Letter Identity and Position Coding in the Parafovea

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Author Note

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Abstract

Letter position coding has been extensively examined in studies of isolated word identification, spurring the development of computational models. However, these models are largely restricted to explaining word identification in foveal vision despite the fact that early lexical processing during reading occurs in the parafovea. We report four experiments that examined the flexibility of parafoveal letter identity and position coding using a variant of the same-different match task. Participants matched transposed- and substituted-letter strings to reference words, with the former being displayed at various retinal eccentricities for 100 ms versus 300 ms to respectively preclude or allow eye movements. The first pair of experiments demonstrated the relative difficulty of coding parafoveal letter positions as compared to their identities, as well as the standard benefit in identifying words displayed in the right visual field. The second pair of experiments further demonstrated that the location of letter-position uncertainty (i.e., transposed letters) interacts with both eccentricity and visual field. Initial letter transpositions were more easily detected in the left visual field whereas transpositions of the final letters were more accurately detected in the right visual field. As discussed, these results are challenging for existing models of reading which can individually account for some of our findings but not the results in their entirety.

Keywords
eye movements, models of reading, parafoveal processing, reading, transposed-letter effect, word identification

Word count: 8,476 (excluding Abstract, References, Footnotes, Tables, and Figures)

Word identification during reading requires the routine extraction of visual information from upcoming text located in the parafovea—between 2 and 5 degrees from the center of vision. Due to the physiology of the eye, parafoveal word identification is made difficult by both reduced visual acuity and increased visual crowding, and this difficulty increases as a function of *retinal eccentricity* or distance between the center of vision and the word. However, the relationship between word identification on the one hand and acuity and crowding on the other is complex. For example, crowding effects are more pronounced for letters closer to the fovea and are more detrimental than acuity limitations (Bouma, 1973; Latham & Whitaker, 1996; Veldre et al., 2022; see Pelli & Tillman, 2008 for a review). Additionally, in languages read from left to right, such as English, upcoming words are processed in the right visual field, from which information is projected directly to the left hemisphere of the brain where language areas are typically located. However, despite decades of research on both isolated word identification and eye movements during reading, it is not well-understood how these low-level visual factors affect letter and word identification.

Early evidence of the effect of retinal eccentricity on word identification comes from a study by Rayner and Morrison (1981) who assessed the accuracy and latency of naming or making lexical decisions about words presented between 0 and 5 degrees to the right and left of fixation. Critically, participants were either free to move their eyes towards the targets or were instructed to maintain central fixation while responding to the items presented at various eccentricities. Their data showed both a steep decline in performance accuracy and a linear increase in latency with increasing eccentricity under fixed gaze conditions in both tasks (see also Schiepers, 1980). These findings clearly demonstrate that word identification is impaired outside of central vision, but there are reasons to question the validity of their estimates of the effect of eccentricity due to various methodological limitations. For example, the experiments had very small sample sizes both in terms of the number of participants and the number of items; all word targets were high-frequency five-letter words; and the items were repeatedly presented throughout the experiments. Most importantly, the authors do not report whether any trials were excluded because participants moved their eyes in the fixed gaze conditions, nor is it clear whether there were precautions in place to ensure that participants were fixating centrally at the start of each trial (see Veldre et al., 2023a for details).

To provide more robust estimates of the impact of eccentricity on lexical processing, Veldre et al. (2023a) conducted a large-scale replication and extension of Rayner and Morrison's (1981) study in which participants performed lexical decision and naming tasks for words presented at various eccentricities in the left and right visual fields. Importantly, an eye tracker was used to ensure that participants maintained central fixation and a gaze-contingent trigger was used to terminate trials on which participants made an eye movement towards the target stimulus. Despite these methodological improvements, the results of these experiments were remarkably similar to those reported by Rayner and Morrison, with response accuracy decreasing and response latencies increasing as eccentricity increased, and with better performance in the right than left visual field.

Extending this work, Veldre et al. (2023a) developed a variant of the aforementioned eccentricity paradigm for web-based data collection to assess the role of eye movements on eccentricity effects by manipulating the duration of target presentation. Specifically, separate blocks of lexical-decision trials presented the target stimuli for either 300 ms or 100 ms at either central fixation, or at 1- or 2-degrees eccentricity in the right or left visual field. The 300-ms presentation duration provided participants with enough time to make a saccade and fixate on an eccentric target before responding. In contrast, because participants did not have foreknowledge of the position of the target on any given trial, when the target was presented for 100 ms, the participant did not have sufficient time to program and execute an eye movement to fixate on an eccentric target (Becker & Jürgens, 1979; Reichle & Reingold, 2013). The 300 ms versus 100 ms duration manipulation thereby served as an analogue of the eye-movement and fixed-gaze conditions, respectively, in Rayner and Morrison's (1981) original study. Comparing the data from the 100-ms duration condition in the web-based paradigm to the findings of the laboratory-based eye-tracking experiment for the same word targets revealed a strikingly similar pattern of effects of both eccentricity and visual field on lexical-decision accuracy (see Figure 1; see also Angele et al., 2023; Parker et al., 2021 for demonstrations that web-based word identification paradigms involving precise display timing yield interpretable data). Specifically, performance accuracy declined significantly with each degree of eccentricity, and the decline was more pronounced in the left visual field than in the right visual field. That is, there was a significant right visual field advantage, consistent with the findings of lateralized letter-string/word-identification and lexical-decision studies (e.g., Bouma, 1973; Eng & Hellige, 1994; Hellige et al., 1989; Levy et al., 1983).

However, a related body of research has also examined the implications of hemispheric asymmetry in processing words in central vision. Specifically, studies have tested whether visual information from letters to the left and right of fixation within a fixated word are initially projected to the contralateral hemisphere (so-called *split fovea theory*), or whether all foveal letters are projected to both hemispheres (see Ellis & Brysbaert, 2010, for a review). Brysbaert et al. (1996) demonstrated that the right visual field advantage occurs for both foveal presentation as well as parafoveal presentation, suggesting that they reflect the same underlying mechanism. The present study does not address this debate because it instead focuses on visual field and eccentricity effects for words that are presented entirely in the left or right visual field.

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Veldre et al. (2023b) used the web-based eccentricity paradigm to assess performance on tasks designed to tap various component processes involved in word identification: low-level visual processing, letter identification, discriminating words from nonwords and pseudowords, and making semantic decisions. It was expected that eccentricity and visual field effects in the 100-ms duration condition (which precludes eye movements) would be more pronounced for tasks requiring “deeper” linguistic processing versus tasks requiring more superficial visual and/or orthographic analysis. Although the expected pattern was observed for response latency, the relationship between performance accuracy and processing depth was more complex. Specifically, accuracy on tasks requiring semantic processing (i.e., discriminating animal and object words; discriminating concrete and abstract words) showed minimal effects of either eccentricity or visual field in contrast to both lexical-decision and letter-identification tasks, for which accuracy was severely impaired outside the fovea and particularly in the left visual field. This pattern of findings was interpreted as evidence that participants use higher-level knowledge about superordinate and linguistically defined categories in combination with partial orthographic information extracted from the parafovea to effectively extend the visual span. The present study used a variant of the eccentricity paradigm to investigate the pre-lexical orthographic processing of letter identity and letter position in parafoveal words.

Letter Position Coding

Studies of isolated word identification have demonstrated that the coding of letter position involves some flexibility and/or uncertainty. This conclusion is based on evidence that *transposed-letter* (*TL*) words and nonwords, in which the order of two adjacent letters within a string is reversed (jugde-JUDGE), are often misperceived as their TL neighbor (Andrews, 1996; Chambers, 1979; Christianson et al., 2005; Forster et al., 1987; O'Connor & Forster, 1981; Perea & Fraga, 2006; Perea & Lupker, 2003a, 2003b, 2004; Schoonbaert &

Grainger, 2004). Studies using the masked priming paradigm (Forster & Davis, 1984) have found that briefly presented TL nonwords produce greater facilitatory priming than matched *substituted-letter* (*SL*) nonwords (jugde-JUDGE vs. jupte-JUDGE; e.g., Forster et al., 1987; Perea & Lupker, 2003). But transposition similarity effects have also been observed for strings of both non-letter characters and symbols (e.g., Duñabeitia et al., 2012; Garcia-Orza et al., 2010; Ktori et al., 2019; Massol et al., 2013), suggesting that the TL effect may reflect the outcome of noisy perceptual processing (e.g., Norris & Kinoshita, 2012), possibly with an additional letter-specific coding mechanism (e.g., Grainger, 2018).

Demonstrations of TL similarity effects challenged existing models of word identification that used “slot-coding” schemes in which letter identities are associated with specific positions within words, e.g., models incorporating an interactive-activation framework (McClelland & Rumelhart, 1981) such as the Dual-Route Cascaded model (Coltheart et al., 2001) and the Multiple Read Out Model (Grainger & Jacobs, 1996). These models treat TL and SL strings as being equally similar to the corresponding base word because both types of strings have incorrect letters in exactly two positions.

Alternatives to slot coding schemes include models that code ordered letter pairs (e.g., *JU*, *JD*, *JG*, *JE*, *UD*, *UG*, *UE*, *DG*, *DE*, *GE*), such as the Open Bigram (Grainger, 2008; Grainger & van Heuven, 2003; see also Snell et al., 2018) and SERIOL (Whitney, 2001a, 2001b, 2008; Whitney & Cornelissen, 2005, 2008) models. These models account for TL similarity effects because, relative to SL strings, TL strings share more bigrams with the corresponding base word. For example, *jugde* shares all bigrams with JUDGE with the exception of *DG*, whereas *jutpe* and JUDGE share only *JU*, *JE*, and *UE*. In contrast, the Overlap model (Gomez et al., 2008) assumes that there is some amount of uncertainty in the coding of letter positions, such that the letter *D* in *JUDGE* will be most strongly associated with letter position 3 but will to a lesser extent also be associated with letter positions 2 and

4. All of these models are inherently limited, however, because they only explain data from isolated word-identification paradigms and have not been extended to account for the processes involved in identifying words during the reading of text (but see Snell et al., 2018). For example, these models do not make any assumptions about how letter position coding may be affected by the allocation of attention and the planning of saccadic eye movements, the visual constraints imposed by the parafovea, or differences between the visual hemifields. A primary goal of the present study was to estimate the impact of these factors on letter position coding, with the ultimate goal of developing more complete models of reading.

Transposed-Letter Effects Outside the Fovea

There is only limited existing evidence concerning the precision of letter position coding for words in the parafovea. Van der Haegen et al. (2009) conducted a masked priming study in which they manipulated both the position of the transposed letters and the position of the participant's fixation within the letter string. The results showed increased TL priming relative to a SL nonword prime with increased distance between the fixation point and the transposed letters. This suggests that letter position coding is less precise with increasing eccentricity, but this study only presented primes and targets in foveal vision.

Perea and Fraga (2006) used a lateralized lexical-decision paradigm to investigate transposed-letter effects for parafoveally presented letter strings in the left and right visual fields. In their experiments, words and nonwords were briefly presented for 175 ms at 2.5 degrees to the left or right of central fixation. Their critical comparison was between nonwords formed from the transposition of non-adjacent letters in Spanish base words (e.g., TRADEGIA from TRAGEDIA) or one- or two-letter-different SL nonwords (TRAGEPIA or TRATEPIA, respectively). The results showed the typical right visual field advantage on lexical-decision accuracy and latency for word targets. TL nonwords yielded substantially more false-alarms than did SL nonwords, particularly in the right visual field. Thus, the TL nonwords showed a *left* visual field advantage on both accuracy and latency (i.e., easier to reject TL nonwords in the left versus right visual field) whereas there were no visual field effects for either one- or two-letter-different SL nonwords. These data suggested that parafoveally presented TL nonwords are perceptually more similar to their base words than are SL nonwords—even those that differed from the base word by only a single letter.

Evidence consistent with this conclusion comes from eye-movement studies which showed that flexible letter position coding is also observed in word identification during reading of connected text (Acha & Perea, 2008; Blythe et al., 2014; Johnson et al., 2007; Johnson, 2009; Rayner et al., 2006; Warrington et al., 2019; White et al., 2008). Johnson et al. (2007) used the *gaze-contingent boundary paradigm* (Rayner, 1975) to manipulate the availability of letter identity and position information for a word in the parafovea prior to direct fixation. They demonstrated that TL nonwords provided greater preview benefit compared to SL nonwords, consistent with a privileged role of the extraction of letter identity information from upcoming words. The relative flexibility of letter position coding during reading also appears to differ within words. Specifically, there is a greater cost to reading fluency from transpositions of word-initial letters compared to medial or ending letters (Johnson & Eisler, 2012; Rayner et al., 2006; see also Chambers, 1979; Perea & Lupker, 2003; Schoonbaert & Grainger, 2004 for similar evidence from the lexical-decision paradigm). White et al. (2008) showed that the greater cost for word-initial transpositions was observed regardless of whether the word had been visible in the parafovea, suggesting that it reflects the importance of beginning letters in lexical identification of English words. This evidence aligns with findings of a first-position benefit in letter and character identification within strings (e.g., Scaltritti & Balota, 2013; Tydgat & Grainger, 2009).

Present Study

The present study was designed to assess the combined impact of visual field and retinal eccentricity on the processing of letter identity and position during the earliest stages of word identification by analyzing “different” responses in a variant of a perceptual match task (e.g., Bamber, 1969). To examine the contribution of eye-movement planning to these effects, we adapted the paradigm developed by Veldre et al. (2023a) in which participants respond to target letter strings presented at various eccentricities in the left or right visual fields for either 300 ms or 100 ms which allows or precludes eye movements, respectively. To measure sensitivity to letter identity and order during orthographic processing, we varied the relationship between the target and a *reference stimulus* that was presented in uppercase at central fixation prior to the target being presented in lowercase in the parafovea. The participants’ task was to decide whether the target was the *same* as or *different* to the reference stimulus. Of greatest interest was the effect of eccentricity and visual field on the accuracy and latency of “different” responses for form-related targets (i.e., either TL nonwords or SL words/nonwords). The same-different match task has been argued to reflect pre-lexical orthographic processing (Kinoshita & Norris, 2009). Although this task has long been used to study the processing of letter order within strings (e.g., Angiolillo-Bent & Rips, 1982; Proctor & Healy, 1985; Ratcliff, 1981; see Proctor, 1981 for a review), no prior studies have examined the effect of eccentricity on letter position coding using the same-different match task.

EXPERIMENTS 1A & 1B

In Experiments 1A and 1B, participants judged whether a briefly presented lowercase target stimulus was the same as or different to an uppercase reference word (e.g., SAMPLE). Critical “different” targets were either a one-letter-different word (e.g., simple) or nonword neighbor (e.g., somple) of the reference stimulus, or a TL nonword (e.g., smaple). These related target conditions were each compared to an orthographically unrelated word baseline condition (e.g., vanity). Experiment 1A presented targets at 1° and 2° eccentricity in the left visual field (*LVF*) and right visual field (*RVF*), whereas Experiment 1B presented targets at 2° and 4° eccentricity in the LVF and RVF.

It was expected that performance accuracy and latency in the same/different judgement would depend on the degree of similarity between the target and reference strings, particularly in the 100-ms duration condition in which participants did not have time to move their eyes to fixate on the target. Specifically, responses were expected to be slower and less accurate with increasing eccentricity for SL words and nonwords compared to unrelated words. Based on the findings of studies examining TL effects in lexical decision, eye movements, and same-different matching, it was expected that performance would be poorest for TL nonword targets because these items are perceptually more similar to their base words than SL words and nonwords. However, this TL similarity effect was predicted to depend on eccentricity such that TL targets would be more likely to be misperceived as the base words at more eccentric positions due to the combined impact of reduced visual acuity and increased crowding on letter position coding.

Given evidence that the RVF advantage is task-dependent and strongest for tasks requiring detailed orthographic analysis (e.g., letter identification; discriminating words from pseudowords; Veldre et al., 2023b), we expected to observe a significant RVF advantage on accuracy and latency of “different” responses to SL words. The pattern of visual field differences for nonword targets was more difficult to predict. If evidence of equivalent performance in the RVF and LVF for SL nonwords (e.g., Perea & Fraga, 2006) is specific to the lexical-decision task, we may expect to see a similar RVF advantage for both SL words and nonwords in our same-different task that does not require lexical access. Furthermore, if the LVF advantage that Perea and Fraga observed for TL nonwords was also due to task-specific requirements of lexical decision, i.e., TL nonwords are more likely to activate the base word when presented in the RVF, we may not see such an effect in the same-different task.

Method

Participants

The final samples comprised 70 participants in Experiment 1A and a separate group of 70 participants in Experiment 1B. All participants were undergraduate students from The University of Sydney who reported normal or corrected-to-normal vision, and who either were first-language (L1) English speakers or began to speak English by age 5. Participants received partial course credit as compensation. Participants were replaced if they reported that they failed to comply with the experiment setup instructions relating to the device, screen, or viewing distance, or if they had mean accuracy below 80% in the easiest experimental conditions (i.e., 300-ms presentation duration for identical and unrelated targets at the closest position in the RVF). In Experiment 1A, 1 participant was replaced for failing to meet the accuracy criterion. In Experiment 1B, 3 participants were replaced because they did not follow the setup instructions and a further 8 participants were replaced for failing to meet the accuracy criterion.

Stimuli and Design

The critical stimuli were 125 6-8-letter words that served as referents in the same-different task. Each of the referents was displayed in uppercase at the center of the screen (e.g., SAMPLE) prior to the presentation of a lowercase target stimulus that was either: (1) identical (e.g., sample); (2) an unrelated word (e.g., vanity); (3) a higher-frequency SL word (e.g., simple); (4) an SL nonword (e.g., somple); or (5) a TL nonword (e.g., smaple). The position of the letter substitution/transposition varied between items but was held constant across conditions for a given item. To balance the proportion of 'same' and 'different' trials during the experiment, the critical stimuli were intermixed with 75 6-8-letter filler word referents that were presented before an identical lowercase target. The lexical properties of the critical and filler stimuli are summarized in Table 1.

---INSERT TABLE 1---

Experiments 1A and 1B tested the impact of eccentricity and visual field by presenting the targets at either 1° or 2° (Experiment 1A) and 2° or 4° (Experiment 1B) of visual angle to the left or right of the center of the display. The role of eye movements was assessed by presenting the targets for either 300 ms, which allowed participants enough time to plan and execute a saccade to fixate on the target, or 100 ms, which did not allow enough time for participants to fixate on the target. The critical and filler items were presented four times, once at each position. Critical items were rotated across target conditions in a Latin Square design such that participants never saw an item in the same target condition more than once, but across participants, all items appeared in all conditions with equal frequency.

Statistical Power

The sample size was based on the recommendations of Brysbaert and Stevens (2018) of a minimum 1,600 data points per condition for within-subjects designs with crossed participants and items. Furthermore, simulations of Veldre et al.'s (2023a) data using the *simR* package (Green & MacLeod, 2016) demonstrated >.9 power to detect a 20-ms effect of eccentricity on RT at this sample size. In each of the experiments reported in this paper, there were 1,750 data points per condition (70 participants and 25 items in each cell).

Apparatus and Procedure

The experiments were programmed in JavaScript using the *jspsych* library (de Leeuw, 2015) and administered online in a web browser via the participant's personal desktop or laptop device.

The experiments began with the participant inputting the dimensions of their display by resizing a box to match the size of a credit card held up to the screen using the *resize* plugin. Participants were instructed to sit 60 cm from the screen and to maintain this viewing distance throughout the experiment. The participant's screen dimensions were used to scale the stimuli so that three letter spaces equaled 1° of visual angle. As illustrated in Figure 2, each trial began with a fixation cross presented at the center of the display for 250 ms, followed by the reference stimulus in uppercase at the center of the display for 500 ms, and then the target in lowercase at one of the eccentric locations (i.e., either at 1° or 2° to the left or right in Experiment 1A, or at 2° or 4° to the left or right of the center of the screen in Experiment 1B) for 100 or 300 ms, and then finally a blank screen until the participant pressed a key to make their response. Participants were instructed to press the *Z* key if the target and probe were the same and the *M* key if the target and probe were different. The mapping of response keys to same/different was counterbalanced across participants. Feedback was displayed following incorrect responses ("Wrong" in red text) for 500 ms before the start of the next trial. The experiment began with 16 practice items, to familiarize participants with the experimental procedure with feedback for both incorrect and correct responses ("Right" in green text). The order of trials was individually randomized for each participant. Participants completed the experiment in two sessions, separated by at least one hour. Stimulus duration was blocked within sessions, and the order of blocks was counterbalanced across participants. Viewing position was randomized within blocks. Each session comprised 800 trials and participants were given the opportunity to take a break after completing 25%, 50%, and 75% of the trials within each session. The entire experiment lasted approximately 90 minutes.

---INSERT FIGURE 2---

Ethical approval for this study was granted by the Human Research Ethics Committee at The University of Sydney (protocol 2016/204). All participants provided informed consent prior to commencement of the study.

Transparency and Openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. The data, analysis code, and stimulus materials are available at osf.io/6khdt/. Data were analyzed using *R* (version 4.1.2; R Core Team, 2021) and the packages *lme4* (version 1.1-27.1; Bates et al., 2015), *plyr* (version 1.8.6; Wickham, 2011), and *ggplot* (version 3.3.5; Wickham, 2016). This study's design and its analysis were not pre-registered.

Results

Data Preparation and Analysis

Decision accuracy and (log transformed) RT data for the 'different' trials were analyzed with (G)LMMs. LMM analyses of d' are included in the Appendix, and any discrepancies with the accuracy analyses are noted in text. Trials with RTs below 200 ms or above 2,000 ms were discarded prior to analysis (Experiment 1A: 1.95% of trials; Experiment 1B: 3.03% of trials), leaving 54,907 and 54,302 trials in Experiment 1A and Experiment 1B, respectively. Models contained participant and item random intercepts; participant random slopes for stimulus duration and target condition, and stimulus position; and item random slopes for duration; but did not include random correlation parameters. Models with more complex random-effects structures failed to converge.

For the analyses of both experiments, the models tested the fixed effects of stimulus position, target condition, and Position × Condition interactions *nested under* stimulus duration, i.e., stimulus position and condition effects separately at 300 ms and 100 ms duration. Stimulus position was coded as a set of three contrasts that tested the effect of (1) eccentricity (1° vs. 2° and 2° vs. 4° in Experiment 1A and 1B, respectively); (2) visual field (LVF vs. RVF); and (3) the Visual field × Eccentricity interaction. Target condition was coded as a set of three contrasts that compared the unrelated word baseline to each of the related conditions.

Mean same/different decision accuracy and mean correct RT are shown in Tables 2 and 4 and Figure 3, and the GLMM model summaries are shown in Tables 3 and 5.

---INSERT TABLES 2-5 & FIGURE 3---

Accuracy

In both experiments there was a significant overall effect of stimulus duration reflecting better performance when the target was displayed for 300 ms and participants had time to move their eyes to fixate on the target versus the 100 ms condition in which planning and executing an eye movement to the target was not possible.

300-ms duration. The pattern of results was the same for both experiments. Compared to unrelated word targets, accuracy was significantly lower for SL words, SL nonwords, and TL nonwords, with the latter having the lowest level of accuracy. Accuracy did not differ significantly as a function of either eccentricity or visual field in the 300 ms condition.

100-ms duration. In both experiments, relative to unrelated words, accuracy was significantly lower for SL words and SL nonwords. These differences were modulated by visual field because both SL words and SL nonwords showed an RVF advantage on accuracy. Performance accuracy for TL nonwords was at or below chance-level and significantly lower than accuracy for unrelated words. In Experiment 1A, the TL cost was not significantly modulated by visual field or eccentricity. In Experiment 1B, there was a significant interaction between the TL nonword condition and visual field that reflected an LVF advantage for discriminating TL nonwords from the reference word.

In both experiments, there was a significant effect of eccentricity on accuracy in the 100 ms condition, reflecting poorer performance for targets presented at 2° versus 1°, and at

4° versus 2°. There was a significant interaction between the TL nonword condition and eccentricity, reflecting surprisingly higher accuracy for more eccentric TL stimuli. However, this interaction was not significant in the d' analysis, suggesting the accuracy effect may have reflected differences in response criterion (i.e., a tendency to respond ‘different’ when uncertain; see Appendix). Finally, in Experiment 1B, there was a significant three-way interaction between the SL nonword condition, visual field, and eccentricity. This interaction reflected a stronger effect of eccentricity in the RVF versus the LVF for SL nonwords.

RT

Correct decision latency was not significantly affected by stimulus duration in Experiment 1A, but RT was significantly faster in the 100 ms condition versus the 300 ms condition in Experiment 1B.

300-ms duration. In both experiments, compared to unrelated words, RTs were significantly longer for SL words, SL nonwords, and TL nonwords. In Experiment 1B, there was a significant overall visual field effect which reflected slightly longer RTs in the LVF. In Experiment 1A, the SL word and SL nonword contrasts were significantly modulated by visual field, which reflected an RVF advantage on RT for both conditions.

In Experiment 1A, there were no significant effects of eccentricity on RT in the 300 ms condition. However, in Experiment 1B, there was a significant eccentricity effect because RTs were longer for targets presented at 4° versus 2°. Finally, in Experiment 1B, the difference between unrelated words and SL words depended on the joint impact of both visual field and eccentricity because the effect of eccentricity for unrelated words was restricted to the LVF whereas SL words showed a symmetrical eccentricity effect in the LVF and RVF.

100-ms duration. In both experiments, compared to unrelated words, responses were significantly longer for SL words, SL nonwords, and TL nonwords. In Experiment 1A, the difference between unrelated words and TL nonwords depended on visual field because the latter condition showed an LVF advantage on RT. In Experiment 1B, somewhat surprisingly, there was a significant LVF advantage for each of the related conditions although this was most pronounced for the TL nonword condition.

In Experiment 1A, there was a significant effect of eccentricity in the 100 ms condition due to longer RTs for targets presented at 2° versus 1°. There was also a significant eccentricity effect in Experiment 1B due to longer RTs at 4° than at 2°. Finally, the SL word condition interacted with eccentricity in Experiment 1B because this condition showed a reverse eccentricity effect, i.e., faster RTs at 4° than at 2°.

Discussion

Experiments 1A and 1B were designed to assess whether eccentricity and visual field effects differed for the detection of TL nonwords compared to SL words and nonwords, thereby providing insight into the processing of letter identity and letter order in the parafovea during word identification. The results demonstrated the expected lower overall accuracy for the related target conditions compared to the unrelated word baseline. A comparison of the effect sizes for the related target showed that, in both duration conditions in Experiments 1A and 1B, participants were more accurate in deciding that SL words and nonwords were different from the reference word than they were at discriminating TL nonwords from the reference word. Indeed, performance accuracy for TL nonwords presented for 100 ms was at or below chance at all positions in both experiments. This finding aligns with studies of isolated word recognition and reading that have demonstrated that TL letter strings are highly confusable with their base words (Acha & Perea, 2008; Andrews, 1996; Blythe et al., 2014; Chambers, 1979; Christianson et al., 2005; Forster et al., 1987; Johnson et al., 2007; Johnson, 2009; O'Connor & Forster, 1981; Perea & Fraga, 2006;

Perea & Lupker, 2003a, 2003b, 2004; Rayner et al., 2006; Schoonbaert & Grainger, 2004; Van der Haegen et al., 2009; Warrington et al., 2019; White et al., 2008).

The 100-ms duration condition of both experiments showed evidence of visual field asymmetries that depended on condition. Decision accuracy was higher in the RVF versus LVF for SL words and nonwords in Experiments 1A and 1B. In contrast, accuracy was higher in the LVF versus RVF for TL nonwords in Experiment 1B. In Experiment 1A, there were no visual field differences on decision latency for SL words or nonwords, but there was a LVF advantage for TL nonwords. In Experiment 1B, there was an unexpected LVF advantage for all conditions on latency relative to the unrelated word baseline. These visual field effects are partly in line with Perea and Fraga’s (2006) lexical-decision data, which demonstrated a LVF advantage for TL nonwords, but no visual field differences for SL nonwords. The similar pattern observed for SL words and nonwords in the present study may reflect the fact that the same-different match task taps pre-lexical orthographic processing and does not require lexical access. Furthermore, the finding of an LVF advantage for TL nonwords in same-different judgements demonstrates that flexible letter position coding is not specific to tasks requiring word identification.

Finally, performance in the task was affected by eccentricity, with poorer accuracy and longer latencies for more eccentric stimuli in the 100-ms condition in which participants did not have time to make an eye movement to fixate on the target. However, there was only minimal evidence that these eccentricity effects differed by target condition or between the LVF and RVF. In Experiment 1B, the three-way interaction between the SL nonword condition, visual field, and eccentricity suggested a stronger effect of eccentricity in the RVF for SL nonwords, which was reflected in enhanced accuracy at the 2° right position relative to the other positions. However, this interaction failed to reach significance in the d' analysis.

EXPERIMENTS 2A & 2B

Experiments 2A and 2B were designed to provide further insight into the source of visual field effects on letter position coding. In Experiments 1A and 1B, the TL nonword condition involved letter transpositions at any position within the word. Experiments 2A and 2B used the same-different task to systematically compare TL nonword targets in which the transposition involved the word-initial letters to TL nonwords with either a word-medial transposition (Experiment 2A) or a word-final transposition (Experiment 2B). Evidence from previous studies of TL effects has shown that transpositions of the word-initial letter are easier to detect than transpositions of word-medial letters (Johnson & Eisler, 2012; Rayner et al., 2006; see also Chambers, 1979; Perea & Lupker, 2003; Schoonbaert & Grainger, 2004). This implies that letter position coding is more precise for letters at the beginning of a word. This benefit for word-initial letters may reflect their critical role in accurate word identification (e.g., White et al., 2008). Alternatively, letter position coding may be more precise for word-initial letters because the beginning of an upcoming word is closer to the fovea in languages that are read from left to right. Given the importance of letter position for assessing the role of eccentricity in orthographic processing, Experiments 2A and 2B directly compared TL nonwords in which the transposition occurred at word-initial, medial, and final positions.

Method

Participants

The final samples comprised 70 participants in Experiment 2A and a separate group of 70 participants in Experiment 2B. All participants were undergraduate students from The University of Sydney who received partial course credit as compensation. Participants were either L1 English speakers or began to speak English by age 5, and reported normal or corrected-to-normal vision. None of the participants had completed Experiment 1A or 1B. The same exclusion criteria were used as in Experiments 1A and 1B. In Experiment 2A, 7 participants were replaced for failing to meet the accuracy criterion. In Experiment 2B, 4 participants were replaced because they did not follow the setup instructions.

Stimuli and Design

The critical stimuli used in Experiments 2A and 2B were the same 125 6-8-letter word referents as in Experiments 1A and 1B. The lowercase targets were: (1) identical; (2) unrelated word; (3) higher-frequency SL word; (4) TL-initial nonword (transposition of letters 1 and 2; e.g., asmple). In Experiment 2A the final condition was: (5) TL-medial nonword (transposition of two internal letters; e.g., sapmle). In Experiment 2B the final condition was: (5) TL-final nonword (transposition of two final letters; e.g., sampel). The critical stimuli were intermixed with the same 75 6-8-letter filler word referents with identical lowercase targets as in Experiments 1A and 1B.

The position and duration conditions were the same as in Experiment 1A, i.e., targets were presented at 1° or 2° of visual angle to the left or right of the center of the display for either 300 ms or 100 ms. The stimulus counterbalancing procedure was identical to Experiments 1A and 1B.

Apparatus and Procedure

Experiments 2A and 2B were administered in the same way as Experiments 1A and 1B.

Results

Data Preparation and Analysis

Decision accuracy and (log transformed) RT data for the 'different' trials were analyzed with (G)LMMs. Trials on which the participant failed to respond or with RTs less than 200 ms or greater than 2,000 ms were discarded (Experiment 2A: 2.22% of trials; Experiment 2B: 2.07% of trials), leaving 54,756 and 54,841 trials in the analysis for Experiment 2A and Experiment 2B, respectively. All models contained participant and item random intercepts. Accuracy models contained participant random slopes for stimulus duration, target condition, and stimulus position; and item random slopes for duration; but did not include random correlation parameters. RT models contained participant and item random slopes for duration and did not include random correlation parameters. Models with more complex random-effects structures failed to converge.

In the analyses of both Experiment 2A and Experiment 2B, models tested the fixed effects of stimulus position, target condition, and Position × Condition interactions *nested under* stimulus duration, i.e., stimulus position and condition effects separately at 300 ms and 100 ms duration. Stimulus position was coded in the same way as in Experiment 1A. Three condition contrasts compared each of the related targets to the unrelated word baseline. Means are presented in Tables 6 and 8 and Figure 4, and the GLMM output is shown in Tables 7 and 9.

---INSERT TABLES 6-9 & FIGURE 4---

Accuracy

In both experiments, decision accuracy was significantly higher in the 300 ms than in the 100 ms condition.

300-ms duration. In Experiment 2A, relative to unrelated words, accuracy was significantly lower for the SL word and TL-medial conditions, but not significantly different for the TL-initial condition. There were also significant Condition × Visual field × 1° vs. 2° eccentricity interactions for each of the targets. For SL words, this interaction reflected a slight reverse eccentricity effect that was stronger in the RVF than the LVF. For TL-initial nonwords, the interaction reflected a slight LVF advantage and no effect of eccentricity in comparison to unrelated words. Finally, for TL-medial nonwords, the interaction reflected a stronger eccentricity effect in the LVF than the RVF. However, these effects should be interpreted with caution as the equivalent interactions were not significant in the analysis of d' (see Appendix).

In Experiment 2B, relative to unrelated words, accuracy was significantly lower for the SL words, TL-initial nonwords, and TL-final nonwords. There was also a significant LVF advantage in the TL-initial condition.

100-ms duration. In both experiments, compared to unrelated words, accuracy was significantly lower for SL words, TL-initial nonwords, TL-medial nonwords (Experiment 2A), and TL-final nonwords (Experiment 2B). Accuracy was significantly lower for targets presented at 2° versus 1° eccentricity. In Experiment 2A, the eccentricity effect was significantly more pronounced for TL-initial nonwords compared to unrelated words. However, this effect did not reach significance in the analysis of d'.

In Experiment 2A, the effect of visual field depended on the target condition: SL words showed an RVF advantage while TL-initial nonwords showed an LVF advantage. In Experiment 2B, the RVF advantage for SL words did not reach significance on accuracy, but it was significant in the analysis of d'. The visual field effects for TL nonwords depended on the location of the transposition: There was a significant LVF advantage for TL-initial nonwords, but there was a significant RVF advantage for TL-final nonwords. The eccentricity effect was also significantly stronger in the LVF versus the RVF for TL-final nonwords.

RT

In Experiment 2A, RT was significantly faster in the 100 ms condition compared to the 300 ms condition, but RT did not differ significantly in the two duration conditions in Experiment 2B.

300-ms duration. In both experiments, compared to unrelated words, RT was significantly longer for SL words, TL-initial nonwords, TL-medial nonwords (Experiment

2A), and TL-final nonwords (Experiment 2B). There was also a significant eccentricity effect in both experiments, which interacted with the TL-initial condition, reflecting a pronounced LVF advantage on RT. In contrast, the TL-final condition in Experiment 2B showed a significant RVF advantage on RT.

100-ms duration. In both experiments, RT was significantly longer in each of the related conditions compared to the unrelated word condition, and there was a significant effect of eccentricity. Again, the two TL conditions showed opposite visual field effects: TL-initial nonwords showed a significant LVF advantage in both experiments whereas TL-final nonwords showed a significant RVF advantage in Experiment 2B. In Experiment 2A, the TL-medial nonword × Visual field × 1° vs. 2° eccentricity interaction was also significant because this condition showed a stronger effect of eccentricity in the LVF versus the RVF. However, given the very low accuracy in this condition, the RT data (based on correct responses) should be interpreted with caution.

Discussion

Experiments 2A and 2B were designed to provide further insight into letter position coding in the parafovea by comparing same-different responses to nonwords formed by transposing letters at the initial, medial, or final position of words. Across both experiments, there was clear evidence that the flexibility of letter position coding varied as a function of position within the letter string. Overall, the detection of word-initial transpositions was faster and more accurate than the detection of medial transpositions—and this was true even for letter strings presented for 300 ms. When targets were briefly presented for 100 ms, performance accuracy for medial TL nonwords was well below chance level, suggesting that participants were especially likely to misperceive these items as their base words. TL-medial nonwords also demonstrated limited evidence of the LVF advantage that has been observed for TL stimuli in which the position of the transposition was not controlled, including in Experiments 1A and 1B of the present study.

The most striking feature of the data was the opposite effects of visual field shown for the TL-initial and TL-final conditions.[1] Specifically, on both accuracy and latency, TL-initial nonwords showed a strong LVF advantage in both duration conditions. In contrast, TL-final nonwords showed a robust RVF advantage in both duration conditions. These opposite visual field advantages were observed despite the distance of the transposed letters from the point of fixation: Initial letters are further into the parafovea when the item is presented in the LVF, whereas final letters are further into the parafovea when the item is presented in the RVF. The difference between the TL-initial and TL-final conditions on both accuracy and latency was also more pronounced in the LVF compared to the RVF. The implications of these findings are considered in the General Discussion.

General Discussion

This study investigated the role of low-level visual factors such as acuity and crowding on the processing of letter identity and letter order within words in the parafovea. The same-different match task was used to examine pre-lexical orthographic processing with a view to informing the assumptions of computer models of reading (for a review, see Reichle, 2021). The contribution of eye movements and attention allocation to these effects

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[1] To directly test the difference between the TL-initial and TL-final conditions, we conducted follow-up analyses using successive difference contrasts (i.e., Unrelated word vs. SL word; SL word vs. TL initial; TL initial vs. TL final; see Supplementary Materials for full model summaries). On accuracy in the 100 ms duration condition, there was a significant TL-initial versus TL-final main effect (b=0.75; SE=0.09; z=8.82), reflecting better performance accuracy overall for TL-initial nonwords. There was also a significant TL-initial vs. TL-final × Visual field × 1° vs. 2° eccentricity interaction (b=0.43; SE=0.10; z=4.42) reflecting the opposite effects of visual field on the two conditions and stronger eccentricity effects in the RVF vs. LVF for TL-initial nonwords but stronger eccentricity effects in the LVF vs. RVF for TL-final nonwords. On RT in the 100 ms duration condition, responses were significantly faster for TL-initial nonwords versus TL-final nonwords overall (b=-0.07; SE=0.01; z=-12.18). This difference significantly interacted with visual field because the difference in response time between the conditions was substantially larger in the LVF versus RVF (b=0.11; SE=0.01; z=12.16).

was assessed by manipulating the presentation duration of the critical target string such that participants either did or did not have enough time to make a saccade to fixate on the target.

Overall, the manipulation of presentation duration had the intended effect. Consistent with our previous findings (Veldre et al., 2023a, 2023b), performance accuracy was higher in the 300 ms duration condition compared to the 100 ms duration condition, and there was a considerably more pronounced effect of eccentricity in the latter condition. In general, decision accuracies were lower and response latencies were longer for targets presented at more eccentric positions.

We also observed clear evidence of flexible letter position coding in the parafovea. Across the experiments, in both duration conditions, TL nonwords showed a substantially larger accuracy effect than either SL words or nonwords, suggesting that the former were more likely to be misperceived as the reference word. This extends evidence from studies of isolated word recognition (Acha & Perea, 2008; Andrews, 1996; Blythe et al., 2014; Chambers, 1979; Christianson et al., 2005; Forster et al., 1987; O'Connor & Forster, 1981; Perea & Fraga, 2006; Perea & Lupker, 2003a, 2003b, 2004; Schoonbaert & Grainger, 2004; Van der Haegen et al., 2009) and eye movements during reading (Johnson et al., 2007; Johnson, 2009; Rayner et al., 2006; Warrington et al., 2019; White et al., 2008) to the eccentricity paradigm. However, there was only minimal evidence that eccentricity effects were more pronounced for TL items. Specifically, TL-medial nonwords showed a larger effect of eccentricity relative to unrelated words on decision latency in the LVF, and TL-final nonwords showed a larger effect of eccentricity relative to unrelated words on decision accuracy in the LVF. Given that both of these effects were specific to processing in the LVF, we are unable to conclude that parafoveal letter position coding is more impacted by eccentricity than letter identification during normal reading.

The most novel finding of the present study was that the sensitivity to letter order depended on both the location of the transposition within the string and the visual field in which the target was presented. Specifically, under conditions that precluded eye movements to the target, nonwords formed by transpositions of word-initial letters were detected almost as accurately as unrelated words in the LVF, but were less likely to be detected than word-final transpositions in the RVF. In contrast, the detection of word-final letter transpositions was much less accurate in the LVF than in the RVF. That is, there were essentially opposite effects of visual field on letter position coding for initial versus final letter transpositions. This pattern was observed despite the fact letter transpositions were closest to the fovea in word-initial positions in the RVF and word-final positions in the LVF. Briefly presented TL strings in the LVF showed the largest difference in accuracy and latency as a function of TL type.

The pattern of positional asymmetry in letter transposition effects observed in our experiment bears some resemblance to the findings of studies by Hellige and colleagues (e.g., Hellige et al., 1995; Hellige & Cowin, 1996). In these studies, participants were required to identify briefly presented letter trigrams in the LVF or RVF. Performance accuracy on the task showed a strong RVF advantage. However, participants made more errors in identifying the final letter compared to the initial letter in the LVF, but this pattern was much less pronounced in the RVF. This pattern of findings was taken to support distinct processing modes in the two hemispheres: efficient parallel processing of letter strings in the language-dominant left hemisphere, and slower, serial processing in the right hemisphere. Whitney (2001) demonstrated that this pattern of hemispheric asymmetry could be accounted for by the SERIOL model's assumptions of temporal order processing and an acuity-based gradient of activation.

Although our observed patterns of findings are admittedly complex, they have immediate ramifications for computer models of reading, especially those that simulate the identification of printed words or eye movements during natural reading. To appreciate why, first consider that the pattern of effects observed in our experiments can be attributed to three factors: (1) visual input (e.g., how eccentricity modulates visual acuity and crowding, how attention is allocated, visual field asymmetry); (2) stimulus materials (e.g., the informativeness of letters at different positions within letter strings, how lexical information is represented in memory); and (3) lexical processing (e.g., how visual features are mapped onto orthographic forms, how letters are perceived and represented in their correct order).[2] Models of word identification typically attempt to explain the second and third factors while largely ignoring the first, whereas models of eye-movement control typically emphasize the first while saying little about the second or third. Although these oversights were arguably necessary due to the complexity of what needed to be explained, any *comprehensive* model of reading (i.e., one that explains how words are identified during natural reading) requires consideration of all three factors, and as such, our results have ramifications for the development of any such model.

For example, first consider the 300-ms conditions in Experiments 1A and 1B: Their results show that unrelated words are the easiest (i.e., most accurate and rapid) to discriminate from other reference words, and that TL nonwords are conversely the most difficult, with the difficulty of SL words and nonwords being in between. (The TL condition was more difficult than the SL conditions despite the fact that the former stimuli differed from the reference stimuli by two letters whereas the latter differed by only one letter.) Because participants in these conditions had ample time to move their eyes, the observed

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[2] We will ignore a fourth logically possible factor contributing to our results, the processes that are involved in making binary decisions. It is worth noting, however, that the counterbalanced experimental designs should have minimized any response bias within any given experiment.

differences are unlikely to reflect visual acuity but are instead attributable to the stimulus materials or how they are mapped onto lexical representations. The implication here is that the identities of letters are encoded and/or represented more efficiently than their positions, allowing mismatches of the former to be detected more readily than mismatches of the latter. Several existing models of word identification models explain this difference (e.g., Davis, 2010; Gomez et al., 2008; Whitney, 2001), and thus, any complete model of reading would likewise have to provide an account of this finding.[3]

However, in the 100-ms conditions of Experiments 1A and 1B, where the participants' eye movements were precluded, the aforementioned differences become more pronounced and the effect of visual input becomes evident, with better discrimination of SL words and nonwords in the RVF but no such advantage for TL nonwords. Collectively, these findings again indicate that letter identities are perceived/represented more rapidly and accurately than their positions, but the results also suggest that this difference is more pronounced for letter strings displayed in the RVF. Although a few existing word-identification models (e.g., Davis, 2010) attempt to explain how letters are perceived in their correct order (i.e., the *alignment problem*) or why letter position uncertainty increases with eccentricity (e.g., Gomez et al., 2008), fewer models provide detailed accounts of why the coding of letter identity and position information differs across the left and right visual field (e.g., Whitney, 2001; Whitney & Cornelissen, 2005, 2008), and none of these models attempt to explain eye-movement control during reading.

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[3] Another interesting example worth mentioning is the connectionist *split-fovea model* of Chinese word identification (Hsiao & Shillcock, 2004, 2005). Because the model simulates the identification of two-character Chinese words (for a brief overview of the Chinese writing system, see Yu & Reichle, 2017), it does not explain effects associated with letter identity or position coding. The model does, however, provide a tentative account of visual field effects because of its architecture: Visual information to either side of central vision is propagated to separate collections of nodes corresponding to the left and right cerebral hemispheres, where the information is then shared via connections that correspond to the corpus callosum.

One recent model of word identification warrants some consideration. *PONG* (*Positional Ordering of N-Grams*; Snell, 2024), assumes that the positions of multi-letter units (N-grams) within words are computed by their relative activation levels in each hemisphere. Activation of N-grams is assumed to be a function of both visual acuity and the width of the attentional window. Thus, the model can potentially account for both overall effects of letter transpositions, and the influence of eccentricity on the coding of letter identity and position. However, the model does not currently account for hemispheric asymmetries and, therefore, could not explain the visual field effects observed in our experiments. Furthermore, the model's predictions concerning the impact of transposition location (i.e., smaller TL effects at greater eccentricities) do not appear to provide an adequate account of our findings.

Turning now to Experiments 2A and 2B, which provide additional clues about how the coding of letter identity and position are affected by the visual input, stimulus materials, and lexical processing. In the 300-ms condition, where participants could move their eyes, unrelated words were once again the easiest to discriminate from the reference words, with TL-initial nonword, TL-final nonwords, and SL words being of intermediate difficulty and TL-medial nonwords being most difficult. However, task performance in the TL conditions was most affected by eccentricity and visual field, with those interactions becoming more pronounced in the 100-ms condition, where eye movements were precluded. Overall, TL-initial nonwords were easier to discriminate from their base words than TL-final nonwords, consistent with evidence of a privileged role for the initial letters in word identification (e.g., Scaltritti & Balota, 2013; Tydgat & Grainger, 2009; White et al., 2008). However, as mentioned earlier, one perplexing result from Experiment 2B was the lower discrimination accuracy for TL-initial than TL-final nonwords in the RVF, even though the critical (i.e., transposed) letters necessary to detect a mismatch are closer to the center of vision in the former than latter condition. (A qualitatively similar but weaker pattern was observed for TL-initial and TL-medial nonwords in Experiment 2A.) One possible account of this finding is related to the relative costs associated with visual acuity versus crowding as a function of eccentricity; if the cost associated with crowding exceeds that of acuity, then the pattern can be attributed to the fact that critical letters of TL-initial/TL-final nonwords are subject to less crowding in the LVF/RVF, even though they are farther from the center of vision.

To date, two models of eye-movement control explain the differential costs associated with visual acuity versus crowding, *E-Z Reader* (Veldre et al., 2023a) and *OB1-Reader* (Snell et al., 2018), although both models are limited. For example, although E-Z Reader assumes that interhemispheric transmission time (as specified by a parameter, *IHT*) explains at least some part of the normal RVF advantage, the model does not provide a detailed account of how words are identified and, therefore, does not make predictions about letter-transposition effects or letter coding more generally. Contrariwise, OB1-Reader provides a detailed account of word identification but does not explain hemispheric differences. A third model, *SERIF* (McDonald et al., 2005), also provides an account of how hemispheric differences affect word identification during natural reading but assumes that the influence of eccentricity can be entirely relegated to visual acuity. Finally, the last model to be considered here, *Über-Reader* (Reichle, 2021; see also Veldre et al., 2020), is perhaps the most comprehensive model of reading in that it provides detailed accounts of both the alignment problem and how words are actually identified during natural reading; consequently, the model's assumptions should be sufficient to explain effects related to letter identity and position coding. However, despite this broad theoretical scope, the model is limited in that it explains neither the effect of visual crowding nor hemispheric differences in lexical processing.

With this brief review of current reading models, it is fair to say that the current state of the art demonstrates only limited success in explaining how the three factors that contributed to our experimental results, the nature of the stimulus materials, visual input, and lexical processing, might interact to influence the time course and identification accuracy of words in parafoveal vision—as occurs during natural reading. Although we have not provided a definite account of our findings, we maintain that their value is that they can provide an important "benchmark" for both developing and evaluating future models of reading.

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Appendix

Table A1

General Linear Model Analysis of Sensitivity (d') for Experiment 1A

Fixed effect	*b*	*SE*	*t*
Intercept	**2.49**	**0.06**	**41.87**
Stimulus duration	**-1.07**	**0.02**	**-58.92**
300 ms: SL word (SLw)	**-0.36**	**0.04**	**-10.03**
300 ms: SL nonword (SLn)	**-0.17**	**0.04**	**-4.58**
300 ms: TL nonword	**-0.84**	**0.04**	**-23.14**
300 ms: 1° vs. 2° eccentricity	-0.03	0.03	-0.98
300 ms: LVF vs. RVF	0.05	0.03	1.92
300 ms: Visual field × 1° vs. 2°	**-0.06**	**0.03**	**-2.24**
300 ms: SLw × 1° vs. 2°	0.06	0.07	0.80
300 ms: SLn × 1° vs. 2°	0.01	0.07	0.17
300 ms: TL × 1° vs. 2°	0.05	0.07	0.73
300 ms: SLw × LVF vs. RVF	-0.01	0.07	-0.18
300 ms: SLn × LVF vs. RVF	0.03	0.07	0.37
300 ms: TL × LVF vs. RVF	-0.06	0.07	-0.86
300 ms: SLw × VF × 1° vs. 2°	0.00	0.07	0.03
300 ms: SLn × VF × 1° vs. 2°	0.00	0.07	0.04
300 ms: TL × VF × 1° vs. 2°	0.03	0.07	0.47
100 ms: SL Word (SLw)	**-0.80**	**0.04**	**-21.96**
100 ms: SL Nonword (SLn)	**-0.76**	**0.04**	**-21.01**
100 ms: TL Nonword	**-1.69**	**0.04**	**-46.70**
100 ms: 1° vs. 2° eccentricity	**0.24**	**0.03**	**9.20**
100 ms: LVF vs. RVF	**0.17**	**0.03**	**6.50**
100 ms: Visual field × 1° vs. 2°	0.01	0.03	0.35
100 ms: SLw × 1° vs. 2°	0.07	0.07	1.01
100 ms: SLn × 1° vs. 2°	0.11	0.07	1.58
100 ms: TL × 1° vs. 2°	0.04	0.07	0.49
100 ms: SLw × LVF vs. RVF	**0.20**	**0.07**	**2.73**
100 ms: SLn × LVF vs. RVF	**0.18**	**0.07**	**2.49**
100 ms: TL × LVF vs. RVF	-0.06	0.07	-0.88
100 ms: SLw × VF × 1° vs. 2°	-0.02	0.07	-0.27
100 ms: SLn × VF × 1° vs. 2°	0.12	0.07	1.69
100 ms: TL × VF × 1° vs. 2°	0.01	0.07	0.14

Note. Significant effects indicated in bold.

Table A2

General Linear Model Analysis of Sensitivity (d') for Experiment 1B

Fixed effect	*b*	*SE*	*t*
Intercept	**2.24**	**0.06**	**36.95**
Stimulus duration	**-1.31**	**0.02**	**-71.88**
300 ms: SL word (SLw)	**-0.40**	**0.04**	**-10.98**
300 ms: SL nonword (SLn)	**-0.15**	**0.04**	**-4.10**
300 ms: TL nonword	**-0.88**	**0.04**	**-24.17**
300 ms: 2° vs. 4° eccentricity	**0.07**	**0.03**	**2.73**
300 ms: LVF vs. RVF	0.04	0.03	1.55
300 ms: Visual field × 2° vs. 4°	**-0.08**	**0.03**	**-3.05**
300 ms: SLw × 2° vs. 4°	-0.07	0.07	-0.92
300 ms: SLn × 2° vs. 4°	-0.04	0.07	-0.50
300 ms: TL × 2° vs. 4°	-0.02	0.07	-0.23
300 ms: SLw × LVF vs. RVF	0.05	0.07	0.73
300 ms: SLn × LVF vs. RVF	0.03	0.07	0.41
300 ms: TL × LVF vs. RVF	-0.08	0.07	-1.04
300 ms: SLw × VF × 2° vs. 4°	-0.01	0.07	-0.17
300 ms: SLn × VF × 2° vs. 4°	0.04	0.07	0.50
300 ms: TL × VF × 2° vs. 4°	-0.03	0.07	-0.45
100 ms: SL word (SLw)	**-0.93**	**0.04**	**-25.65**
100 ms: SL nonword (SLn)	**-0.87**	**0.04**	**-23.94**
100 ms: TL Nonword	**-1.61**	**0.04**	**-44.20**
100 ms: 2° vs. 4° eccentricity	**0.36**	**0.03**	**13.88**
100 ms: LVF vs. RVF	**0.20**	**0.03**	**7.77**
100 ms: Visual field × 2° vs. 4°	0.04	0.03	1.53
100 ms: SLw × 2° vs. 4°	0.10	0.07	1.44
100 ms: SLn × 2° vs. 4°	0.14	0.07	1.90
100 ms: TL × 2° vs. 4°	-0.13	0.07	-1.76
100 ms: SLw × LVF vs. RVF	0.11	0.07	1.48
100 ms: SLn × LVF vs. RVF	**0.16**	**0.07**	**2.13**
100 ms: TL × LVF vs. RVF	**-0.19**	**0.07**	**-2.57**
100 ms: SLw × VF × 2° vs. 4°	0.07	0.07	1.01
100 ms: SLn × VF × 2° vs. 4°	0.14	0.07	1.95
100 ms: TL × VF × 2° vs. 4°	0.06	0.07	0.79

Note. Significant effects indicated in bold.

Table A3

General Linear Model Analysis of Sensitivity (d') for Experiment 2A

Fixed effect	*b*	*SE*	*t*
Intercept	**2.37**	**0.06**	**41.52**
Stimulus duration	**-1.14**	**0.02**	**-61.82**
300 ms: SL word (SLw)	**-0.33**	**0.04**	**-8.97**
300 ms: TL initial (TLi)	-0.02	0.04	-0.54
300 ms: TL medial (TLm)	**-1.06**	**0.04**	**-28.66**
300 ms: 1° vs. 2° eccentricity	0.02	0.03	0.69
300 ms: LVF vs. RVF	0.04	0.03	1.51
300 ms: Visual field × 1° vs. 2°	0.00	0.03	0.10
300 ms: SLw × 1° vs. 2°	-0.08	0.07	-1.13
300 ms: TLi × 1° vs. 2°	0.02	0.07	0.32
300 ms: TLm × 1° vs. 2°	0.02	0.07	0.22
300 ms: SLw × LVF vs. RVF	-0.01	0.07	-0.13
300 ms: TLi × LVF vs. RVF	-0.09	0.07	-1.19
300 ms: TLm × LVF vs. RVF	-0.04	0.07	-0.50
300 ms: SLw × VF × 1° vs. 2°	-0.10	0.07	-1.40
300 ms: TLi × VF × 1° vs. 2°	-0.06	0.07	-0.76
300 ms: TLm × VF × 1° vs. 2°	-0.10	0.07	-1.37
100 ms: SL word (SLw)	**-0.76**	**0.04**	**-20.65**
100 ms: TL initial (TLi)	**-0.41**	**0.04**	**-11.07**
100 ms: TL medial (TLm)	**-2.40**	**0.04**	**-65.07**
100 ms: 1° vs. 2° eccentricity	**0.19**	**0.03**	**7.26**
100 ms: LVF vs. RVF	0.00	0.03	-0.05
100 ms: Visual field × 1° vs. 2°	0.02	0.03	0.67
100 ms: SLw × 1° vs. 2°	0.10	0.07	1.32
100 ms: TLi × 1° vs. 2°	0.13	0.07	1.70
100 ms: TLm × 1° vs. 2°	0.08	0.07	1.05
100 ms: SLw × LVF vs. RVF	**0.27**	**0.07**	**3.73**
100 ms: TLi × LVF vs. RVF	**-0.61**	**0.07**	**-8.22**
100 ms: TLm × LVF vs. RVF	0.06	0.07	0.76
100 ms: SLw × VF × 1° vs. 2°	-0.04	0.07	-0.59
100 ms: TLi × VF × 1° vs. 2°	0.03	0.07	0.38
100 ms: TLm × VF × 1° vs. 2°	0.06	0.07	0.81

Note. Significant effects indicated in bold.

Table A4

General Linear Model Analysis of Sensitivity (d') for Experiment 2B

Fixed effect	*b*	*SE*	*t*
Intercept	**3.02**	**0.06**	**54.08**
Stimulus duration	**-0.87**	**0.02**	**-47.87**
300 ms: SL word (SLw)	**-0.52**	**0.04**	**-14.32**
300 ms: TL initial (TLi)	**-0.11**	**0.04**	**-2.90**
300 ms: TL final (TLf)	**-0.32**	**0.04**	**-8.94**
300 ms: 1° vs. 2° eccentricity	0.03	0.03	1.08
300 ms: LVF vs. RVF	**0.07**	**0.03**	**2.79**
300 ms: Visual field × 1° vs. 2°	**0.06**	**0.03**	**2.48**
300 ms: SLw × 1° vs. 2°	-0.01	0.07	-0.15
300 ms: TLi × 1° vs. 2°	0.04	0.07	0.52
300 ms: TLf × 1° vs. 2°	0.01	0.07	0.20
300 ms: SLw × LVF vs. RVF	0.03	0.07	0.44
300 ms: TLi × LVF vs. RVF	**-0.21**	**0.07**	**-2.85**
300 ms: TLf × LVF vs. RVF	**0.15**	**0.07**	**2.04**
300 ms: SLw × VF × 1° vs. 2°	0.01	0.07	0.07
300 ms: TLi × VF × 1° vs. 2°	0.02	0.07	0.33
300 ms: TLf × VF × 1° vs. 2°	0.03	0.07	0.37
100 ms: SL word (SLw)	**-0.88**	**0.04**	**-24.32**
100 ms: TL initial (TLi)	**-0.51**	**0.04**	**-14.01**
100 ms: TL final (TLf)	**-0.92**	**0.04**	**-25.30**
100 ms: 1° vs. 2° eccentricity	**0.26**	**0.03**	**10.03**
100 ms: LVF vs. RVF	**0.22**	**0.03**	**8.75**
100 ms: Visual field × 1° vs. 2°	0.01	0.03	0.41
100 ms: SLw × 1° vs. 2°	0.08	0.07	1.12
100 ms: TLi × 1° vs. 2°	0.08	0.07	1.11
100 ms: TLf × 1° vs. 2°	**0.16**	**0.07**	**2.22**
100 ms: SLw × LVF vs. RVF	**0.16**	**0.07**	**2.22**
100 ms: TLi × LVF vs. RVF	**-0.72**	**0.07**	**-9.93**
100 ms: TLf × LVF vs. RVF	**0.83**	**0.07**	**11.38**
100 ms: SLw × VF × 1° vs. 2°	-0.08	0.07	-1.05
100 ms: TLi × VF × 1° vs. 2°	0.11	0.07	1.49
100 ms: TLf × VF × 1° vs. 2°	**-0.16**	**0.07**	**-2.17**

Note. Significant effects indicated in bold.

Table 1

Summary of the Lexical Properties of Critical and Filler Referents Used in the Experiments

Target	*N*	ELP Accuracy (%)	Mean Length	Orthographic Neighborhood Size	Mean Log HAL Frequency	Log HAL Frequency Range
Critical	125	94.71	6.65	1.11	7.20	(3.93, 10.76)
Filler	75	91.44	6.49	1.33	7.53	(3.58, 12.44)

Table 2

Mean (and SD) Same/Different Decision Accuracy and Response Time as a Function of Target Duration, Condition, and Position in Experiment 1A

Target duration and condition	Accuracy				RT (ms)			
	-2°	-1°	1°	2°	-2°	-1°	1°	2°
300 ms duration								
Identical word	.93	.93	.91	.94	710	719	695	708
	(.06)	(.06)	(.07)	(.06)	(50)	(64)	(62)	(53)
Unrelated word	.97	.97	.97	.97	674	665	666	670
	(.05)	(.05)	(.06)	(.06)	(47)	(59)	(54)	(57)
SL word	.89	.90	.90	.89	760	766	746	749
	(.08)	(.07)	(.08)	(.07)	(59)	(64)	(49)	(62)
SL nonword	.93	.93	.94	.94	732	729	716	722
	(.05)	(.06)	(.06)	(.06)	(55)	(49)	(55)	(52)
TL nonword	.79	.78	.78	.76	783	786	785	786
	(.11)	(.10)	(.11)	(.10)	(62)	(60)	(62)	(67)
100 ms duration								
Identical word	.82	.84	.87	.84	716	710	691	710
	(.11)	(.10)	(.09)	(.11)	(82)	(66)	(69)	(77)
Unrelated word	.95	.96	.95	.94	681	670	668	682
	(.05)	(.07)	(.06)	(.06)	(53)	(50)	(52)	(45)
SL word	.73	.76	.79	.77	763	778	761	776
	(.10)	(.11)	(.11)	(.11)	(63)	(56)	(64)	(82)
SL nonword	.76	.76	.82	.75	759	738	739	762
	(.10)	(.11)	(.11)	(.10)	(67)	(57)	(73)	(74)
TL nonword	.47	.49	.46	.42	746	727	760	755
	(.12)	(.09)	(.14)	(.14)	(75)	(71)	(98)	(79)

Table 3

(G)LMM Model Summaries for Analyses of Same/Different Decision Accuracy and Response Time in Experiment 1A

	Accuracy			RT (Log)		
Fixed effect	*b*	*SE*	*z*	*b*	*SE*	*t*
Intercept	**2.27**	**0.12**	**18.93**	**6.56**	**0.02**	**338.10**
Stimulus duration	**1.39**	**0.09**	**16.17**	0.00	0.01	-0.08
300 ms: SL word (SLw)	**-1.49**	**0.10**	**-15.47**	**0.12**	**0.00**	**26.14**
300 ms: SL nonword (SLn)	**-0.90**	**0.10**	**-9.32**	**0.08**	**0.00**	**19.55**
300 ms: TL nonword	**-2.65**	**0.10**	**-26.23**	**0.17**	**0.00**	**33.77**
300 ms: 1° vs. 2° eccentricity	-0.01	0.05	-0.15	0.00	0.00	-1.62
300 ms: LVF vs. RVF	0.05	0.06	0.82	**-0.01**	**0.00**	**-3.18**
300 ms: Visual field × 1° vs. 2°	0.00	0.05	-0.08	0.00	0.00	-0.33
300 ms: SLw × 1° vs. 2°	0.28	0.17	1.64	0.01	0.01	0.76
300 ms: SLn × 1° vs. 2°	0.15	0.18	0.81	0.00	0.01	0.38
300 ms: TL × 1° vs. 2°	0.20	0.16	1.23	0.01	0.01	1.17
300 ms: SLw × LVF vs. RVF	0.05	0.17	0.27	**-0.02**	**0.01**	**-2.70**
300 ms: SLn × LVF vs. RVF	0.16	0.18	0.89	**-0.02**	**0.01**	**-2.10**
300 ms: TL × LVF vs. RVF	-0.19	0.16	-1.16	0.00	0.01	0.13
300 ms: SLw × VF × 1° vs. 2°	-0.09	0.17	-0.53	-0.01	0.01	-0.90
300 ms: SLn × VF × 1° vs. 2°	-0.18	0.18	-0.96	0.00	0.01	-0.10
300 ms: TL × VF × 1° vs. 2°	-0.02	0.16	-0.12	0.00	0.01	-0.28
100 ms: SL Word (SLw)	**-1.94**	**0.08**	**-25.34**	**0.13**	**0.00**	**27.30**
100 ms: SL Nonword (SLn)	**-1.86**	**0.07**	**-26.24**	**0.10**	**0.00**	**23.52**
100 ms: TL Nonword	**-3.62**	**0.09**	**-41.85**	**0.12**	**0.01**	**20.69**
100 ms: 1° vs. 2° eccentricity	**0.19**	**0.04**	**4.84**	**-0.01**	**0.00**	**-4.15**
100 ms: LVF vs. RVF	0.04	0.05	0.86	0.00	0.00	1.45
100 ms: Visual field × 1° vs. 2°	0.04	0.04	0.98	0.00	0.00	-0.39
100 ms: SLw × 1° vs. 2°	0.07	0.13	0.56	0.01	0.01	1.60
100 ms: SLn × 1° vs. 2°	0.11	0.13	0.84	-0.01	0.01	-1.42
100 ms: TL × 1° vs. 2°	0.01	0.13	0.09	0.01	0.01	0.85
100 ms: SLw × LVF vs. RVF	**0.49**	**0.13**	**3.74**	-0.01	0.01	-0.80
100 ms: SLn × LVF vs. RVF	**0.44**	**0.13**	**3.37**	0.00	0.01	-0.38
100 ms: TL × LVF vs. RVF	-0.09	0.13	-0.75	**0.03**	**0.01**	**2.89**
100 ms: SLw × VF × 1° vs. 2°	0.05	0.13	0.35	-0.01	0.01	-1.05
100 ms: SLn × VF × 1° vs. 2°	0.24	0.13	1.80	0.00	0.01	-0.10
100 ms: TL × VF × 1° vs. 2°	0.04	0.13	0.32	0.01	0.01	1.25

Note. Significant effects indicated in bold.

Table 4

Mean (and SD) Same/Different Decision Accuracy and Response Time as a Function of Target Duration, Condition, and Position in Experiment 1B

Target duration and condition	Accuracy -4°	Accuracy -2°	Accuracy 2°	Accuracy 4°	RT (ms) -4°	RT (ms) -2°	RT (ms) 2°	RT (ms) 4°
300 ms duration								
Identical word	.89	.93	.92	.92	744	717	720	720
	(.08)	(.06)	(.09)	(.08)	(64)	(63)	(72)	(66)
Unrelated word	.96	.97	.96	.97	706	679	692	694
	(.06)	(.06)	(.05)	(.05)	(58)	(49)	(57)	(52)
SL word	.87	.86	.87	.89	780	764	758	775
	(.09)	(.09)	(.08)	(.08)	(48)	(55)	(60)	(55)
SL nonword	.93	.93	.93	.94	750	738	735	738
	(.06)	(.06)	(.07)	(.06)	(55)	(47)	(58)	(51)
TL nonword	.76	.77	.74	.75	804	795	799	800
	(.11)	(.11)	(.11)	(.11)	(64)	(60)	(72)	(64)
100 ms duration								
Identical word	.73	.80	.83	.79	719	688	671	678
	(.15)	(.13)	(.14)	(.15)	(83)	(73)	(70)	(76)
Unrelated word	.92	.93	.92	.91	674	654	653	666
	(.07)	(.06)	(.09)	(.08)	(50)	(63)	(56)	(52)
SL word	.65	.69	.73	.67	729	742	748	742
	(.11)	(.12)	(.13)	(.11)	(60)	(56)	(54)	(76)
SL nonword	.67	.69	.78	.68	726	719	731	735
	(.11)	(.11)	(.10)	(.13)	(72)	(74)	(55)	(62)
TL nonword	.50	.46	.41	.42	728	714	738	742
	(.14)	(.12)	(.13)	(.13)	(88)	(84)	(87)	(80)

Table 5

(G)LMM Model Summaries for Analyses of Same/Different Decision Accuracy and Response Time in Experiment 1B

	Accuracy			RT (Log)		
Fixed effect	*b*	*SE*	*z*	*b*	*SE*	*t*
Intercept	**1.98**	**0.11**	**17.51**	**6.55**	**0.02**	**302.45**
Stimulus duration	**1.57**	**0.09**	**17.22**	**0.05**	**0.01**	**5.05**
300 ms: SL word (SLw)	**-1.58**	**0.08**	**-18.71**	**0.11**	**0.00**	**23.95**
300 ms: SL nonword (SLn)	**-0.81**	**0.09**	**-9.32**	**0.07**	**0.00**	**17.07**
300 ms: TL nonword	**-2.59**	**0.10**	**-26.71**	**0.15**	**0.01**	**26.94**
300 ms: 2° vs. 4° eccentricity	-0.02	0.05	-0.46	**-0.01**	**0.00**	**-5.09**
300 ms: LVF vs. RVF	0.03	0.05	0.63	**-0.01**	**0.00**	**-2.22**
300 ms: Visual field × 2° vs. 4°	-0.06	0.05	-1.10	0.01	0.00	1.79
300 ms: SLw × 2° vs. 4°	-0.14	0.16	-0.88	0.00	0.01	0.02
300 ms: SLn × 2° vs. 4°	-0.04	0.17	-0.21	0.01	0.01	0.94
300 ms: TL × 2° vs. 4°	-0.02	0.15	-0.11	0.01	0.01	1.44
300 ms: SLw × LVF vs. RVF	0.17	0.16	1.06	-0.01	0.01	-0.86
300 ms: SLn × LVF vs. RVF	0.10	0.17	0.58	-0.01	0.01	-1.95
300 ms: TL × LVF vs. RVF	-0.11	0.15	-0.73	0.00	0.01	-0.43
300 ms: SLw × VF × 2° vs. 4°	-0.02	0.16	-0.14	**-0.02**	**0.01**	**-2.18**
300 ms: SLn × VF × 2° vs. 4°	0.06	0.17	0.33	-0.01	0.01	-1.43
300 ms: TL × VF × 2° vs. 4°	0.02	0.15	0.11	-0.01	0.01	-1.36
100 ms: SL word (SLw)	**-1.99**	**0.06**	**-32.10**	**0.11**	**0.00**	**23.27**
100 ms: SL nonword (SLn)	**-1.85**	**0.06**	**-31.40**	**0.10**	**0.00**	**21.67**
100 ms: TL Nonword	**-3.19**	**0.08**	**-39.09**	**0.11**	**0.01**	**17.43**
100 ms: 2° vs. 4° eccentricity	**0.20**	**0.04**	**5.19**	**-0.01**	**0.00**	**-2.98**
100 ms: LVF vs. RVF	0.02	0.04	0.60	**0.01**	**0.00**	**2.70**
100 ms: Visual field × 2° vs. 4°	0.07	0.04	1.76	0.00	0.00	-0.08
100 ms: SLw × 2° vs. 4°	0.11	0.11	1.00	**0.03**	**0.01**	**3.80**
100 ms: SLn × 2° vs. 4°	0.22	0.11	1.93	0.01	0.01	1.38
100 ms: TL × 2° vs. 4°	**-0.25**	**0.11**	**-2.27**	0.01	0.01	0.91
100 ms: SLw × LVF vs. RVF	**0.28**	**0.11**	**2.50**	**0.02**	**0.01**	**2.04**
100 ms: SLn × LVF vs. RVF	**0.37**	**0.11**	**3.29**	**0.02**	**0.01**	**2.32**
100 ms: TL × LVF vs. RVF	**-0.24**	**0.11**	**-2.20**	**0.03**	**0.01**	**3.48**
100 ms: SLw × VF × 2° vs. 4°	0.13	0.11	1.13	-0.01	0.01	-1.07
100 ms: SLn × VF × 2° vs. 4°	**0.31**	**0.11**	**2.75**	-0.01	0.01	-0.96
100 ms: TL × VF × 2° vs. 4°	0.20	0.11	1.77	-0.01	0.01	-0.81

Note. Significant effects indicated in bold.

Table 6

Mean (and SD) Same/Different Decision Accuracy and Response Time as a Function of Target Duration, Condition, and Position in Experiment 2A

Target duration and condition	Accuracy -2°	Accuracy -1°	Accuracy 1°	Accuracy 2°	RT (ms) -2°	RT (ms) -1°	RT (ms) 1°	RT (ms) 2°
300 ms duration								
Identical word	.92	.92	.93	.92	721	709	699	716
	(.06)	(.07)	(.07)	(.08)	(64)	(62)	(61)	(80)
Unrelated word	.97	.96	.98	.97	669	667	663	674
	(.06)	(.06)	(.05)	(.06)	(47)	(50)	(52)	(51)
SL word	.90	.89	.88	.91	760	749	744	755
	(.07)	(.07)	(.08)	(.06)	(58)	(57)	(54)	(68)
TL initial	.97	.97	.96	.96	677	669	689	694
	(.05)	(.05)	(.05)	(.05)	(49)	(46)	(49)	(42)
TL medial	.68	.70	.68	.69	836	841	835	855
	(.16)	(.18)	(.18)	(.17)	(69)	(72)	(83)	(82)
100 ms duration								
Identical word	.78	.84	.85	.83	714	690	689	679
	(.10)	(.10)	(.11)	(.11)	(63)	(72)	(60)	(65)
Unrelated word	.95	.94	.94	.94	668	661	657	659
	(.06)	(.06)	(.06)	(.06)	(58)	(62)	(55)	(54)
SL word	.71	.75	.81	.79	761	740	737	750
	(.09)	(.10)	(.09)	(.10)	(63)	(61)	(61)	(65)
TL initial	.91	.93	.79	.74	673	675	707	722
	(.06)	(.05)	(.13)	(.14)	(55)	(61)	(64)	(62)
TL medial	.22	.21	.25	.20	832	788	818	828
	(.14)	(.14)	(.14)	(.12)	(200)	(152)	(149)	(170)

Table 7

(G)LMM Model Summaries for Analyses of Same/Different Decision Accuracy and Response Time in Experiment 2A

	Accuracy			RT (Log)		
Fixed effect	*b*	*SE*	*z*	*b*	*SE*	*t*
Intercept	**2.00**	**0.09**	**23.10**	**6.55**	**0.02**	**414.45**
Stimulus duration	**1.58**	**0.10**	**15.46**	**0.02**	**0.01**	**2.06**
300 ms: SL word (SLw)	**-1.39**	**0.09**	**-15.07**	**0.12**	**0.00**	**28.51**
300 ms: TL initial (TLi)	-0.17	0.11	-1.61	**0.03**	**0.00**	**6.77**
300 ms: TL medial (TLm)	**-3.00**	**0.11**	**-28.50**	**0.23**	**0.00**	**52.33**
300 ms: 1° vs. 2° eccentricity	0.00	0.06	-0.09	**-0.01**	**0.00**	**-3.73**
300 ms: LVF vs. RVF	-0.06	0.06	-0.93	0.01	0.00	1.70
300 ms: Visual field × 1° vs. 2°	0.01	0.06	0.27	0.00	0.00	-1.28
300 ms: SLw × 1° vs. 2°	-0.27	0.17	-1.59	0.00	0.01	-0.23
300 ms: TLi × 1° vs. 2°	-0.05	0.20	-0.24	0.00	0.01	0.07
300 ms: TLm × 1° vs. 2°	-0.08	0.16	-0.50	0.00	0.01	-0.33
300 ms: SLw × LVF vs. RVF	-0.08	0.17	-0.49	-0.01	0.01	-0.70
300 ms: TLi × LVF vs. RVF	**-0.62**	**0.20**	**-3.16**	**0.03**	**0.01**	**4.08**
300 ms: TLm × LVF vs. RVF	-0.17	0.16	-1.11	0.00	0.01	0.49
300 ms: SLw × VF × 1° vs. 2°	**-0.49**	**0.17**	**-2.91**	0.01	0.01	1.04
300 ms: TLi × VF × 1° vs. 2°	**-0.43**	**0.20**	**-2.19**	0.01	0.01	1.03
300 ms: TLm × VF × 1° vs. 2°	**-0.44**	**0.16**	**-2.80**	-0.01	0.01	-1.06
100 ms: SL word (SLw)	**-1.69**	**0.07**	**-24.25**	**0.12**	**0.00**	**28.12**
100 ms: TL initial (TLi)	**-0.99**	**0.07**	**-13.51**	**0.05**	**0.00**	**11.02**
100 ms: TL medial (TLm)	**-4.32**	**0.09**	**-47.18**	**0.17**	**0.01**	**25.50**
100 ms: 1° vs. 2° eccentricity	**0.13**	**0.04**	**3.39**	**-0.01**	**0.00**	**-3.21**
100 ms: LVF vs. RVF	**-0.25**	**0.05**	**-5.22**	**0.02**	**0.00**	**5.19**
100 ms: Visual field × 1° vs. 2°	0.07	0.04	1.77	0.01	0.00	1.95
100 ms: SLw × 1° vs. 2°	0.16	0.12	1.34	-0.01	0.01	-1.52
100 ms: TLi × 1° vs. 2°	**0.26**	**0.13**	**2.01**	0.00	0.01	-0.05
100 ms: TLm × 1° vs. 2°	0.15	0.12	1.19	-0.01	0.01	-0.64
100 ms: SLw × LVF vs. RVF	**0.52**	**0.12**	**4.29**	0.00	0.01	0.20
100 ms: TLi × LVF vs. RVF	**-1.25**	**0.13**	**-9.50**	**0.06**	**0.01**	**7.38**
100 ms: TLm × LVF vs. RVF	0.16	0.12	1.31	**0.05**	**0.01**	**3.79**
100 ms: SLw × VF × 1° vs. 2°	-0.10	0.12	-0.85	0.01	0.01	0.73
100 ms: TLi × VF × 1° vs. 2°	-0.03	0.13	-0.25	-0.01	0.01	-1.59
100 ms: TLm × VF × 1° vs. 2°	0.08	0.12	0.62	**0.03**	**0.01**	**2.30**

Note. Significant effects indicated in bold.

Table 8

Mean (and SD) Same/Different Decision Accuracy and Response Time as a Function of Target Duration, Condition, and Position in Experiment 2B

Target duration and condition	Accuracy -2°	Accuracy -1°	Accuracy 1°	Accuracy 2°	RT (ms) -2°	RT (ms) -1°	RT (ms) 1°	RT (ms) 2°
300 ms duration								
Identical word	.91	.91	.93	.91	707	693	683	682
	(.07)	(.08)	(.06)	(.06)	(56)	(64)	(57)	(57)
Unrelated word	.97	.97	.97	.97	685	672	670	676
	(.05)	(.05)	(.05)	(.06)	(66)	(56)	(51)	(54)
SL word	.86	.85	.86	.86	769	764	753	759
	(.09)	(.09)	(.10)	(.08)	(72)	(55)	(62)	(55)
TL initial	.97	.97	.94	.92	692	675	702	710
	(.05)	(.05)	(.05)	(.08)	(68)	(52)	(47)	(48)
TL final	.89	.88	.92	.91	769	752	723	739
	(.08)	(.08)	(.09)	(.09)	(46)	(57)	(59)	(51)
100 ms duration								
Identical word	.79	.82	.87	.83	707	699	687	678
	(.12)	(.10)	(.10)	(.10)	(72)	(69)	(83)	(63)
Unrelated word	.95	.95	.95	.95	676	668	675	672
	(.05)	(.06)	(.05)	(.06)	(55)	(55)	(62)	(49)
SL word	.70	.75	.76	.75	763	760	757	777
	(.12)	(.11)	(.11)	(.10)	(74)	(67)	(61)	(66)
TL initial	.92	.92	.77	.70	692	677	727	745
	(.07)	(.06)	(.14)	(.16)	(62)	(54)	(60)	(78)
TL final	.54	.65	.84	.82	796	763	743	751
	(.16)	(.15)	(.12)	(.11)	(97)	(64)	(73)	(62)

Table 9

(G)LMM Model Summaries for Analyses of Same/Different Decision Accuracy and Response Time in Experiment 2B

	Accuracy			RT (Log)		
Fixed effect	*b*	*SE*	*z*	*b*	*SE*	*t*
Intercept	**1.81**	**0.09**	**20.79**	**6.54**	**0.02**	**295.30**
Stimulus duration	**1.10**	**0.09**	**12.77**	0.00	0.01	-0.34
300 ms: SL word (SLw)	**-1.78**	**0.09**	**-19.36**	**0.12**	**0.00**	**30.58**
300 ms: TL initial (TLi)	**-0.50**	**0.11**	**-4.68**	**0.04**	**0.00**	**9.16**
300 ms: TL final (TLf)	**-1.33**	**0.10**	**-13.14**	**0.11**	**0.00**	**27.40**
300 ms: 1° vs. 2° eccentricity	0.00	0.06	0.05	**-0.01**	**0.00**	**-5.20**
300 ms: LVF vs. RVF	**-0.16**	**0.07**	**-2.33**	-0.01	0.00	-1.95
300 ms: Visual field × 1° vs. 2°	0.11	0.06	1.94	0.00	0.00	1.10
300 ms: SLw × 1° vs. 2°	-0.03	0.16	-0.21	0.01	0.01	1.05
300 ms: TLi × 1° vs. 2°	0.04	0.19	0.21	0.00	0.01	-0.02
300 ms: TLf × 1° vs. 2°	0.05	0.17	0.30	-0.01	0.01	-0.85
300 ms: SLw × LVF vs. RVF	0.01	0.16	0.05	0.00	0.01	-0.27
300 ms: TLi × LVF vs. RVF	**-1.01**	**0.19**	**-5.32**	**0.05**	**0.01**	**5.89**
300 ms: TLf × LVF vs. RVF	0.32	0.17	1.91	**-0.03**	**0.01**	**-4.16**
300 ms: SLw × VF × 1° vs. 2°	-0.02	0.16	-0.12	0.00	0.01	-0.35
300 ms: TLi × VF × 1° vs. 2°	0.15	0.19	0.79	0.00	0.01	0.19
300 ms: TLf × VF × 1° vs. 2°	0.07	0.17	0.42	0.00	0.01	-0.21
100 ms: SL word (SLw)	**-2.00**	**0.08**	**-26.33**	**0.13**	**0.00**	**30.22**
100 ms: TL initial (TLi)	**-1.29**	**0.08**	**-15.49**	**0.05**	**0.00**	**12.34**
100 ms: TL final (TLf)	**-2.05**	**0.08**	**-24.30**	**0.12**	**0.00**	**28.44**
100 ms: 1° vs. 2° eccentricity	**0.18**	**0.04**	**4.34**	**-0.01**	**0.00**	**-4.74**
100 ms: LVF vs. RVF	0.00	0.06	-0.04	**0.01**	**0.00**	**2.77**
100 ms: Visual field × 1° vs. 2°	0.00	0.04	0.00	0.00	0.00	0.38
100 ms: SLw × 1° vs. 2°	0.11	0.13	0.84	-0.01	0.01	-0.82
100 ms: TLi × 1° vs. 2°	0.13	0.14	0.97	-0.01	0.01	-1.42
100 ms: TLf × 1° vs. 2°	**0.27**	**0.13**	**2.10**	-0.02	0.01	-1.95
100 ms: SLw × LVF vs. RVF	0.23	0.13	1.81	0.01	0.01	0.73
100 ms: TLi × LVF vs. RVF	**-1.49**	**0.14**	**-10.82**	**0.06**	**0.01**	**7.86**
100 ms: TLf × LVF vs. RVF	**1.35**	**0.13**	**10.42**	**-0.04**	**0.01**	**-5.14**
100 ms: SLw × VF × 1° vs. 2°	-0.21	0.13	-1.66	-0.01	0.01	-1.72
100 ms: TLi × VF × 1° vs. 2°	0.14	0.14	0.99	-0.01	0.01	-1.34
100 ms: TLf × VF × 1° vs. 2°	**-0.30**	**0.13**	**-2.30**	0.00	0.01	0.57

Note. Significant effects indicated in bold.

Figure 1

Comparison of Lexical Decision Accuracy (Upper Panels) and Latency (Lower Panels) from the Eye-Tracking Laboratory Experiment (Left Panels) and Online Experimental Paradigm (Right Panels) Conducted by Veldre et al. (2023a).

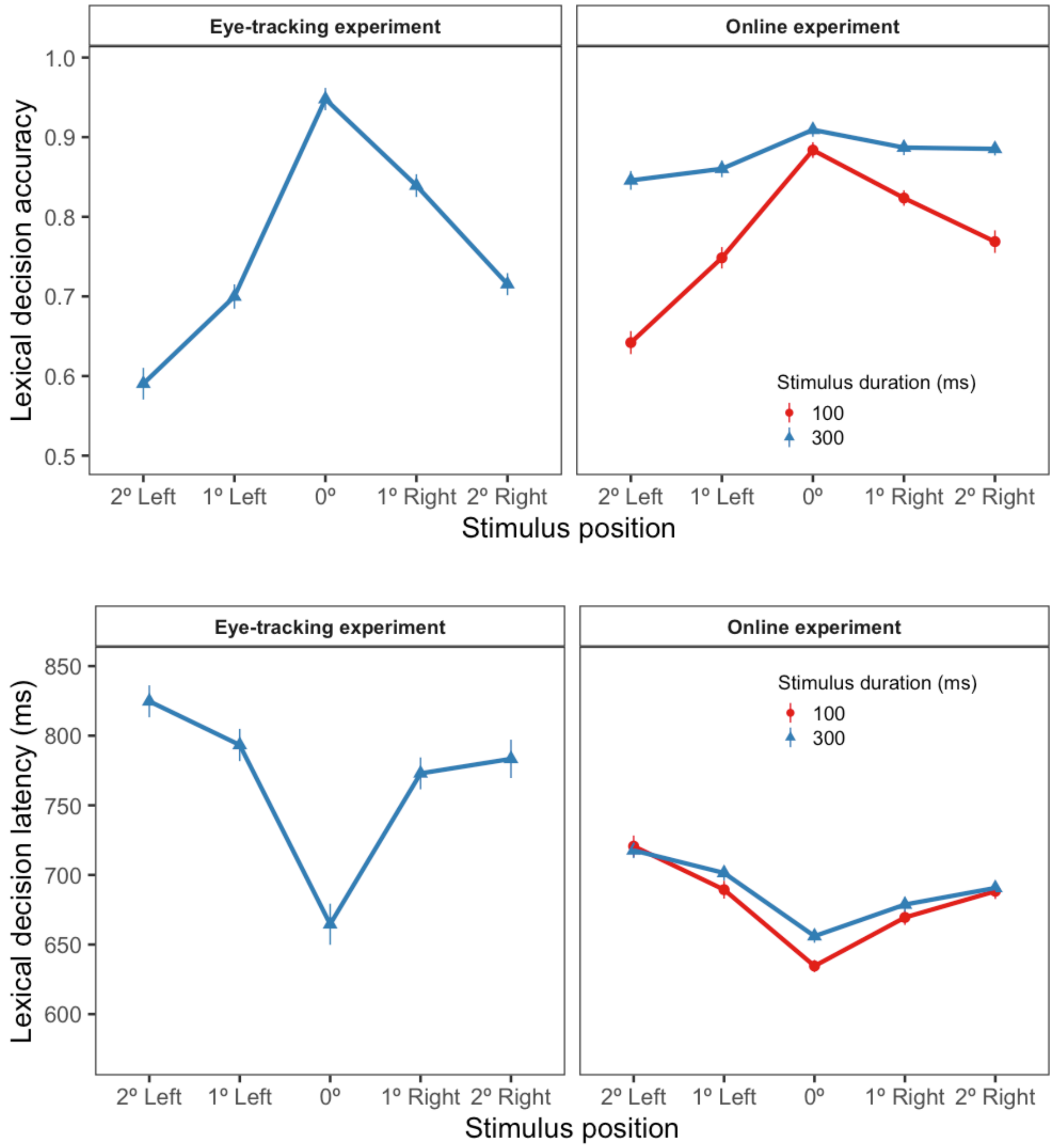


Figure 2

Schematic Diagram of the Procedure for Each Trial.

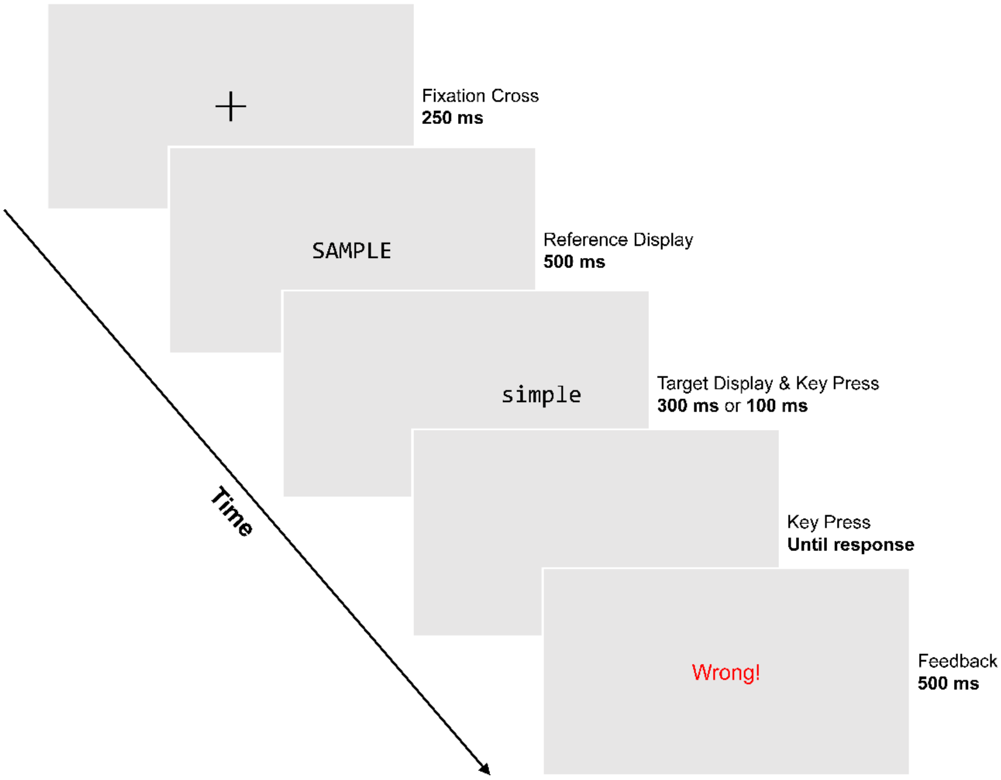
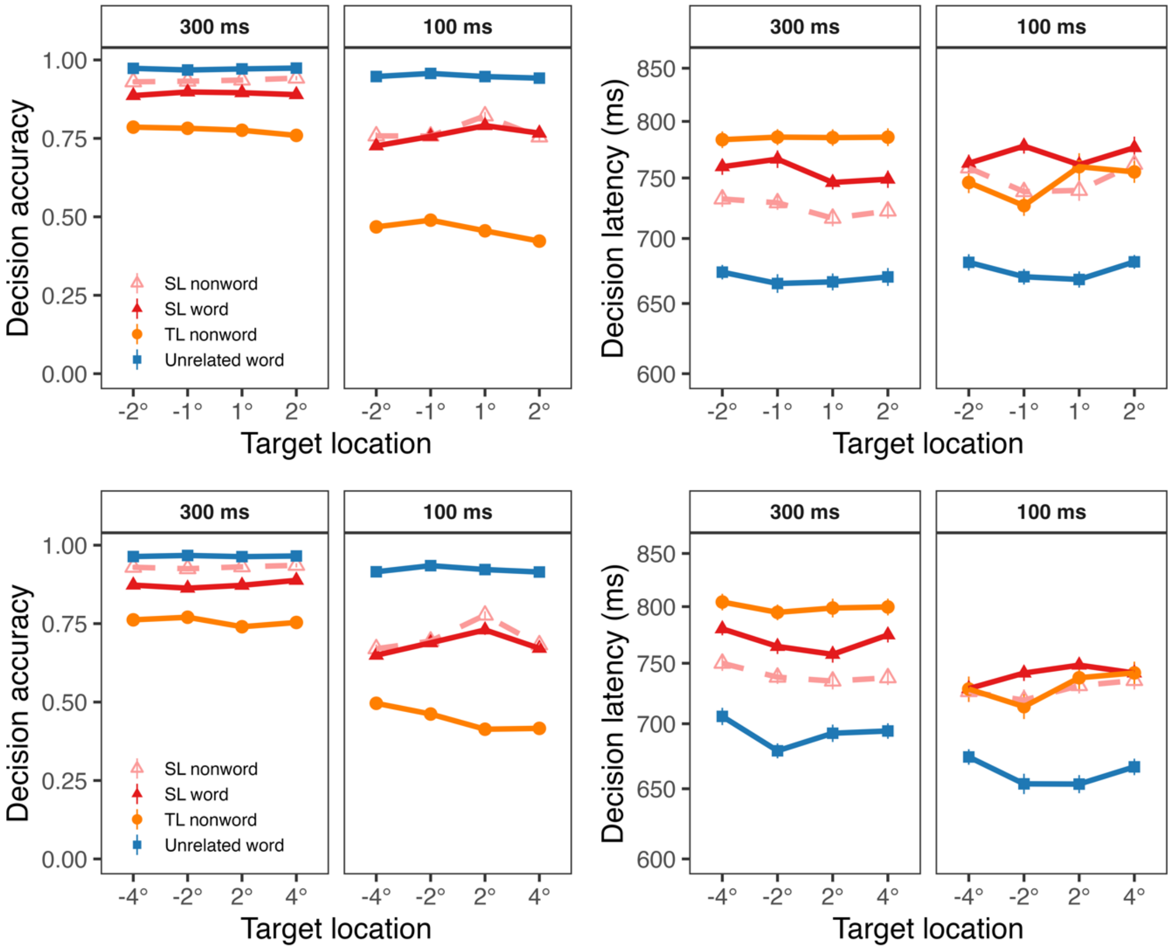


Figure 3

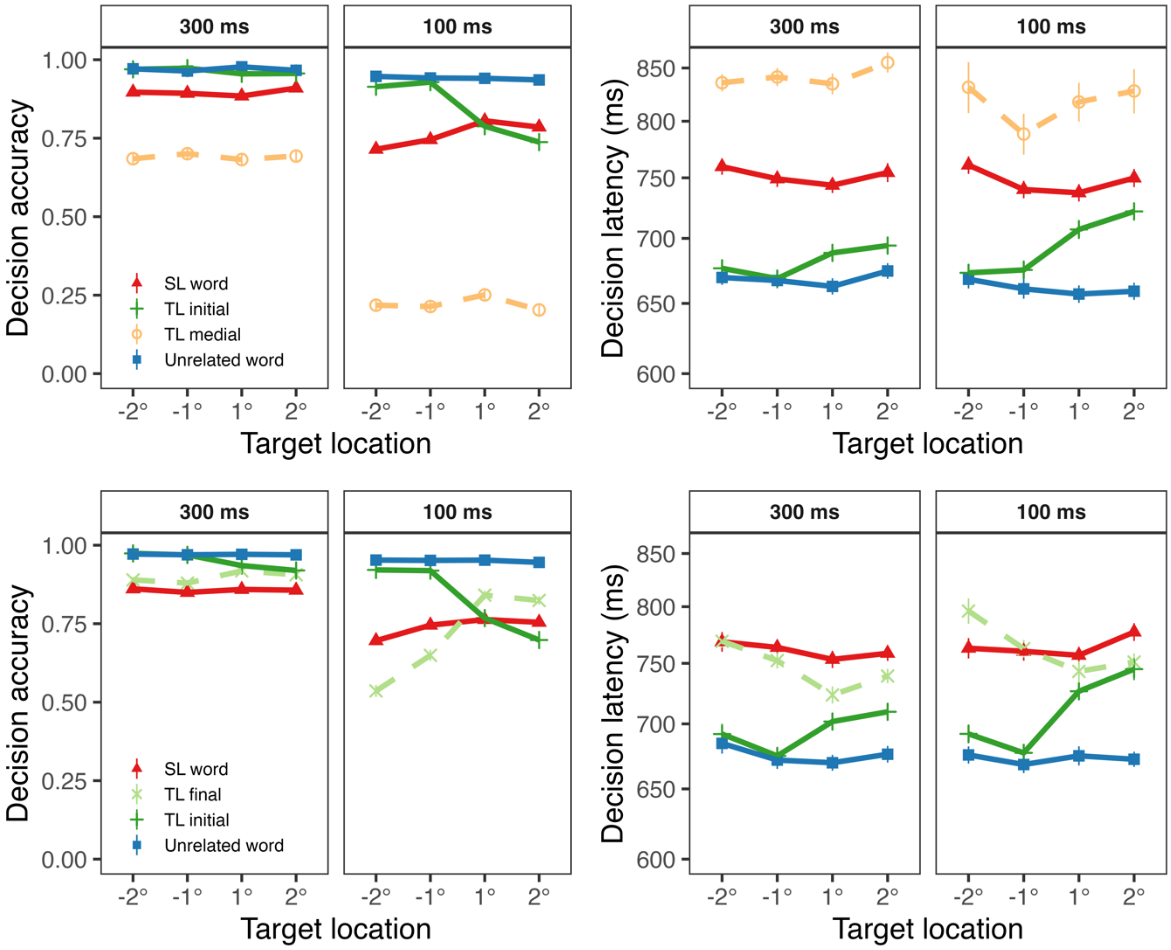
Same-Different Decision Accuracy and Latency as a Function of Target Condition, Position, and Duration in Experiment 1A (Upper Panels) and Experiment 1B (Lower Panels).



Note. Error bars are +/- SEM.

Figure 4

Same-Different Decision Accuracy and Latency as a Function of Target Condition, Position, and Duration in Experiment 2A (Upper Panels) and Experiment 2B (Lower Panels).



Note. Error bars are +/- SEM.