional shift towards the saccadic target (e.g., Deubel & Schneider, 1996; Henderson, 1993; Hoffman & Subramaniam, 1995; Hoffman, 1998; Kowler, Anderson, Dosher, & Blaser, 1995; Rafal, Calabresi, Brennan, & Sciolto, 1989; Rayner, McConkie, & Ehrlich, 1978; Remington, 1980; Schneider & Deubel, 1995; Shepherd, Findlay, & Hockey, 1986). Furthermore, covert orienting of attention has been shown to enhance perceptual discriminability of stimuli within the attended region (e.g., Bashinski & Bacharach, 1980; Briand & Klein, 1987; Downing, 1988; Eriksen & Yeh, 1985; Jonides, 1980; for reviews see Carrasco 2011, 2014; Treue, 2004). In addition to perceptual enhancement within the attended region, another consequence of both foveation (i.e., overt eye movements) and covert orienting of attention is the selection of stimulus information for higher level cognitive processing (i.e., eye movements and attentional shifts serve as a gating function; see Rensink, 2002; Simons, 2000).

Although the precise nature of the spatial distribution of covert attention is still unknown, the existence of a location based selection mechanism operating early in visual processing is well established. Specifically, in addition to behavioral studies, neurophysiological correlates of such a mechanism were inferred from demonstrations that the retinotopic representations of attended regions exhibit increased fMRI BOLD activation in humans (Brefczynski & DeYoe, 1999; Gandhi, Heeger, & Boynton, 1999; Kastner, De Weerd, Desimone, & Ungerleider, 1998;

Martínez et al., 1999; Müller et al., 2003; Somers, Dale, Seiffert, & Tootell, 1999; Tootell, Hadjikhani, Mendola, Marrett, & Dale, 1998) and increased neural firing in primate single-unit recordings (Connor, Preddie, Gallant, & Van Essen, 1997; Ito & Gilbert, 1999; Luck, Chelazzi, Hillyard, & Desimone, 1997; Mcadams & Maunsell, 2000; Moran & Desimone, 1985; Reynolds, Chelazzi, & Desimone, 1999; Treue & Maunsell, 1999).

Within the domain of reading, a very powerful demonstration of the role of covert attention emerged from investigations of the preview benefit for word *N+1* which employed the *invisible boundary paradigm* (Rayner, 1975). This paradigm involves a manipulation of the availability of target word information for parafoveal processing during fixations on pre-target words. The critical contrast is between a *valid preview* condition which corresponds to normal reading (i.e., target words are available for parafoveal processing) versus an *invalid preview* condition in which during fixations on pre-target words, a letter string (mask) occupies the position of the target word in the sentence, and is replaced with the target word during a saccade that crosses an invisible boundary located just prior to the location of the target word. The magnitude of the preview benefit is typically measured by computing the increase in fixation times on target words when parafoveal processing was prevented by presenting an unrelated letter string as a preview compared to normal presentation (i.e., fixation times in the invalid minus the valid preview condition). Using the invisible boundary paradigm, the word *N+1* preview benefit has been established as one of the most robust findings in the literature on eye-movement control in reading (for reviews see Rayner, 1998, 2009; Schotter et al., 2012). Furthermore, lexical parafoveal processing of word *N+1* was demonstrated to play a crucial role in enabling rapid and pervasive lexical control of fixation times in reading (Reichle & Reingold, 2013; Reingold, Reichle, Glaholt, & Sheridan, 2012; Reingold, Sheridan, & Reichle, 2015).

Another critical influence of covert attention on eye-movement control in reading is revealed by the fact that readers do not fixate (i.e., skip) between 10–30% of words in the text (see Rayner, 1998, 2009), with increased probability of skipping for shorter words, more frequent words, and words with higher contextual constraint (i.e., more predictable words). Given intact comprehension, it is reasonable to assume that some skipped words are identified up to a high degree parafoveally, thereby providing another illustration of facilitation of lexical processing by covert attention. In addition, Reingold and Stampe (2004) demonstrated that covert attention during reading produced an extremely rapid perceptual enhancement in the direction of reading as compared to the opposite direction. Finally, taking into account the fact that most saccades in reading are in the forward direction, the asymmetry of the perceptual span might, at least in part, reflect covert orienting of attention towards the direction of the saccadic target, that is, upcoming words that have not as yet been directly fixated. Thus, it is safe to conclude that research on eye-movement control in reading has produced ample evidence for the critical role of covert attention in determining both *when* the eyes move (i.e., fixation duration) as well as *where* they move (i.e., fixation location). Consequently, as discussed below, it is not surprising that models of eye-movement control in reading implicitly or explicitly incorporate covert attention mechanisms as part of their architecture.

While SAS and GAG models are in general agreement about covert attention serving as a visuospatial selection mechanism, there are important differences between these two frameworks. Specifically, SAS models are based on the *spotlight* metaphor of covert attention (see Inhoff, Pollatsek, Posner, & Rayner, 1989; Posner, Snyder, & Davidson, 1980). Text information inside the spotlight is assumed to be perceptually enhanced and prioritized for lexical processing as compared to information outside the spotlight, and the progression of this

spotlight is strictly serial. Lexical units are typically assumed to correspond to a single word, and units are "illuminated" sequentially one at a time. Importantly, the spotlight has a well-defined boundary such that enhanced processing is distributed in an all-or-none manner (i.e., the processing of text information outside the attentional beam is not facilitated regardless of its proximity to the attended region).

In contrast to the spotlight metaphor, GAG models, are based on the *Attentional Gradient* metaphor (Downing & Pinker, 1985; LaBerge & Brown, 1989; Shulman, Sullivan, Gish, & Skaoda, 1986; Shulman, Wilson, & Sheehy, 1985). GAG models describe the spatial distribution of covert attention in terms of an asymmetric gradient (similar in extent to the perceptual span). Rather than an all-or-none attentional distribution, GAG models suggest that enhanced processing of text information is greatest at the center of the fixated region and falls off gradually with distance. The attentional gradient concept was further extended in recent formulations of SWIFT (e.g., Schad & Engbert, 2012) that incorporated dynamic modulation of the size of the covertly attended region as an inverse function of the processing difficulty of the fixated word. This concept of the dynamic modulation of the attentional gradient was inspired by the *zoom-lens* metaphor of covert attention (e.g., Eriksen & St James, 1986).

In comparison to the spotlight concept, the attention gradient is larger and does not require precise aiming due to its broader extent of coverage. The larger attended region defined by the gradient likely has a processing cost as well. This suggestion is supported by studies which demonstrated that when attention was distributed over a larger region of the visual field, there was reduced spatial resolution and reduced processing efficiency for any smaller area within the attended region (Castiello & Umiltá, 1990; 1992; Eriksen & Murphy, 1987; Eriksen & Schultz, 1977; Eriksen & St James, 1986; Eriksen & Yeh, 1985; Eriksen, 1990; Shulman & Wilson,

1987). In addition, as compared to the spotlight all-or-none distribution of attention, the attentional gradient with its larger size and ill-defined boundary might be less effective in excluding or filtering out irrelevant information that is located near the attended location.

The present Paradigm

The Selective Reading Paradigm introduced in the present paper involves inserting irrelevant words or nonwords into the text, while clearly differentiating between the constituents of the sentence and the distractor words by using a salient perceptual cue (color in the present experiments) that can be efficiently processed parafoveally. There is substantial evidence from studies of visual search that parafoveal and peripheral processing of perceptual features such as color and shape is commonly used to guide saccades (for reviews see Reingold & Glaholt, 2014; Zelinsky, 2008). Specifically, analyses of the distribution of saccadic endpoints have convincingly demonstrated a bias towards fixating distractors that are similar to a target (i.e., share features with the target) as compared to dissimilar distractors (e.g., Findlay, Brown, & Gilchrist, 2001; Findlay & Gilchrist, 1998; Hooge & Erkelens, 1999; Pomplun, Reingold, & Shen, 2001, 2003; Scialfa & Joffe, 1998; Williams & Reingold, 2001) and such saccadic selectivity has been shown to be extremely flexible in rapidly adapting to changes in the characteristics of the search array (e.g., Shen, Reingold, & Pomplun, 2000; see also Reingold & Glaholt, 2014 for a demonstration of saccadic selectivity and preview benefit in visual search).

Whilst the inclusion of distractors means that the presentation of the text in the present paradigm differs from the standard procedure used in laboratory experiments, it is important to note that text presented in real world conditions (e.g., mobile devices, websites) is often intermingled with salient irrelevant distractors in the form of symbols, images, icons or messages. More importantly, the inclusion of distractors in the text has several advantages for the

investigation of covert attention in reading. Specifically, depending on the spatial arrangement of distractors versus relevant text, it is possible to manipulate the distance and spatial relationship between two successive words in the text (e.g., by inserting a distractor between them). Given that efficient selective reading requires that distractors be excluded or filtered, the present paradigm allows us to explore how covert attention might permit the suppression of irrelevant information during reading. Such a role for covert attention in reading is consistent with the finding that despite its proximity to fixation, text on adjacent lines is not linguistically processed (Inhoff & Briihl, 1991; Inhoff & Topolski, 1994; Pollatsek, Raney, Lagasse, & Rayner, 1993). Furthermore, this finding indicates that regardless of whether attention is allocated in a discrete precisely bounded way, or in a graded manner in the horizontal dimension, it is clearly very precisely bounded in relation to its vertical spread. More importantly for the present study, investigations of visual attention in both humans and primates have demonstrated a role for covert attention not only in facilitating the processing of information within the attended region, but also in actively suppressing distractor information (e.g., Cepeda, Cave, Bichot, & Kim, 1998; Gaspar & McDonald, 2014; Moran & Desimone, 1985). Consequently, the inclusion of distractors in the selective reading paradigm might be useful for studying the inhibitory component of covert attention in reading.

The selective reading paradigm has an additional useful characteristic. Through manipulation of the lexical status and characteristics of the distractor stimuli, it is possible to investigate the depth with which those distractors are processed either when directly foveated or when skipped. For example, given that word frequency effects constitute a primary empirical marker for lexical processing (e.g., Inhoff & Rayner, 1986; Rayner & Duffy, 1986; Rayner, 1977; Reingold et al., 2012), using word distractors which vary in frequency allows us to

determine whether or not distractors are obligatorily lexically processed. To be clear, in using the term obligatory, we mean processing that is automatic, reflexive and mandatory, as per Fodor (1983). Obligatory lexical processing might be predicted by interpretations of the famous Stroop effect (Stroop, 1935; see MacLeod, 1991 for review) as demonstrating involuntary or automatic word identification by skilled readers even when it may be detrimental to task performance (though for an opposing view see Besner, Stolz & Boutilier, 1997). Furthermore, the selective reading paradigm allows for examination of the extent to which various eye-movement parameters are impacted by the relevance of the fixated text. Finally, by employing our paradigm in conjunction with the boundary technique (Rayner, 1975) that was described earlier, it is possible to examine the impact of including distractors on the efficiency of parafoveal processing as measured by the magnitude of the preview benefit.

Experiments 1 and 2

In the next section we will report data from two experiments. We present these results together due to their degree of commonality in terms of method and experimental manipulation. In both experiments we presented participants with sentences including embedded distractor strings on a single line for them to read. Relevant sentence words were presented in blue color while distractor strings were shown in orange color. Specifically, a distractor (four characters in length) was presented between each successive pair of words in the sentence. Also, each sentence contained a target word and a critical distractor string immediately prior to the target (see Figure 1). Target word availability for parafoveal processing (i.e., valid vs. invalid preview condition) was manipulated using the boundary paradigm (Rayner, 1975) with the invisible boundary positioned in the middle of the space between the critical distractor and the target word. As shown in Figure 1, in both experiments the target word was a four-letter word (e.g.,

pipe). In Experiment 1, the critical distractor was either a high frequency word (e.g., **next**), a low frequency word (e.g., **flit**) or a symbol string (e.g., **%#&@**). In Experiment 2, the critical distractor was either the same word as the target (repeated condition, e.g., **pipe**), an unrelated frequency-matched word (control condition, e.g., **chip)** , or a symbol string (e.g., **%#&@**). In addition to preview validity and distractor type, after the experiment, trials were also classified based on whether or not the critical distractor was skipped (henceforth, distractor-skipped trials) or fixated (henceforth, distractor-fixated trials) in first pass reading. Finally, if target preview benefits were obtained in either distractor-skipped or distractor-fixated trials, it would be important to establish whether or not such effects are modulated by distractor type (e.g., symbol vs. word in both Experiments 1 and 2; high vs. low frequency word in Experiment 1; repeated word vs. unrelated matched control word in Experiment 2).

Method

Participants. A total of 60 students or volunteers (30 in each of the two experiments) were tested at the University of Southampton. None of the participants in Experiment 1 were included in Experiment 2. All participants had normal or corrected-to-normal vision and normal color vision (assessed using Ishihara plates; Ishihara, 1964). The participants were all native English speakers. They were naïve with respect to the purpose of the experiment and received either course credit or £6 per hour for their participation.

Materials and design. A total of 300 4-letter words were used as target words (M = 43.9 words per million; Van Heuven, Mandera, Keuleers, & Brysbaert, 2014). Low-constraint sentence frames were composed for each of the 300 target words (Predictability < .01% as estimated by collecting cloze-task sentence completion norms from a separate group of 10 participants). All sentences were 7 words in length and the target word appeared in position 3, 4

or 5 in the sentence. For each of the 300 sentences, a distractor (4 letter spaces in length) that was either a word or a string of symbols was presented between each pair of words in the sentence for a total of 6 distractors per sentence (see Figure 1). Importantly, each sentence contained one critical distractor that was presented immediately prior to the target word, and which was manipulated across experimental conditions. The other 5 non-critical distractors and all the words in the sentence including the target word did not vary across experimental conditions. Across all of the sentences in both experiments, approximately half of the non-critical distractors were words and the other half were symbol strings.

In Experiment 1, each participant was shown 100 sentences with a high frequency critical distractor (M = 831.8 words per million; Van Heuven et al., 2014), 100 sentences with a low frequency critical distractor (M = 0.2 words per million, Van Heuven, et al., 2014), and 100 sentences with a 4-symbol string as a critical distractor (symbol distractors were created by randomly choosing 1 of 24 unique combinations of @, #, % and &). In Experiment 2, each participant was shown 100 sentences in the symbol condition (which was identical to Experiment 1), 100 sentences in the repeated condition that contained a critical distractor that was identical to the target word, and 100 sentences in the control condition that contained a critical distractor that was matched on frequency to the target (M = 44.2 words per million; Van Heuven et al., 2014).

In both Experiments 1 and 2, in addition to the distractor type manipulation, on half of the trials (valid preview trials), the sentences appeared normally, while in the other half of the trials (invalid preview trials), a pronounceable 4-letter non-word (see Figure 1) was initially displayed in the target location and was replaced with the target word during the saccade that crossed an invisible boundary located in the middle of the space between the critical distractor and the target. Thus, 6 experimental conditions resulted in each experiment from crossing Distractor type

(Experiment 1: high frequency condition, low frequency condition, symbol condition; Experiment 2: repeated condition, control condition, symbol condition) and Preview validity (valid vs. invalid). Each participant read any given target word and sentence frame only once and the assignment of critical distractor words to sentence frames and preview conditions was counterbalanced across participants. Participants read 6 practice sentences followed by 300 experimental sentences that were presented in a random order.

Apparatus and Procedure. The apparatus and procedure were identical in Experiments 1 and 2. Eye movements were measured with an SR Research EyeLink 1000 Plus system with a sampling rate of 1000 Hz. Viewing was binocular, but only the right eye was monitored. A chin rest and forehead rest were used to minimize head movements. Following calibration, average gaze-position error was less than 0.5º. The sentences were presented on a 24 inch Asus VG248QE monitor with a refresh rate of 144 Hz and a screen resolution of 1920 x 1080 pixels. All letters were lowercase (except where capitals were appropriate) and were shown in bold mono-spaced Courier New font. The letters were presented either in blue or orange on a white background (the words in the sentence were in blue and distractors were in orange; RGB Values: 0, 0, 255 [blue] and 255, 102, 0 [orange]). Participants were seated 95 cm from the monitor and 4 characters equalled approximately 1 degree of the visual angle. In both Experiments 1 and 2, participants were told to read the blue sentence for comprehension and to ignore the orange text. At the beginning of a trial, participants were required to fixate a cross on the left hand side of the screen and to press a button. This triggered the text to appear. After reading the sentence, participants pressed a button to end the trial and proceed to the next trial. To ensure that participants were reading for comprehension, about 17% of the experimental sentences were followed by multiple-choice comprehension questions.

Results and Discussion

The average comprehension accuracy rates were very high (Experiment 1 = 98%; Experiment 2 = 97%). We examined the influence of the Preview validity by Distractor type manipulation on several eye-movement parameters pertaining to the processing of the target word and the critical distractor in both experiments. Trials were excluded from the analyses described below due to track losses (0.01% of all trials). In the invalid preview conditions, trials in which the invisible boundary was crossed during a fixation were also excluded (11.3% of invalid preview trials). In addition, trials in which there was no first-pass fixation on either the target or the critical distractor (i.e. they were both skipped) were also excluded from the analyses (0.07% of all trials). We begin by reporting the results from an analysis of the proportion of skipping. Next, we will examine the impact of our experimental manipulations on first-pass fixation duration measures. Finally, we will investigate differences in fixation location across experimental conditions as well as the impact of fixation location on other aspects of saccadic performance.

Proportion of Skipping

A crucial component of the selective reading paradigm is the availability of a salient perceptual cue (color in the present experiments) that clearly distinguishes the relevant text from the irrelevant distractor text, and which would be expected to produce higher skipping rates for distractors than for sentence words. We investigated variations across experiments and conditions in the proportion of skipping of either the target or the critical distractor. Analyses of variance (*ANOVA*s) were conducted on the proportion of skipping data via both subjects (F_1) and items (F_2). Figure 2 shows the proportion of distractor skipping (top panel) and proportion of target skipping (bottom panel) by experimental condition in Experiments 1 and 2. As can be seen

in the figure, while the proportions of target skipping were within the normal range of reading performance (Brysbaert, Drieghe, & Vitu, 2005), skipping rates for the critical distractor across all conditions and experiments were much higher, and this occurred despite the fact that the target and distractor were matched on length (all Fs > 297.8, all ps < .001). This result demonstrates clearly that readers were able to use color cues associated with parafoveal words to modulate their saccadic targeting during reading.

Proportion of Skipping: Critical distractor

To examine the pattern in more detail, for each experiment, 2 x 3 ANOVAs were carried out, with Preview validity and Distractor type as independent variables. The pattern of skipping rates for the critical distractor was consistent across experiments. Specifically, the main effect of Distractor type was significant (all Fs > 55.4, all ps < .001), but neither the main effect of Preview validity (all Fs < 1) nor the interaction between Distractor type and Preview validity approached significance (all Fs < 1.8, all ps > .17). In addition, planned comparisons indicated that in both experiments the proportion of skipping was substantially higher when the critical distractor was a symbol string than when it was a word (all ts > 6.2, all ps < .001). Clearly word distractors captured attention, and more critically a fixation, to a greater degree than symbol distractors. Consequently, although saccadic selectivity due to parafoveal processing of distractors was primarily driven by the color cue, the potential relevance of distractors to the reading task also exerted a sizable influence on distractor skipping rates with the linguistically meaningless symbol distractors being skipped more often than the linguistically meaningful word distractors. In addition, in Experiment 1, there was a small but significant increase in skipping rates when the distractor was a high frequency word than a low frequency word [$t_1(29) = 2.19$, $p < 0.05$; $t_2(299) = 3.14$, $p < 0.01$]. In contrast, in Experiment 2, skipping rates did not

differ between the two word distractor conditions (repeated vs. control) that were matched on word frequency. Finally, we also evaluated the influence of practice on distractor skipping rates by comparing skipping performance during the first half versus the second half of each experiment. The only significant effect of practice was a small increase in the probability of skipping of word distractors (first half: 0.535, second half: 0.567; $t(59) > 2.7$, $p < .01$). There were no other significant effects or interactions with practice (all Fs < 1). Taken together, the present findings demonstrate that parafoveal processing of distractors was not restricted to their color; the word/symbol and word frequency effects demonstrate some form of parafoveal orthographic (and likely phonological) processing and some parafoveal lexical processing of distractors.

Proportion of Skipping: Target word

As shown in Figure 2 (bottom panel), in both Experiment 1 and 2, when critical distractors were fixated, the next word (i.e., the target word), was more likely to be skipped in the case of symbol distractors than word distractors (all ts > 2.33, all ps < .05). Further examination of the proportion of target skipping in Experiment 1 indicated that the target was numerically more likely to be skipped when the distractor was a high frequency word than a low frequency word, and this effect was marginally significant by subjects [$t_1(29) = 1.81$, $p = 0.08$] and significant by items [$t_2(299) = 2.51$, $p < 0.05$]. Thus, in Experiment 1, fixating distractors that were more likely to be skipped (symbol > high frequency > low frequency) resulted in higher rates of target skipping. This pattern might suggest that the influence of Distractor type on target skipping rates was due to the modulation of parafoveal processing of the target during fixations on the critical distractor. That is, fixating distractors that were easier to process and discard might have facilitated parafoveal processing of the targets leading to an increase in target skipping rates.

Such an interpretation would be consistent with the foveal load hypothesis (Henderson & Ferreira, 1990), which stipulates that when foveal processing load is high, parafoveal processing of upcoming words is reduced. However, if this interpretation was correct then such a modulation should have been largely restricted to the valid preview condition in which target information was available for parafovoeal processing. This prediction was not supported by the analysis of target skipping rates in Experiment 1, which indicated that there was no main effect of Preview validity and no interaction between Preview validity and Distractor type (all Fs < 1).

In marked contrast to Experiment 1, the analysis of target skipping data in Experiment 2 produced a significant interaction between Preview validity and Distractor type [$F_1(2,58) = 4.0$, $p < 0.05$; $F_2(2,598) = 4.7$, $p < 0.01$]. Specifically, in invalid preview trials the symbol condition produced higher skipping rates (all ts > 3.84, all ps < .001) than either of the 2 word distractor conditions which did not differ (i.e., repeated vs. control; all ts < 1). While, in valid preview trials the probability of target skipping in the repeated condition and the symbol condition did not significantly differ (all ts < 1), and both of these conditions exhibited higher skipping rates than in the control condition (all ts > 2.14, all ps < .05). Thus, it appears that when the target was available for parafoveal processing (i.e., valid preview), fixating a critical distractor that was identical to the target increased the likelihood of target skipping as compared to fixating a distractor that was unrelated to the target. In contrast, when parafoveal processing was rendered ineffective (i.e., invalid preview) the repeated and control conditions did not differ. In other words, there is clear evidence that the parafoveal processing of the target word was facilitated or "primed" during a fixation on an identical critical distractor.

Fixation durations

We examined the influence of the Distractor type by Preview validity manipulation on first-pass fixation durations on both the target word and the critical distractor. Specifically, we analyzed variation in *first-fixation duration* (i.e., the duration of the first forward fixation on the target or the distractor, regardless of the number of subsequent fixations), and *gaze duration* (i.e., the sum of all the consecutive first-pass fixations on the target or the distractor, prior to a saccade to another part of the text). In addition, in both Experiments 1 and 2, these first-pass duration measures were computed separately for fixations on the critical distractor, fixations on the target word in trials in which the critical distractor was fixated (distractor-fixated trials), and fixations on the target word in trials in which the critical distractor was skipped (distractor-skipped trials).

Figure 3 illustrates the findings from the analysis of mean first-fixation duration and gaze duration by experimental condition in Experiments 1 and 2. As was the case for skipping rates, there was a very robust effect of sentence relevance (i.e., target vs. distractor) on first-pass fixation durations. Specifically, across all experimental conditions in both experiments, first-fixation duration and gaze duration on the critical distractor were substantially shorter than the corresponding values on the target word (all Fs > 263.9, all ps < .001). These results, along with the skipping data, suggest that despite minimal practice participants were adept at modifying their reading behavior to suppress irrelevant distractor information. For the most part, distractors were discarded based on parafoveal processing and were either skipped or fixated only briefly. These findings clearly demonstrate flexible and precise allocation of covert attention in the selective reading paradigm.

First-pass fixation durations: Critical distractor

In order to further analyze fixation times on the critical distractor, for each dependent measure, 2 x 3 ANOVAs with Preview validity and Distractor type as independent variables were carried out via subjects and items in both Experiment 1 and 2. Across all analyses, the main effect of Distractor type was significant (all Fs > 20.8, all ps < .001) but there was no significant main effect of Preview validity (all Fs < 1.5, all ps > .22) or interaction between Distractor type and Preview validity (all Fs < 1.7, all ps > .22). This pattern of results mirrors the effects that we observed for the distractor skipping data. As was the case for skipping rates, the analysis of first-pass fixation duration measures indicated that readers spent longer processing word distractors than symbol distractors (all Fs > 11.0, all ps < .001), a finding consistent with the suggestion of truncated processing of non-linguistic (i.e., symbol) as compared to linguistic (i.e., word) distractors. There was also a numerical trend indicating a slight processing advantage for high frequency than low frequency distractors in Experiment 1 (i.e., numerically shorter fixation times for high frequency than low frequency distractors; first-fixation: $F_1(1,29) = 3.7$, $p = 0.07$; $F_2(1,299) = 4.6$, $p < 0.05$; gaze duration: $F_1(1,29) = 1.9$, $p = 0.18$; $F_2(1,299) = 2.6$, $p = 0.11$). In addition, in Experiment 2, first-pass fixation duration measures did not differ across the two word distractor conditions (repeated vs. control) which were matched on word frequency (all Fs < 1). Finally, there was no significant influence of practice on fixation durations on distractors (all Fs < 1). Overall, the pattern of first-pass fixation durations on distractors closely resembles the findings observed for the distractor skipping data in Experiments 1 and 2.

First-pass fixation durations: Target word

To examine first-pass fixation durations on the target word, for each experiment and dependent measure, 2 x 3 x 2 ANOVAs were carried out via subjects and items with Preview

validity, Distractor type, and Trial type (i.e., fixated-distractor trials vs. skipped-distractor trials) as independent variables. All of these analyses produced significant main effects of Preview validity reflecting significant preview benefits (i.e., shorter first-pass fixation times in valid preview than invalid preview) for both distractor-fixated trials (all Fs > 52.6, all ps < .001) and distractor-skipped trials (all Fs > 10.7, all ps < .01). However, the size of the preview benefit was significantly larger for distractor-fixated trials than distractor-skipped trials, and this was reflected in significant interactions across all analyses between Preview validity and Trial type (all Fs > 24.7, all ps < .001). This pattern presumably occurs because the fixation prior to the first fixation on the target word was at least one word further away from the target in the case of distractor-skipped trials than distractor-fixated trials. In light of this difference, it is not surprising that smaller preview effects were obtained in the former than the latter condition, and this finding likely reflects the fact that parafoveal processing of the target was more efficient when readers were in closer proximity to the target. More importantly, despite the increase in distance and associated visual acuity limitations, we obtained robust preview benefits in distractor-skipped trials. We will return to this point in the discussion.

In addition, across all analyses in Experiment 1, there was a main effect of Distractor type (all Fs > 5.6, all ps < .01) reflecting shorter first-pass fixation times on the target word for a symbol distractor than for either of the 2 word distractor conditions (all Fs > 3.9, all ps < .05) which did not significantly differ (despite a numerical difference showing shorter first-pass fixation times on the target word for high frequency than low frequency distractors; all Fs < 1.4, all ps > .24). A similar effect to this was also reported by Risse and Kliegl, (2014). Again, though, as with the target skipping results, shorter target word fixation times occurred in the case

of a symbol distractor regardless of Preview validity indicating that Distractor type did not modulate the size of the preview benefit (all Fs < 2.0, all ps > .14).

In marked contrast to Experiment 1, the analyses of first-pass fixation times on the target word in Experiment 2 demonstrated significant interactions between Distractor type and Preview validity (all Fs > 4.1, all ps < .05). To further explore this modulation of the size of the preview benefit by Distractor type in Experiment 2, we contrasted each pair of Distractor type conditions (repeated vs. control, repeated vs. symbol, control vs. symbol) using 2 x 2 x 2 ANOVAs that were carried out via subjects and items with Preview validity, Distractor type, and Trial type as independent variables. These analyses demonstrated larger preview benefits in the repeated condition than in either the control condition or the symbol condition (all Fs > 7.5, all ps < .01), and the control and symbol conditions did not significantly differ (all Fs < 1). Once again, there is considerable consistency between the skipping data and the fixation duration data across the two experiments. As with the skipping data, there appears to have been sensitivity to the identity of the distractor when it was the same as the target relative to when it was not. Presumably, a distractor that was identical to the target facilitated or "primed" parafoveal processing of the target resulting in a greater likelihood of the target being skipped and shorter first-pass fixation durations when it was fixated. Thus, Experiments 1 and 2 demonstrated two qualitatively different effects of the type of fixated distractors on target processing: 1) easier to process distractors produced higher rates of skipped targets and shorter first-pass fixation durations on targets regardless of preview validity, and 2) distractors which were identical to the targets increased target skipping rates and produced shorter first-pass fixation durations, but only when targets were available for parafoveal processing (i.e., valid preview).

Fixation location

Figure 4 shows differences in the location of the first fixation (i.e., initial landing position) on the target word (Panel a) and on the critical distractor (Panel b). There were no significant differences in the mean initial landing position (all Fs < 1) between: 1) valid versus invalid preview, 2) Experiment 1 versus Experiment 2, and 3) different word distractor conditions (high frequency, low frequency, repeated and control). Consequently, the results are shown collapsed over these conditions. Note that the lack of effects of different distractors on landing positions is in contrast with the effects observed for the fixation duration measures. This supports the suggestion that decisions about where and when to move the eyes are made independently (see Findlay & Walker, 1999).

Fixation location: Landing positions

As can be seen in Figure 4 (Panels a and b), there was a dramatic difference in the distribution of first-fixation landing locations between the target words and the critical distractors. In order to quantify this difference, we classified initial fixations as central fixations if they landed on the 2 center letter bins (i.e., letters 2 and 3 of a four letter word), while all other fixations were classified as outer fixations. Whereas the distribution of initial fixation locations on the target word replicated prior findings showing more central than outer fixations (Dunn-Rankin, 1978; McConkie, Kerr, Reddix, & Zola, 1988; Rayner, 1979; Vitu, O'Regan, & Mittau, 1990), the reverse pattern occurred for initial fixation locations on the critical distractor, and this interaction was highly significant ($F(1,58) = 108.9$, $p < 0.001$). Furthermore, for initial fixations on the critical distractor there was a higher proportion of central fixations for word distractors than for symbol distractors ($t(59) = 3.36$, $p < 0.001$), but there was no such effect of Distractor type on the proportion of central fixations on the target word ($t < 1$). These differences might

indicate that mislocated fixations (either due to saccadic overshoot or undershoot) represent a smaller proportion of the total number of fixations on target words relative to the corresponding proportion of mislocated fixations on critical distractors. In particular, a large proportion of fixations on the non-linguistic symbol distractors might constitute mislocated fixations.

Fixation location: Modulation of first and single fixation durations

Next, we conducted 2 x 2 x 2 ANOVAs with Location (central vs. outer) by Distractor type (symbol vs. word) by Text type (target word vs. critical distractor) as independent variables, and first-fixation duration, single fixation duration (i.e., the first-fixation duration value for the subset of trials in which there was only one first-pass fixation), and the proportion of refixations (i.e., the proportion of trials in which multiple first-pass fixations occurred), as dependent variables. As can be seen in Figure 4, for the target word we replicated prior findings (e.g., Nuthmann, Engbert, & Kliegl, 2005; Vitu, McConkie, Kerr, & O'Regan, 2001; for a review see Vitu, Lancelin, & Marrier d'Unienville, 2007) demonstrating that first-fixation durations and single fixation durations were longer for central than outer fixations (first-fixation: word distractor, $t(59) = 5.89$, $p < 0.001$, symbol distractor, $t(59) = 4.69$, $p < 0.001$; single fixation: word distractor, $t(59) = 3.96$, $p < 0.001$, symbol distractor, $t(59) = 2.64$, $p < 0.05$). In contrast, for the critical distractor (see Figure 4, Panels d and f), outer fixations were longer than central fixations (first-fixation: word distractor, $t(59) = 3.99$, $p < 0.001$, symbol distractor, $t(59) = 7.09$, $p < 0.001$; single fixation: word distractor, $t(59) = 3.87$, $p < 0.001$, symbol distractor, $t(59) = 6.68$, $p < 0.001$). This difference in the pattern of fixation times was reflected in significant interactions between Text type and Location (first-fixation: $F(1,58) = 116.4$, $p < 0.001$; single fixation: $F(1,58) = 83.4$, $p < 0.001$).

Fixation location: Refixations

Another striking difference between the target word and the critical distractor concerns the impact of fixation location on the proportion of refixations (see Figure 4 Panels g-h). Trials with refixations on the critical distractor were very uncommon and the proportion of such trials did not vary between central and outer initial fixations (both *ts* < 1). In marked contrast, the pattern of refixations on the target word replicated the typical findings in the literature (for a review see Vitu et al., 2007) demonstrating a higher proportion of refixations for outer than central initial fixations (both *t*s > 8.83, both *p*s < .001). This difference in the pattern of refixation data was reflected in significant interactions between Text type and Location ($F(1,58) = 101.4$, $p < 0.001$). These differences in the pattern of results for refixations on the target words compared with the critical distractors are dramatic. Readers were approximately four times more likely to make a refixation on a target than on a distractor. Furthermore, for the target words refixations were over twice as likely when an outer rather than an inner letter was initially fixated, whilst for distractor strings, there was little difference. Overall, the initial landing position effects are very consistent with the suggestion that readers modified their reading behavior in order to maximally selectively attend to the content words and actively suppress the acquisition of information from irrelevant distractors.

Discussion

The implementation of the selective reading paradigm in Experiments 1 and 2 yielded a striking pattern of differences between the processing of target words and critical distractors. Specifically, in comparison to targets, distractors were much more likely to be skipped or briefly fixated and much less likely to be refixated, and these findings clearly indicate much shallower processing of distractors than targets. Furthermore, the depth to which the distractors were

processed also depended upon their linguistic characteristics. Readers devoted more processing resources to words than symbol distractors, and numerically, more to distractors which were low frequency words than high frequency words. In addition to these quantitative differences, the processing of distractors appears qualitatively different than normal reading. In particular, first-pass fixation times on critical distractors demonstrated greatly attenuated effects of word frequency in comparison to normal reading. Given that word frequency effects constitute a primary empirical marker for lexical processing (Inhoff & Rayner, 1986; Rayner & Duffy, 1986; Rayner, 1977; Reingold et al., 2012), the present findings suggest that lexical processing of word distractors was greatly reduced. The attenuation of lexical processing of irrelevant distractors in the current paradigm is similar to the findings that during mind-wandering episodes (sometimes referred to as mindless reading), word-frequency effects are absent or much reduced in size (e.g., Reichle, Reineberg, & Schooler, 2010; Schad, Nuthmann, & Engbert, 2012). Thus, it seems that reading in the absence of attentional engagement or with active attentional suppression is qualitatively different than normal reading.

Similar to the influence of word frequency, the landing position of the first-fixation on a word (i.e., central vs. outer fixations) is known to exert very robust and consistent effects on eye-movement parameters in normal reading. Accordingly, the remarkable differences between targets and distractors in terms of the distributions of fixation location and in the impact of this variable on eye movements (see Figure 4) constitute another dramatic illustration that the processing of irrelevant text within the selective reading paradigm is qualitatively different than normal reading. It is noteworthy that location effects on eye-movement control in reading have been demonstrated to be extremely rapid and are typically assumed to be mediated by a non-lexical control mechanism (e.g., Nuthmann et al., 2005; Nuthmann, Engbert, & Kliegl, 2007;

Vitu et al., 2001, 2007). Importantly, the present findings suggest that, just like word frequency effects, location effects in reading might not be immune to the influence of top-down attentional factors. Furthermore, it is interesting to consider the theoretical implications of the finding that location effects (i.e., initial landing position effects) for the critical distractors were almost the mirror image of those for the target words. In contrast, the pattern of distractor skipping data was more similar to normal reading despite increased skipping rates and attenuated word frequency effects. Given that both the landing position data and the skipping data reflect oculomotor control decisions regarding where to move the eyes in reading (i.e., which word to select as the target of a saccade vs. where within a word to target a saccade), the effects obtained within the selective reading paradigm suggest differential levels of flexibility in relation to these different types of "where" decisions[1]. That is, it appears that whilst some aspects of "where" decision making in reading are relatively pliable, others are more impervious to strategic control. At present, current models of eye-movement control in reading do not provide a straightforward explanation for this pattern of findings. Further research is required in order to explore the behavioral and neurophysiological factors underpinning these different aspects of "where" decision making.

The above findings concerning the processing of distractors raise several important issues. Although readers displayed impressive efficiency in selectively ignoring distractors as compared to target words, one may wonder why readers ever fixated the distractor strings at all. It is clearly the case that saccadic targeting in selective reading is not perfect (otherwise readers would never have fixated the distractor strings and skipping rates for these would be 100%). To put this issue in perspective, it is instructive to consider similar findings concerning saccadic selectivity in visual search (see Reingold & Glaholt, 2014, for a recent summary). Specifically,

perfect saccadic selectivity based on color cues was similarly not obtained in visual search studies (see Williams & Reingold, 2001) despite the fact that such studies employed minimum distances between adjacent display items that were much larger than the space between distractors and targets in the present paradigm. In general terms, it is likely that some of the fixations on distractors in the present study arose due to oculomotor noise. It is well documented that saccadic targeting in reading is inherently noisy (e.g. McConkie, Kerr, Reddix, & Zola, 1988), and therefore some saccades to distractors will simply reflect mislocated fixations (Drieghe, Rayner, & Pollatsek, 2008). The large increase in the proportion of outer fixations on distractors relative to targets is consistent with this explanation (i.e., possibly indicating that mislocated fixations constitute a substantial proportion of fixations on distractors). Furthermore, normal reading involves the operation of highly practiced oculomotor routines. Readers make very fast motoric responses in tight synchrony with complex visual and cognitive processes. Importantly, the default action after every fixation during normal reading is to target the next saccade to the upcoming word in the sentence. Usually a word is skipped when it is short, predictable and/or high frequency. To be clear, skipping of words – although frequent - is the exception rather than the norm. In contrast, in the selective reading paradigm, the default action is to skip. That is to say, for perfect performance to occur in the current implementation of the selective reading paradigm, readers must make a saccade to skip a word after each fixation. This required action is in direct conflict with the default motoric response required in the overlearned activity of normal reading. It is perhaps unsurprising, therefore, that readers often make fixations on distractors when they are engaged in selective reading.

The above considerations notwithstanding, the proportion of fixations on distractors exceeds what we might reasonably anticipate as a consequence of oculomotor error.

Furthermore, the fact that the nature of the distractors systematically influenced saccadic targeting indicates that there are clearly other influential factors involved. In particular, despite the fact that the color of a critical distractor categorically indicated that it was irrelevant to sentence meaning, there remained differences in distractor skipping rates and first-pass fixation durations as a function of Distractor type. Specifically, symbol distractors were much more likely to be skipped or briefly fixated than word distractors. It is clear that parafoveal processing of the color cue permitted the guidance of saccadic endpoints away from irrelevant distractors and towards the relevant sentence words resulting in much higher skipping rates for the former than the latter. It is possible that low level feature differences between symbol distractors and normal text provided shape cues that in parallel to the processing of the color cues increased saccadic selectivity for symbol distractors. According to this interpretation, greater saccadic selectivity in the case of symbol distractors was due to simultaneous parafoveal processing of both color and shape cues, while only the color cue was available to guide saccadic endpoints in the case word distractors. In fact, such a pattern of saccadic selectivity due to simultaneous guidance by color and shape in a visual search task was demonstrated by Williams and Reingold (2001).

However, another non-mutually exclusive explanation of the processing differences between symbol and word distractors is that the linguistically meaningful word distractors were subjected to at least occasional orthographic and/or lexical processing. By this interpretation, it seems likely that readers processed information about the visual form of the parafoveal string, and if that string was word-like in appearance, then they had an increased tendency to fixate and process it. Note also that this pattern of results occurred even though the color of the string indicated categorically that the word was irrelevant to the meaning of the sentence.

Consequently, even when words were irrelevant to the linguistic interpretation underway there might have been an involuntarily tendency to fixate and process these words at least occasionally. This suggestion is consistent with the numerical trend showing greater skipping rates and shorter first-pass fixation durations for high frequency than low frequency distractor words. These word frequency effects, although greatly attenuated compared to those obtained in normal reading, provide some support for at least sporadic lexical processing of distractors.

In the final section of this paper we will consider the present findings in relation to models of eye-movement control in reading. However, it is worth bearing in mind that the selective reading paradigm requires participants to engage in reading behavior that may be quite different than normal reading. Given this, it may be sensible to exhibit caution in using the present findings to evaluate SAS and GAG models. Nevertheless, we would argue that some of the findings obtained in the present experiments might be very informative with respect to eye-movement control in reading. Consider, for example, the fact that in trials in which the distractor was skipped, we observed robust preview benefits (i.e., shorter first-pass fixation durations on the target in valid than invalid preview conditions). This finding provides very strong evidence for parafoveal processing of the target word despite the intervening distractor which occupied the space that under normal reading conditions would constitute word *N+1*. Such a preview benefit is consistent with GAG models that predict word *N+2* preview benefits should occur quite generally due to concurrent processing of words within the attentional gradient. The effect we obtained might also be consistent with SAS models such as the E-Z Reader model, if one assumes that the salient color cue permitted covert attention to shift selectively, and thus largely skip or only briefly pause on distractors. In such a situation, the target word would be processed as the upcoming parafoveal word even in the presence of the intervening distractor string.

Importantly, our findings of robust preview benefits in distractor-skipped trials is in marked contrast to the fact that it has been difficult to obtain consistent demonstrations of word *N+2* preview benefits using a variant of the boundary paradigm (Rayner, Juhasz, & Brown, 2007; see Radach & Kennedy, 2013; Schotter et al., 2012 for reviews). Specifically, findings of modest word *N+2* preview benefits were reported under conditions in which word *N+1* was very short (three-letter) and high frequency (e.g., Kliegl, Risse, & Laubrock, 2007; Radach, Inhoff, Glover, & Vorstius, 2013; Risse & Kliegl, 2011). In contrast, Angele and Rayner (2011) did not obtain word *N+2* preview effects, even when word *N+1* was the word "the". With Chinese text, a word *N+2* preview effect was obtained for a high frequency word *N+1* (Yang, Wang, Xu, & Rayner, 2009) but not for a low frequency word *N+1* (Yang, Rayner, Li, & Wang, 2012). Similarly, Yan, Kliegl, Shu, Pan and Zhou (2010) showed that the ease with which word *N+1* is processed modulates the effectiveness with which word *N+2* is processed in Chinese reading. Thus, the evidence for word *N+2* preview effects is mixed with some studies providing evidence for such effects, and other studies failing to obtain such evidence. It has been proposed that the difficulty in obtaining clear evidence for word *N+2* preview effects might be due to visual acuity drop-off at higher eccentricities as well as by the limited size of the perceptual span (e.g., Radach & Kennedy, 2013). However, the present findings are clearly inconsistent with such a proposal (for a similar argument see Cutter, Drieghe, & Liversedge, 2014). This illustrates one of the promising aspects of the selective reading paradigm, namely, the ability to test the limits of effective parafoveal processing by manipulating the number and/or length of irrelevant distractors which are placed between adjacent words in the text while keeping the relevant sentence unchanged. This would be an obvious extension of the present experiments that might serve to provide critical information for models of eye-movement control in reading.

With respect to the interpretation of the preview benefits that were obtained in either distractor-skipped or distractor-fixated trials, it is important to consider the extent to which these effects were modulated by distractor type. GAG models stipulate that a preview effect results from an attentional gradient that in the selective reading paradigm would include both the critical distractor and the target, and consequently the difficulty of processing the distractor should modulate the magnitude of the preview benefit as they both compete for attentional resources (i.e., greater difficulty of processing the critical distractor should result in a smaller preview effect). In contrast, in line with an all-or-none attentional spotlight as per an SAS model such as E-Z reader, no such modulation of the size of the preview benefit by distractor type should occur. The evidence relating to these possibilities in the present experiments was mixed. Specifically, given that it is clear that symbol distractors were processed to a far lesser degree than word distractors, GAG models might predict a larger preview benefit in the former than the latter condition. While such an effect was not obtained in terms of the pattern of preview effects on first-pass fixation times on the target, target skipping rates were larger for symbol than word distractors. Similarly, while there was no effect on the size of preview benefit as a function of the word frequency of the critical distractor, target skipping rates showed a slight increase for high frequency than low frequency distractors.

The strongest evidence that was obtained in the present experiments for simultaneous processing of the critical distractor and the target occurred in a condition in which both were identical (i.e., the repeated condition in Experiment 2). Specifically, the magnitude of the preview benefit was larger when the critical distractor was identical to the target (repeated condition) than when the distractor was a frequency-matched control word that was unrelated to the target (control condition). This effect is reminiscent of a repetition effect observed by

Angele, Tran, and Rayner (2012). In a boundary change experiment during reading, they observed that the repetition of the foveal word in the parafovea (after the boundary) resulted in shorter fixation durations on the foveal word and no evidence of additional disruption on the parafoveal word when it was fixated after the boundary change. However, in their experiment, processing the foveal word was relevant for the task, whereas in the current experiment the first instance of the repetition was an irrelevant distractor. Note also that in the current experiment the benefit of repetition occurred regardless of whether the distractor was fixated or skipped. It appears that the commonality between the distractor and the target word resulted in facilitation when the eyes moved to fixate the target, and this commonality exerted an influence even when the distractor was processed solely in the parafovea. Importantly, however, when the pre-target critical distractor was fixated, those fixations were uninfluenced by the identical target. If the distractor and target were being processed completely in parallel, then we might have expected facilitation in the form of shorter fixations for both the target (i.e., larger preview benefits) and the distractor (i.e., parafoveal-on-foveal effects). While the former suggestion was clearly supported by our findings there was no evidence consistent with the latter suggestion.

It seems likely that the increased preview benefit for the target word after an identical distractor arose due to the distractor acting as a prime for the target. Within sentence orthographic priming effects have been demonstrated to occur in alphabetic and non-alphabetic languages across a number of experiments (Pagán, Paterson, Blythe, & Liversedge, 2015; Paterson, Alcock, & Liversedge, 2011; Paterson, Liversedge, & Davis, 2009; Wang, Tian, Han, Liversedge, & Paterson, 2014). In these experiments, orthographically related words appear in the same sentence (e.g., *There was a **blur** as the **blue** lights of the police car…*) and effects of the first word (*blur*) relative to a control word (*gasp*) are observed when readers fixate the second

word (*blue*) downstream in the sentence (see also Frisson, Koole, Hughes, Olson & Wheeldon, 2014, for a demonstration of the importance of phonological overlap for obtaining such priming effects). Presumably, the effects we have observed in the present study are similar to these effects reported earlier, except that the two words are identical rather than slightly different. If this explanation is correct, then the effects observed at the target are likely to be orthographically, phonologically and/or lexically based and to result from residual activation of the target word by the identical distractor.

To summarize, considering the entire pattern of findings we obtained in the present experiments, we are tentatively suggesting that the performance in the current implementation of the selective reading paradigm represent a mixture of successes as well as failures on the part of readers in their attempts to override highly practiced and arguably automatic perceptual, cognitive and oculomotor aspects of normal reading. Specifically, the fact that readers were able to quite effectively focus attention on the content words of sentences at the expense of distractor words, and the striking pattern of differences in eye-movement parameters as a function of text relevance, is consistent with the view that in addition to facilitating processing of the text within the attended region, covert attention can also result in irrelevant distractor information being suppressed during reading (at least in a reading paradigm that requires such suppression for successful text comprehension). Such a role for covert attention in reading is consistent with the findings that irrelevant text information on adjacent lines is not lexically processed (Inhoff & Briihl, 1991; Inhoff & Topolski, 1994; Pollatsek et al., 1993; for a non-reading example of distractor suppression see Cepeda et al., 1998; Gaspar & McDonald, 2014; Moran & Desimone, 1985). However, we also demonstrated that the suppression of distractors is not absolute and despite the strong relevance cue that was provided (i.e., color), some differentiation (albeit rather

shallow) as a function of Distractor type was evident. Although the implications of the present findings for models of eye-movements control in reading must be considered with caution, we would strongly argue that the present study illustrates the promise of the selective reading paradigm as a potentially valuable tool for the study of the role of covert attention and eye-movement control in reading.

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Footnotes

[1] We are indebted to Jane Ashby for pointing out this important implication of our data.

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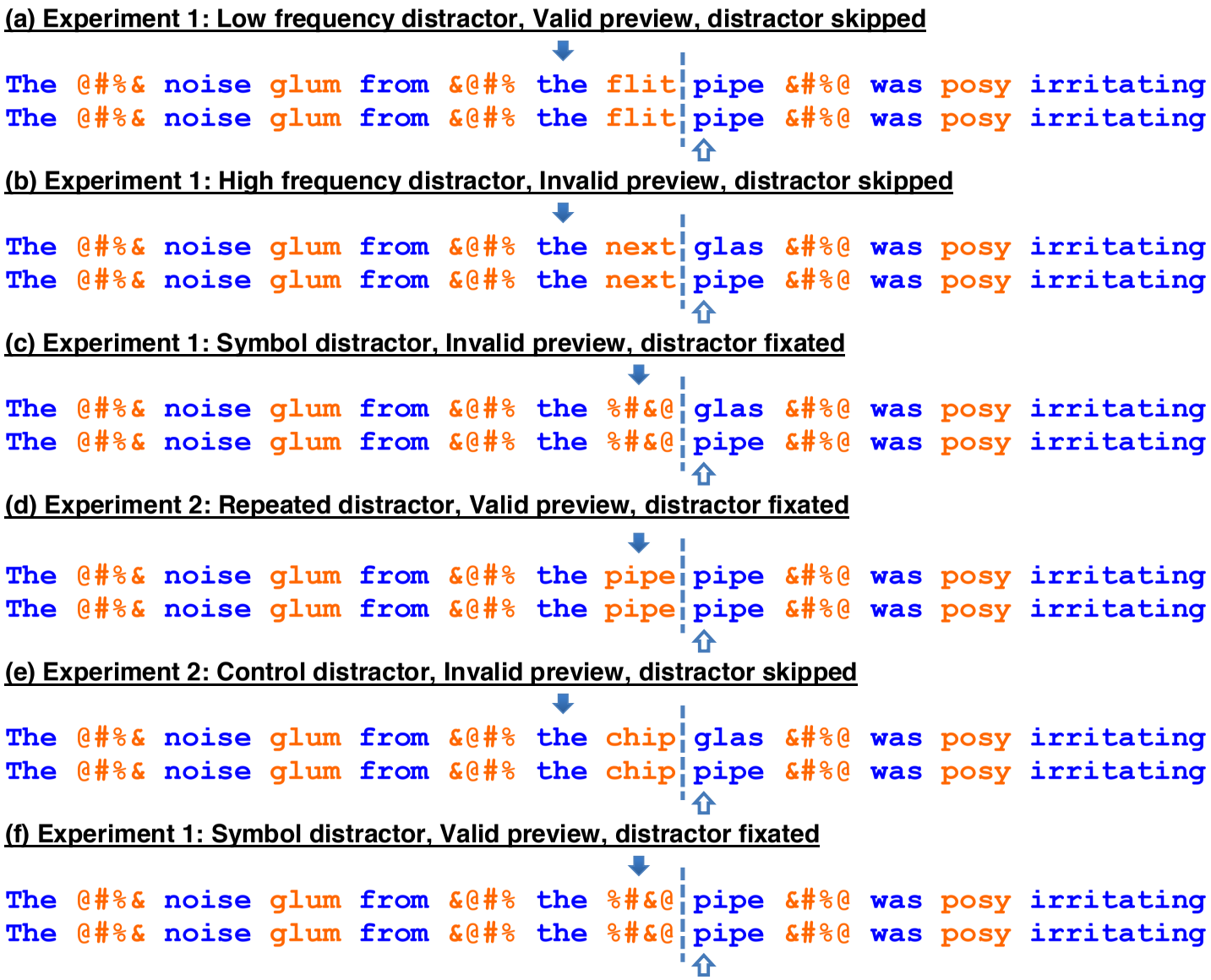

Figure 1. Illustration of trials in the Experiments 1 and 2. Subjects read the blue text and ignored the orange distractors; the vertical dashed line indicates the location of the invisible boundary in the middle of the space between the critical distractor (on the left) and the target word (on the right). The arrows mark the fixation location before (filled arrow) and after (non-filled arrow) the saccade that crossed the invisible boundary. In each trial we illustrate the display prior to (top sentence) and after (bottom sentence) crossing the boundary. In invalid preview trials the target word was only presented after the boundary was crossed and it replaced a nonword that occupied its position during prior fixations (see text for details).

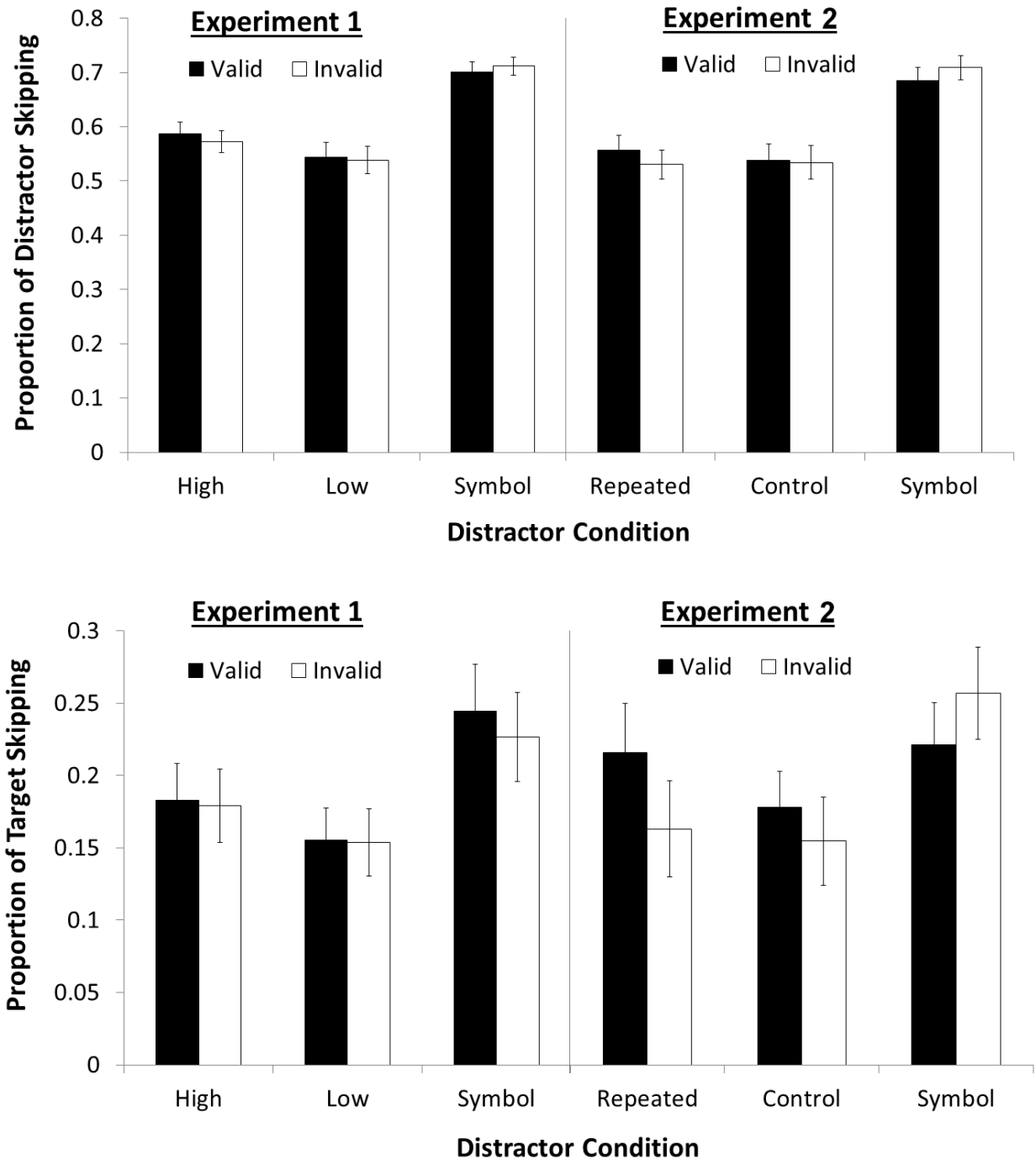

Figure 2. The proportion of critical distractor skipping (top panel) and the proportion of target word skipping (bottom panel) by Preview validity and Distractor type in Experiments 1 and 2.

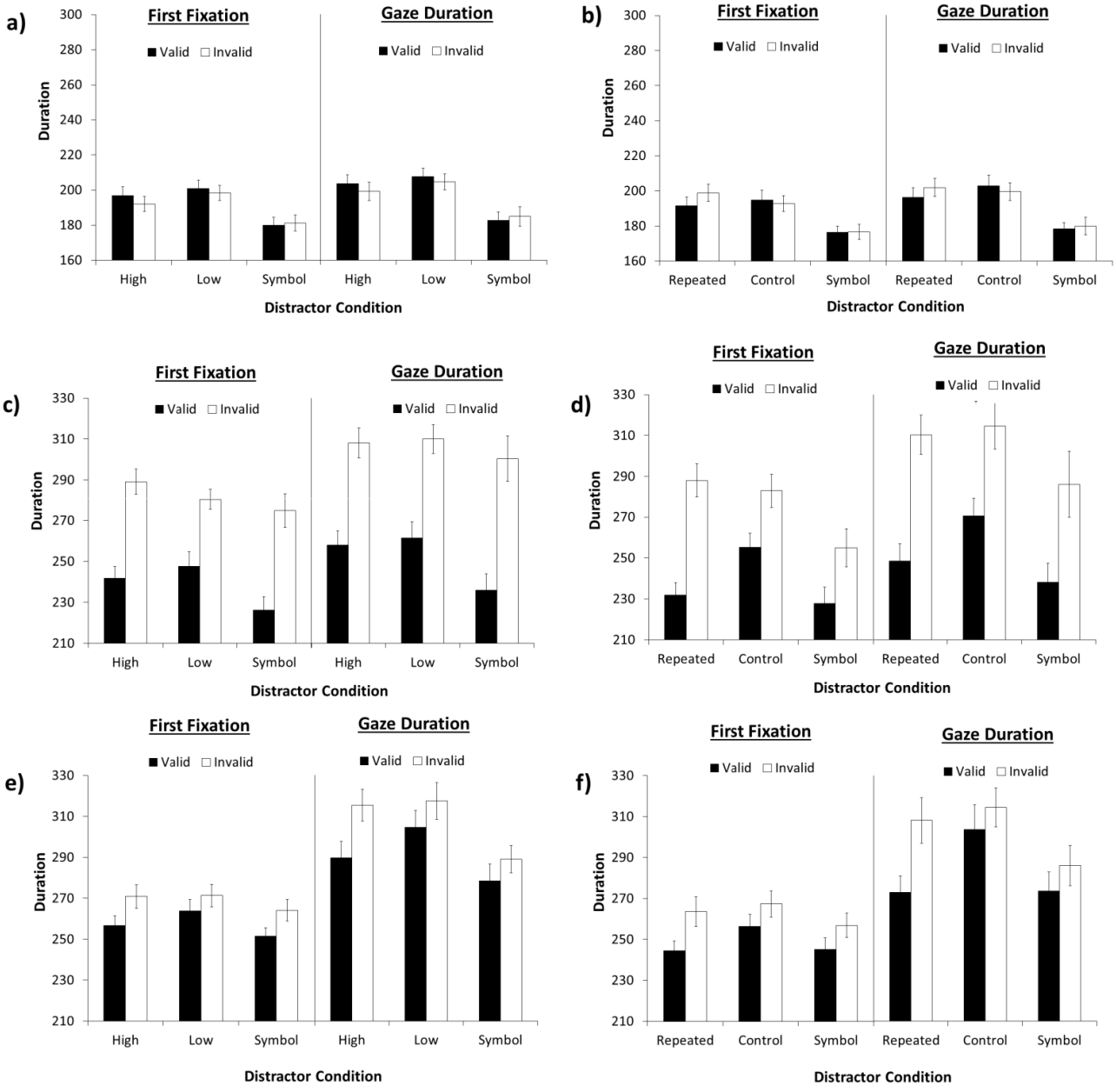

Figure 3. First-fixation duration and gaze duration by Preview validity and Distractor type in Experiment 1 (left column: Panels a, c, and e) and Experiment 2 (right column: Panels b, d, and f). The top row (Panels a-b) shows first-pass fixation duration on the critical distractor. The middle row (Panels c-d) shows first-pass fixation duration on the target word in distractor-fixated trials. The bottom row (Panels e-f) shows first-pass fixation duration on the target word in distractor-skipped trials (see text for details)

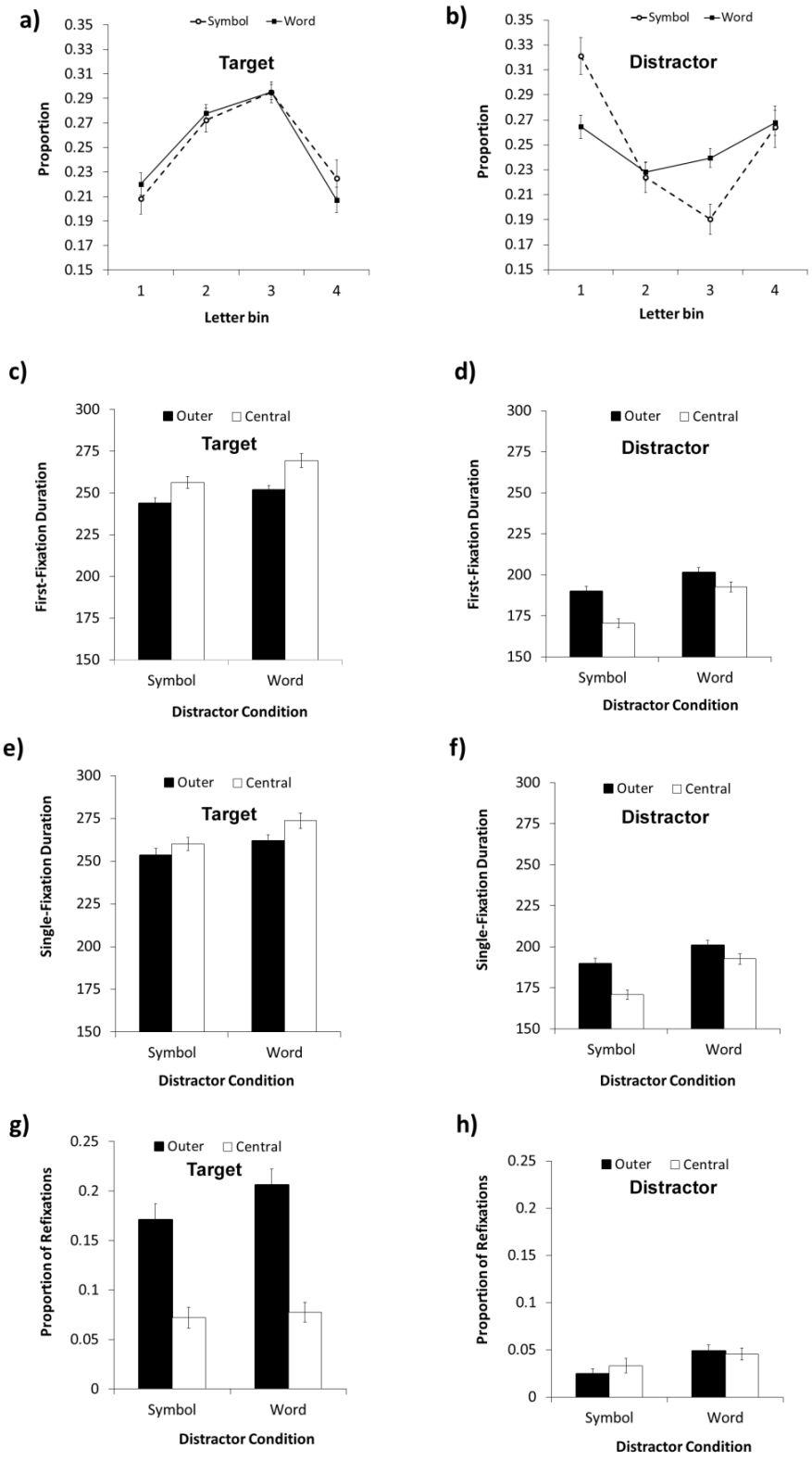

Figure 4. The distribution of the initial fixation location by Distractor type (symbol vs. word) on the target word (Panel a) and on the critical distractor (Panel b) and first-fixation duration (word: Panel c, distractor: Panel d), single fixation duration (word: Panel e, distractor: Panel f), and proportion of refixations (word: Panel g, distractor: Panel h) by Location (central vs. outer) and Distractor type (see text for details).