Neglect Dyslexia: Whole-word and Within-word Errors with Parafoveal and Foveal Viewing

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Abstract

Patients with left-sided neglect dyslexia commit two primary types of errors: omissions of entire words positioned on the left, termed *whole-word errors*, and substitutions or omissions of left-sided letters of words, termed *unilateral paralexias*. In addition, errors have been shown to be exacerbated by simultaneously presented distractors, which has been termed *extinction* and is usually interpreted as a failure of selective attention. In two experiments, we examined the dependency of these deficits on parafoveal versus foveal viewing. First, we replicated studies using a traditional extinction paradigm with parafoveal targets and distractors. We then modified the paradigm so that the target word was always presented at fixation, either alone or with a parafoveal distractor on either side. This enabled a separate evaluation of the influences of stimulus position within an egocentric frame or an allocentric frame based on the pair of words. First, regarding whole-word errors, we found the expected spatial and distractor effects with parafoveal targets and distractors. Surprisingly, intrusions from the distractor word were common in distractor conditions. With foveal targets and parafoveal distractors, however, the spatial effect was effectively eliminated. This is consistent with an egocentric account and not an allocentric account based on the pair of words. Second, we found that unilateral paralexias remained consistent regardless of spatial position or the presence of a distractor. Thus, there is a strong contrast in spatial and distractor effects between whole-word errors and unilateral paralexias. These results are consistent with three distinct deficits: an egocentric deficit across space resulting in whole-word errors, a failure of selective attention that ~~also~~ results in whole-word intrusion errors, and an allocentric deficit within a word resulting in unilateral paralexias.

Key words:
- neglect dyslexia
- unilateral paralexias

1. Introduction

Up to 25% of right hemisphere stroke survivors experience left-sided neglect dyslexia (Esposito et al., 2021; [redacted]), the reading impairment experienced by some, but not all, patients with spatial neglect (Vallar et al., 2010; Behrmann et al., 2002). Studies of word recognition reveal two primary types of errors in neglect dyslexia: *whole-word errors*, in which entire words positioned on the left side are omitted (Beschin et al., 2014); and *unilateral paralexias*, in which the initial (i.e., left-sided) letters of a word are substituted or omitted (Benson, 1985; Siéroff, 2017; Ellis et al., 1987).

The study of whole-word errors versus unilateral paralexias in neglect dyslexia has provided evidence for dissociable deficits of egocentric (i.e., viewer-centered) and allocentric (i.e., object-centered) spatial frames of reference [[redacted]]. Ptak et al. [[redacted]] compared the frequency of whole-word errors to the relative frequency of unilateral paralexias during a single word reading task. Participants were tasked with reading aloud 40 words arranged in five staggered columns (giving the viewer the impression of a random arrangement) spanning the left-to-right margins of an A4 sheet of paper. Words were 10-12 letters long and each had 0-2 orthographic "neighbors," meaning that a new valid word could be formed after exchanging one letter [[redacted]]. Patients with neglect dyslexia committed whole-word errors on approximately 44% of words, which decrement ~~decremented~~ along a left-to-right gradient. In contrast, unilateral paralexias occurred in approximately 9% of words but were evenly distributed across the horizontal extent of the page. Their findings are consistent with an explanation of two distinct spatial deficits underlying errors: one a deficit of egocentric processing resulting in whole-word errors and another a deficit of allocentric processing within a word resulting in unilateral paralexias.

They presented four-letter words either solitarily to the left or right of fixation, or simultaneously with a contralateral word. Participants were asked to orally report all words presented in a given trial. Patients showed effects of both space, with poorer accuracy for left-sided words than right-sided in all conditions; and distractors, with poorer accuracy for left-sided words in bilateral conditions. Their findings and those of similar studies with non-word stimuli (Geeraerts, Lafosse, et al., 2005; Shalev et al., 2005), suggest that extinction plays a role in neglect dyslexia due to the failure of selective attention that arises when two or more words are presented simultaneously. Consider how extinction might affect

~~For instance, during~~ natural reading, the visual system pre-processes upcoming words within a "moving window" that includes as many as 15 character spaces to the right of each fixated word (McConkie & Rayner, 1975). Through a paradigm using gaze-contingent masking of ~~the upcoming words in a reading passage~~ outside of the moving window, numerous studies have shown, for neurotypical readers, improved reading efficiency as the span of the ~~perceptual mask is reduced~~ moving window is increased (see Rayner, 2014, for a review). For those with neglect dyslexia, ~~If the position of the target relative to a right-sided distractor (i.e., positioned on the left side of an allocentric frame around the pair of words), is critical to induce extinction, the moving window,~~ the upcoming word normally a facilitator of efficient reading, becomes, ~~instead,~~ a barrier.

Complicating interpretations of extinction studies with words, there is a well-known right hemifield advantage for single word reading even in neurotypical participants (Mishkin & Forgays, 1952; Siéroff & Riva, 2011). This asymmetry has been attributed to several different sources: the left hemisphere's specialization for language (Behrmann & Plaut, 2013; Bryden, 1982; Hellige, 1993), the eccentricity differences of the first, most informative letter of the word when presented in the left versus right visual hemifield (Kirsner & Schwartz, 1986), or the

habitual reading behaviors of participants that use left-to-right scripts (Battista & Kalloniatis, 2002). In this way, extinction for words differs from extinction results with non-word stimuli.

A limitation of the traditional extinction paradigm is that it does not discern whether the distractor effect is due to the egocentric or allocentric position of the competing stimuli. Are left-sided words at a competitive disadvantage because of their spatial position relative to the viewer (i.e., their egocentric position) or relative to the right-sided word (i.e., their allocentric position within the two-word pair)? These two possibilities have been distinguished previously with non-word stimuli by Mattingley et al. (2000), who reported a single patient who showed extinction for a central target stimulus when flanked by a right-sided distractor (thereby positioning the target on the relative left side of the stimulus pair) but no extinction for a central target flanked by a left-sided distractor.

A second limitation of the traditional extinction paradigm is that this quite unlike natural reading because words are presented parafoveally. Natural reading largely depends on recognizing words in the fovea (Reichle, Rayner, & Pollatsek, 2003). Surprisingly, it is unknown whether extinction for words occurs in the fovea. If extinction for words is dependent on the target word's spatial location relative to a distractor, as was shown by Mattingley et al. (2000) with non-word stimuli, it would provide an allocentric explanation to whole-word errors during naturalistic passage reading: each fixated word is competing for selection with adjacent right-sided word(s).

1.1. Overview of Experiments

Our study builds on previous studies of extinction and different kinds of errors. There were two key features of our experiments. First, we used a modified extinction paradigm, following Mattingley et al. (2000) in addition to the traditional extinction paradigm. In the

To equate difficulty for foveal and peripheral targets, we adjusted their luminance and duration to match performance with solitary targets.

modified paradigm, the target word was presented at the fovea with a parafoveal distractor to the left or right, to distinguish the effects of egocentric spatial position and the allocentric spatial position within a pair of words. If extinction is dependent on the spatial position of the target word relative to the viewer, right-sided distractors would cease to induce errors with foveal targets. Conversely, if extinction is dependent on the spatial position of the target word relative to the distractor, the effect from right-sided distractors would persist with foveal targets.

The second key feature of our experiments is to separately analyze whole-word errors and unilateral paralexias. In this, we follow the distinction made by Ptak et al. (2016) and others. Our initial question for both kinds of errors was whether the spatial effects in the presence of a distractor word are due to the target word's egocentric position or its allocentric position relative to the distractor word.

2. General Methods

2.1. Participants

All participants provided informed consent prior to testing in accordance with the Declaration of Helsinki. Our experimental group was comprised of ten patients with right hemisphere stroke and left-sided neglect dyslexia. Six patients completed Experiment 1 and all ten completed Experiment 2. Patient demographic data are presented in Table 1. All patients were seen within a few weeks of stroke except for two (P-04 and P-10), who completed testing 85 weeks and 150 weeks post-stroke.

Patients were recruited from the inpatient and outpatient rehabilitation facilities of Harborview Medical Center in Seattle, Washington, following referral from treating rehabilitation physicians and therapists based on clinical observation of spatial neglect. They were required to have intact visual fields as determined by confrontation testing, intermediate

patient performance between Experiments 1 and 2, rather than to compare performance of the patient and control groups, which has been investigated in prior studies.

Sample size estimation. In the absence of pilot data, we based our sample size on the n=6 used by Sieroff and Urbanski (2002) in a similar study of extinction with words. Nevertheless, a post hoc analysis of the appropriate sample size can provide some insight into the power of our experiments. The analysis uses the results of Experiment 1 which replicated prior extinction experiments to estimate an appropriate sample size for the more novel Experiment 2. In this analysis, the focus is on the comparison of percent correct for left-sided target words to right-sided target words; and is restricted to the distractor conditions because Experiment 2 measures the left-right difference with a distractor present. In our Experiment 1, the ~~disadvantage~~ increase in ~~in percent correct~~ error for the left word compared to the right word was 40.2% with a standard deviation of 13.9%. We based our sample size calculation on a paired t-test with two tails and assumed a power of 80% (alpha error = .05). To detect a left-sided ~~disadvantage~~ effect of 15% (compared to 40% found in Experiment 1), we would need a minimum sample size of 9. In fact, the sample size in our Experiment 2 was 10. Thus, this experiment can be expected to detect a 15% difference in ~~performance~~ errors on the left and right.

2.2. Stimuli and apparatus

Target and distractor stimuli were drawn randomly from a list of 539 common English words. Each word was four letters in length. The target and distractor words on a given trial were never identical and were orthographically and semantically unrelated unless by chance. Stimulus words were selected based on having one or more valid orthographic neighbors that could be formed by exchanging the first letter (e.g., CARE, DARE, and FARE). This method has been

luminance and longer display durations to achieve comparable accuracy to controls on their ipsilesional right side.

3.2.1. Total errors

Patients committed a significant 35.4±5.6% more total errors for left-sided than right-sided targets (F (1,5) = 40.6, p = .001, 95% CI [21.1%, 50.0%], Cohen's D = 2.6). The effect of adding a distractor was a significant 14.6±2.0% increase in total errors (F (1,5) = 57.2, p < .001, 95% CI [9.6%, 19.6%], Cohen's D = 3.1). Our results with total errors align with those of Siéroff & Urbanski (2002). Patients in both studies showed significantly better performance for right-sided than left-sided targets in both solitary and distractor conditions. They also showed better performance in solitary than distractor conditions. In summary, we replicated the spatial and distractor effects reported in Siéroff & Urbanski (2002).

3.2.2. Whole-word errors

In Figure 3, errors are plotted for patients in the left panels and for controls in the right panels. Within each panel, left target conditions are plotted on the left, and right target conditions on the right. The solitary conditions are represented by filled disks joined by a solid line and the distractor conditions are open disks joined by a dashed line.

Whole-word errors are plotted in panels A and B of Figure 3. Patients committed a significant 26.8±8.0% more whole-word errors for left-sided than right-sided targets (F (1,5) = 11.4, p = .020, 95% CI [6.3%, 47.2%], Cohen's D = 1.4). The effect of adding a distractor was a significant 14.2±2.7% increase in whole-word errors (F (1,5) = 28.0, p = .003, 95% CI [7.3%, 21.0%], Cohen's D = 2.2). Controls committed a non-significant 1.2±1.5% more whole-word errors for left-sided than right-sided targets (F (1,6) = 0.6, p = .466, 95% CI [-2.5%, 4.9%],

For controls,

Cohen's D = 0.3). The effect of adding a distractor was a significant 3.6±1.2% increase in whole-word errors (F (1,6) = 9.4, p = .022, 95% CI [0.7%, 6.4%], Cohen's D = 1.2).

3.2.2.1. Intrusions

A subset of responses in distractor conditions exactly matched the distractor word, a type of whole-word errors we call *intrusions*. For patients, intrusions were significantly different than zero for both left-sided targets (t(5) = 2.6, p = 0.02, one-tailed, Cohen's D = 1.1) and right-sided targets (t(5) = 2.7, p = 0.02, one-tailed, Cohen's D = 1.1). Patients committed a significant 13.5±5.4% more intrusions for left-sided than right-sided targets (t (5) = 3.6, p = .016, 95% CI [3.8%, 23.2%], Cohen's D = 1.2). Controls committed few intrusions for left-sided targets (0.8%), which were not significantly different than zero (t(6) = 1.6, p = .086, one-tailed, Cohen's D = 0.7), and no intrusions for right-sided targets. They had a non-significant 0.8±0.5% more intrusions for left-sided than right-sided targets (t (6) = 2.2, p = .071, 95% CI [0, 1.6%], Cohen's D = 0.8). Closer examination of patients' errors reveals that intrusions comprised a majority of the errors for left-sided targets with right-sided distractors. For this case, distractors increased errors by 19.5±3.6%. Of these errors 16.4±6.2% were intrusions. Thus, they were the bulk of the additional errors caused by the distractor.

3.2.3. Unilateral paralexias. Unilateral paralexias are plotted in panels C and D of Figure 3. For patients, these errors occurred in 15.2±2.2% of trials across all conditions and were significantly more common than right-sided contiguous errors, which occurred in 5.6±1.0% of trials (t (23) = 3.5, p = .002, 95% CI [3.9%, 15.3%], Cohen's D = 1.6). Patients committed a non-significant 1.6±6.4% more unilateral paralexias for left-sided than right-sided targets (F (1,5) = 0.07, p = .808, 95% CI [-14.7%, 18.0%], Cohen's D = 0.1). In distractor conditions, patients had a significant 3.0±1.0% fewer unilateral paralexias (F (1,5) = 9.1, p = .030, 95% CI

One tailed tests are not because negative values are impossible for this case

[-5.6%, -0.4%], Cohen's D = -1.3). Controls did commit unilateral paralexias but their occurrence, 5.6±0.9% of trials across all conditions, was not significantly greater than right-sided contiguous errors (i.e., reversed unilateral paralexias), which occurred in 7.7±1.3% of trials ($t(27) = -1.4$, $p = .161$, 95% CI [-5.3%, 0.9%], Cohen's D = -0.7). Controls committed a non-significant 3.6±1.8% more left-sided errors for left-sided than right-sided targets ($F(1,6) = 3.9$, $p = .097$, 95% CI [-0.9%, 8.0%], Cohen's D = 0.7). In distractor conditions, controls had a non-significant 1.6±1.6% fewer left-sided errors ($F(1,6) = 1.0$, $p = .348$, 95% CI [-5.4%, 2.2%], Cohen's D = -0.4). In summary, patients had a pattern of unilateral paralexias that was different than found for whole-word errors. There was little effect of side and a small, reversed effect of distractors, especially for the left side. Controls had relatively few left-sided errors that were no more common than right-sided contiguous errors and they did not significantly vary with side or distractor.

3.3. Discussion

In this experiment, our examination of error type reveals a distinct pattern of whole-word errors and unilateral paralexias for patients. There were more whole-word errors for left-sided targets and with distractors. Intrusions comprised a substantial portion of whole-word errors in distractor conditions, particularly on the left side. Unilateral paralexias accounted for nearly a third of patients' errors. The ~~reliable~~ reduction in unilateral paralexias in distractor conditions can be explained by the increase in whole-word errors in those conditions (a whole-word error would make the word unavailable for other error processes). Besides this effect, unilateral paralexias were not modulated by spatial position or the presence of a distractor. In summary, there were spatial and distractor effects for whole-word errors but not unilateral paralexias.

4. Experiment 2

for an average of 318 trials. For patients, 0.4% of trials were discarded due to the occurrence of an eye movement, experimenter error, or participants reporting they were not ready.

As in Experiment 1, we used a modified staircase procedure to customize the relative luminance and display durations for each participant to obtain a desired performance level. Distractors were presented at a relative luminance of 3x that of targets to equalize their visibility, based on a pilot experiment completed with our first group of controls (see Appendix).

4.2. Results

Patients had a mean relative luminance of 32% and a mean display duration of 0.08 seconds, resulting in 39.5±3.3% total errors in the solitary condition. Controls had a mean relative luminance of 2% and a mean display duration of 0.03 seconds, resulting in 38.1±6.0% total errors in the solitary condition.

Figure 5 is similar to Figure 3 for Experiment 1. Results for patients are plotted in panels on the left and for controls on the right. Because the target remained in the central position across all conditions, errors are plotted based on the *relative* position of the target. Thus, the right distractor condition is plotted on the left because the target was on the left-sided position relative to the distractor.

4.2.1. Whole-word errors

Whole-word errors are plotted in panels A and B of Figure 5. Patients committed a significant 5.8±2.1% more whole-word errors in distractor conditions than in the solitary condition (F (1,9) = 7.3, p = .014, 95% CI [1.3%, 10.3%], Cohen's D = 0.9). There was a non-significant effect of distractor side, with 4.3±2.5% more errors with right-sided than left-sided distractors (F (1,9) = 3.0, p = .102, 95% CI [-9.5%, 0.9%], Cohen's D = -0.6). Intrusions were significantly different than zero for left-sided targets (t (9) = 2.2, p = .026, one-tailed, Cohen's D

occurred on ___% of the trials for left sided targets and ___% for right sided targets

condition than in the distractor conditions (F (1,6) = 0.9, p = .370, 95% CI [-3.9%, 1.6%], Cohen's D = -0.4). They committed a non-significant 3.0±1.5% more left-sided errors with right-sided distractors than left-sided (F (1,6) = 4.2, p = .063, 95% CI [-6.2%, 0.2%], Cohen's D = -0.8). In summary, for patients, unilateral paralexias comprised a substantial portion of total errors and remained consistent across all conditions. Controls committed few left-sided errors that were no more common than right-sided contiguous errors and did not significantly vary with side or distractor.

4.3. Discussion

In Experiment 2, we modified the traditional extinction paradigm so that the target word was always presented foveally. Whole-word errors were committed more frequently with distractors but were not differently affected by left- or right-sided distractors. Intrusions were more frequent with right-sided distractors but were substantially reduced in comparison to Experiment 1. Also consistent with Experiment 1, unilateral paralexias were common and consistent across conditions.

4.4. Comparison of Experiment 1 and 2

Experiments 1 and 2 can be compared to distinguish whether the spatial effects are due to the target's egocentric position or its allocentric position within a word pair. If its egocentric position is critical, then spatial effects found with Experiment 1 should be eliminated in Experiment 2 which has the target word centered in the fovea. Alternatively, if its allocentric position is critical, then both experiments should have similar spatial effects. The magnitude of the spatial effects in the presence of a distractor for both experiments is plotted in Figure [1]. The panel on the left is for whole-word errors and the panel on the right is for unilateral paralexias. For whole-word errors, there were large spatial effects in Experiment 1 and near zero effects in Experiment 2. The difference

was 31 ± 8% which was statistically significant by a two-sample t-test with unequal variance ($t(5.57) = 3.98, p = .008$, 95% CI [12, 51%], Cohen $d = 1.6$). This is consistent with an egocentric frame of reference and not an allocentric frame of reference based on the pair of words.

For unilateral paralexias, there were no detectable spatial effects for either experiment. The difference was 1.7 ± 4.5% which was not statistically significant by a two-sample t-test with unequal variance ($t(13.6) = 0.38, p = .709$, 95% CI [-8, 12%], Cohen $d = 0.1$). This is consistent with an allocentric frame of reference based on a single word. Furthermore, using the confidence intervals one can rule out an egocentric effect similar to what was found with whole-word errors. Thus, there are sharply contrasting effects for the two kinds of errors consistent with different frames of reference.

5. General Discussion

In this study of word recognition, we investigated the influence of space and distractors on whole-word errors and unilateral paralexias. Experiment 1 was a replication of the traditional extinction paradigm for words with parafoveal targets and distractors. Experiment 2 used a modified paradigm with foveal targets and parafoveal distractors. Thus, Experiment 2 controlled the effects of egocentric space on targets while manipulating allocentric space with the placement of distractors.

Regarding whole-word errors, there were two main results. First, by comparing Experiments 1 and 2 we found whole-word errors to depend on the target's egocentric position and not on its allocentric position within a pair of words. Second, in the presence of a distractor, these whole word errors were largely made up of intrusions from the distractor word.

In addition, to match visibility with foveal and parafoveal targets, we adjusted the luminance and duration of the equate pattern for subjective

Regarding unilateral paralexias, there were two main results. Unilateral paralexias were unaffected by the target word's egocentric position or its allocentric position within a pair of words. Second, unilateral paralexias were unaffected by the presence of a distractor word. Both of these effects were in sharp contrast to the effects found for whole word errors.

Whole-word errors follow a horizontal gradient

Spatial effects. In the solitary conditions of Experiments 1 and 2, we found a substantial effect of the target word's egocentric spatial position on whole-word errors. Patients showed a horizontal gradient of whole-word errors, with accuracy incrementally improving as targets were positioned from left to right. This contralesional-to-ipsilesional gradient is consistent with several prior studies of neglect dyslexia [Miceli & Capasso, 2001; Moore & Demeyere, 2023; Sieroff & Michel, 1987; Behrmann et al., 2002; Ptak et al., 2012].

This gradient of whole-word errors in solitary conditions is ~~supportive of~~ consistent with an egocentric spatial explanation of whole-word errors. That is, the further a target word is positioned in the left egocentric hemispace, the greater the likelihood that a target word ~~will be~~ is omitted. Mechanisms that have been proposed to underlie the horizontal gradient include that left-sided sensory input is degraded as compared to right-sided (Bender, 1952; Farah et al., 1991; Heilman et al., 1985) or that patients experience an anisometric perception of egocentric space, making the left side appear "relaxed" and the right side "constricted" (Bisiach et al., 1998, 1999).

Distractor effects. With parafoveal targets and distractors in Experiment 1, we found extinction-like effects when left-sided targets were presented with right-sided distractors. Although our task was slightly different than Sieroff & Urbanski (2002) in that in the present study participants were asked to report a target word and ignore the distractor word rather than report both words, our findings are consistent with theirs. Both experiments showed a clear effect

of egocentric space in solitary conditions that was exacerbated with the simultaneous presentation of a right-sided word.

Our replication of Sieroff & Urbanski (2002) in Experiment 1 showed that there was a spatially biased distractor effect, but it could not distinguish whether it was dependent on the target's egocentric position or allocentric position within the two-word pair. To make this distinction was one of our primary motivations for Experiment 2.

In contrast to the substantial distractor effect for left-sided words in Experiment 1, we found a significant but *non-lateralized* distractor effect for foveal targets with parafoveal distractors in Experiment 2. That is, accuracy of reporting the central target word was equivalently affected by the presence of a distractor on either the left or right side.

This contrasts with Mattingley et al.'s (2020) experiment using simple detection of non-word stimuli, in which a central target was extinguished with the simultaneous presentation of a right-sided distractor but not a left-sided. There are several possibilities for our incongruent results. First, given the simplicity of the task and stimuli used in Mattingley et al. as compared to ours, it is likely that their single participant had a quite severe presentation of [neglect/extinction] while our participants tended to have milder presentations. [[redacted]]

? cut?

However, our results are consistent with several prior studies with non-word stimuli that have explored the influence of parafoveal stimuli on a foveal target. In line with our findings from Experiment 2, left- and right-sided parafoveal stimuli were shown to have equivalent priming effects (de Haan et al., 2015; Fuentes & Humphreys, 1996; Làdavas et al., 1993) and interference effects (Audet et al., 1991; Cohen et al., 1995; Diedrichsen et al., 2000; Lavie & Robertson, 2001; Ro et al., 1998; Snow & Mattingley, 2008) on the detection or identification of a foveal target. Taken together, these results suggest that left-sided stimuli undergo a degree of

processing sufficient to interfere with a right-sided or foveal target, but insufficient to erroneously be selected over a right-sided or foveal target. [Audet, Bub, & Lecours, 1991; Di Pellegrino & De Renzi, 1995; Cohen, Rafal, Ivry, & Kohn, 1995; Ro, Cohen, Ivry, & Rafal, 1998; Morein-Zamir et al., 2005; Berti & Rizzolatti, 1992].

These distractor effects are usually interpreted as a failure of selective attention. This builds on the biased competition model, in which multiple stimuli compete for limited processing, mediated by top-down behavioral goals and bottom-up stimulus characteristics (Desimone & Duncan, 1995). Lateralized biased competition in SN has been hypothesized to result from a disruption to the reciprocal inhibition of the two cerebral hemispheres (Kinsbourne, 1977). Consequent to damage to the neurons in the right hemisphere that encode left-sided spatial locations, an unopposed left hemisphere selects right-sided for processing at the expense of left-sided stimuli. An alternative account of visual crowding is dismissed because of the wide separation of the words in the distractor conditions of both experiments.

Neglect Dyslexia?

Spell out

Intrusions. A novel result of our study was frequent intrusions of the distractor word. In Experiment 1, intrusions were reliably different than zero for both left-sided and right-sided targets, but intrusions for left-sided targets were reliably more frequent than for right-sided targets. Indeed, the bulk of the extra errors due to distractors were intrusions. In Experiment 2, intrusions were only significant with a right-sided distractor. In contrast to the symmetric distractor effect resulting in whole-word errors in Experiment 2, suggestive of a non-lateralized selective attention deficit, the asymmetric distractor effect causing intrusions is suggestive of a lateralized selective attention deficit.

There are several possible interpretations of intrusions. One is that the cue was sometimes mislocalized to the opposite position within the two-word pair. If a left-sided cue (or relative left-

sided cue in Experiment 2) was mislocalized to the right hemifield, it is natural that the right-sided distractor word was reported rather than the target word.

An alternative interpretation is that the cue was more-or-less correctly localized, but the left-sided word was poorly localized. In that case, the word on the right side might have been judged as the closest to the cued location. Such selection errors occur in normal vision when the cues and competing stimuli are close together in peripheral vision (Palmer & Moore, 2009; Yigit-Elliott, Palmer, & Moore, 2011).

Such mislocalizations have been reported previously in participants with unilateral brain damage. Termed *dyschiria* or *allochiria* (see Meador et al., 1991 for a review on terminology), the phenomena are most commonly reported in the tactile modality (e.g., Bisiach & Berti, 1995; Kawamura et al., 1987; Meador et al., 1991; Ricci et al., 2019) but have also been reported in several sensorimotor modalities, including tactile detection/localization, copying (Lepore et al., 2003, 2004; Halligan et al., 1992), and drawing from memory (Grossi et al., 2004).

Alternatively, intrusions might not signify any deficit beyond an error in selective attention. Patients might have preferred to provide an incorrect response (i.e., the distractor word) rather than a vacant response (i.e., "I don't know"). Regardless of the mechanism underlying these intrusion errors, they are supportive of some kind of deficit in selective attention.

Unilateral paralexias remain consistent across egocentric space

Spatial effects. We found a relatively consistent pattern of unilateral paralexias across all conditions of the two experiments. The reduction of unilateral paralexias we found in the distractor conditions of Experiment 1 can be explained by the reciprocal increase in whole-word errors, ~~representing a~~ such a complete failure of word recognition that removed the opportunity for

unilateral paralexias. The consistency of unilateral paralexias suggests a distinct within-word allocentric deficit that is not modulated by spatial position or the presence of a distractor.

This is in agreement with several prior studies that have reported a consistent unilateral paralexic error rate suggestive of a distinct within-word allocentric deficit. Miceli and Capasso (2001) reported, for a single participant, comparable error rates for the first letter position of 4-letter words when presented centrally or to the left or right of fixation. The error rate for the first letter position of right-sided targets, for example, was 31.7%, while the error rate for the third letter of the centrally presented word, which occupied the identical egocentric position, was just 2.7%. Ptak et al. (2012), who presented 40 words distributed in five columns on a single sheet of paper, reported a generally consistent unilateral paralexic error rate.

There is evidence that single words are perceived in a similar manner to objects. First, substitution errors (e.g., NEAR→BEAR) are more common than omission errors (e.g., NEAR→EAR) or addition errors (e.g., NEAR→CLEAR; Arduino et al., 2002b; Arguin & Bub, 1997; Behrmann et al., 1990). Second, words are read more accurately than non-word strings (Arduino et al., 2002a; Behrmann et al., 1990; Siéroff et al., 1988), unless the cohesion of a word is manipulated through increasing the spacing between letters (Siéroff, 1991). Third, unilateral paralexias have been reported to occur for words positioned in the right egocentric hemispace (Kinsbourne & Warrington, 1962; Siéroff, 1991).

The three-level model for neglect dyslexia, as proposed by Hillis and Caramazza (1995), delineates the progressively abstract stages of word recognition that may underlie unilateral paralexias. They classified errors into one of three reference frames: (1) retinocentric; (2) stimulus-centered; and (3) word-centered. The retinocentric frame represents the early visual features of the word as they are projected onto the retina. In our experiments, which did not

permit eye movements, retinocentric and egocentric coordinates are aligned. In this reference frame, errors are due to their spatial position relative to the viewer. Errors in a stimulus-centered reference frame are due to a within-word allocentric deficit and are unaffected by egocentric spatial location. Finally, word-centered errors represent a more abstract level of processing. They occur on the contralesional side of words even in a mirror-reversed presentation. In other words, the unilateral paralexic error pattern is reversed for mirror-reversed words. A word-centered error pattern indicates a deficit to an abstract level of representation, well after the visual processing stage is complete. Our study did not manipulate words in this way, so we were unable to distinguish between stimulus-centered and word-centered errors as proposed by Hillis & Caramazza (1995), but the occurrence of word-centered errors have been reported in numerous studies since (e.g., Moore & Demeyere, 2020).

Distractor effects. Further evidence for a distinct within-word allocentric spatial impairment is provided by our result of no significant effect of the presence of a distractor on unilateral paralexias in either experiment. Furthermore, we found no significant difference in unilateral paralexias in conditions with left- versus right-sided distractors.

6. Conclusion

In this study, we manipulated the spatial position of target and distractor words within egocentric and allocentric ~~coordinates~~ frames to determine the spatial and attentional contributions to whole-word errors and unilateral paralexias in patients with neglect dyslexia. For whole-word errors, we found both spatial and distractor effects with parafoveal targets and distractors, but only distractor effects with foveal targets and parafoveal distractors. In addition, we found the errors with distractors to be largely intrusions of the distractor word. This reinforces previous interpretations of this extinction effect as a failure of selective attention. In contrast, we found

unilateral paralexias to remain consistent throughout manipulations of spatial position and the presence of a distractor. Thus, these errors are entirely a function of allocentric space within a word with no sign of an effect of egocentric space. In summary, our findings support an account of neglect dyslexia based on three distinct deficits: an egocentric deficit across space resulting in whole-word errors, a failure of selective attention resulting in whole-word errors, and an allocentric deficit within a word resulting in unilateral paralexias.

7. Appendix

Prior to Experiment 2, control participants were tested to determine an appropriate luminance ratio between foveal and parafoveal targets to equate their visibility. Our intention was to compensate for the decrement in the visibility of parafoveal targets due to eccentricity effects by providing a higher luminance for parafoveal distractors in Experiment 2. This preliminary study had four conditions: two solitary conditions (solitary central target, solitary right target) and two distractor conditions (central target/right distractor, right target/central distractor). Stimulus words were positioned either centrally or with their midpoint 3° to the right of fixation. Luminance was adjusted ~~incrementally and~~ separately for the central and parafoveal targets. Left-sided targets were not included since right-sided distractors were expected to have more of an effect than left-sided distractors.

Four control participants were tested. When the right-sided target was set at 2x the luminance, the right-sided target had 22% ~~poorer~~ worse accuracy than the central target. When set at 4x the luminance, the right-sided target had 22.5% better accuracy than the central target. When set between 2x and 4x, performance on the right-sided target was roughly equal to that of the central target. Thus, for Experiment 2 we used 3x luminance for parafoveal distractors for all participants.

Data availability statement:
The dataset generated from this study is available at: https://osf.io/7czse