

## RESEARCH REPORT

# AN INVESTIGATION OF ATTENTIONAL CONTRIBUTIONS TO VISUAL ERRORS IN RIGHT “NEGLECT DYSLLEXIA”

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### ABSTRACT

One type of error that is sometimes produced by patients with acquired dyslexia is the substitution of an orthographically similar word with letters that overlap the target either in early or late letter positions. When such errors affect the left sides of words, they are usually produced by patients with focal right hemisphere lesions who typically show evidence of left neglect in non-reading tasks. This pattern has thus been termed “neglect dyslexia”. When the right sides of words are affected, however, patients frequently fail to show any signs of neglect in tasks other than reading. This study presents results from a patient with left hemisphere damage, and a very clear pattern of right “neglect” errors in reading, on a series of tasks testing attentional and imagery processes. Given the magnitude and consistency of the patient’s reading errors, there was little evidence that these errors resulted from inattention to the right side of space or to the right side of an internally generated visual image. It is argued that the positional errors result from an impairment to an abstract ordinal code with graded activation of letter positions from first to last, and that this code is specific to tasks involving orthographic representations.

Key words: attention, neglect dyslexia, visual errors, ordinal code

The study of patients with neurogenic language impairment often provides insights into the organization and processing of the normal system. Unfortunately, interpretation of patients’ impairments is often complicated by the relationship between mechanisms dedicated to language and those used for more general cognitive and sensory processing, including motor function, visual sensation and perception, memory and attention. This appears to be especially true in interpreting reading disorders, where the disruption of visual (sensory) and attentional mechanisms could easily cause disruptions independently of language processes. For example, many patients have been described who demonstrate what has been termed “neglect dyslexia” (Behrmann et al., 1990; Ellis et al., 1987; Riddoch et al., 1990), often within the context of generalized hemispatial neglect. Study of such patients has been undertaken in an attempt to define the role of attentional processes in reading.

Because hemispatial neglect occurs most frequently in patients with right hemisphere lesions, it is not surprising that most patients with neglect dyslexia have focal right-sided lesions and “neglect” the leftmost parts of words (Ellis et al., 1993). That is, patients with left neglect dyslexia produce errors in which letters in the left portion of words have been omitted or substituted (e.g., LETTER → ‘butter’). Such patients usually show no signs of language difficulty other than these reading errors. However, they often (but not always) show the clinical symptoms of left

hemispatial neglect for objects and pictures. Many of these patients appear simply to “neglect” the parts of words that fall in left space, as manipulating the orientation of written words (e.g., to vertical presentation) greatly attenuates the number of errors produced (Ellis et al., 1993).

Patients with right neglect dyslexia produce errors of omission or substitution of letters in the right portion of words (e.g., PUPIL → ‘puppy’). These patients usually (but not always) have left hemisphere lesions; some show signs of aphasia, while others do not. Some patients with right neglect dyslexia demonstrate the symptoms of hemispatial neglect, but most do not. In contrast to patients with left neglect dyslexia, patients with right neglect dyslexia have been described who continue to make errors on the ends of words when stimuli are oriented vertically or when words are spelled aloud to them, i.e., when the “neglected” portion of words does not fall into right space (see Ellis et al., 1993, for review and discussion).

The first extensively studied patient with right neglect dyslexia (N.G.) was naturally left-handed and had a left hemisphere parietal lesion (Caramazza and Hillis, 1990; Hillis and Caramazza, 1990). N.G. showed no signs of aphasia, but did show clear clinical indications of right hemispatial neglect. However, N.G.’s neglect of right space was not the sole cause of her reading pattern, as she continued to make reading errors on the ends of words even when the words did not fall into right hemispace, e.g., when they had been rotated to vertical orientation. Hillis and Caramazza

(1990) argued that N.G.'s performance reflects a "word-centered" attentional deficit operating over an internally generated *spatial* representation of written words. This interpretation is theoretically important, as it suggests that a spatially-encoded word representation is generated early in the process of normal reading that is dissociable from actual location in space.

Based on a comparison of patient N.G.'s pattern of performance with that of two other patients with (left) neglect dyslexia, Hillis and Caramazza (1995) have proposed that there are three distinct types of spatial representations generated in the course of word (and object) recognition that, when damaged, can give rise to neglect dyslexia. The first is a retinocentric representation that specifies the location of the word or object in the visual field, and the spatial relationships among edges of the stimulus. Patients who are affected at this level should show improvement if the stimulus is moved into the unaffected visual field, or is not presented visually at all (i.e., is spelled aloud). The second, stimulus-centered, level of representation is independent of the visual field but still tightly bound to the visual stimulus. Patients affected at this level continue to neglect the same side of words (or objects) when they are moved to the opposite side of space; when words are mirror reversed, patients continue to neglect the same (right or left) side of the stimulus, even though it is a different part of the word.

Caramazza and Hillis (1990) explicitly claim that neglect dyslexia and neglect for objects and pictures arise from the same underlying cause. One problem for this argument is that neglect dyslexia can dissociate from other forms of neglect, in both directions. Patients have been described with severe unilateral neglect whose reading was largely intact (e.g., Kartsounis and Warrington, 1989), while other patients have demonstrated neglect dyslexia without unilateral spatial neglect (e.g., Costello and Warrington, 1987). There have even been cases of dissociations within a patient: Cubelli et al. (1991) described an individual who showed neglect dyslexia for the left sides of words, but unilateral neglect of right space. Hillis and Caramazza (1995) argue that these dissociations may reflect the contributions of multiple lesions (producing independent deficits), or they may be due to the fact that the degree of specificity and difficulty may differ across stimulus materials, causing the appearance of an impairment for only one type of material. In contrast to this position, Haywood and Coltheart (2000) argue that neglect dyslexia should be viewed as applying only to alphanumeric stimuli. Thus, cases in which neglect dyslexia clearly dissociates from generalized unilateral neglect seem to merit careful investigation.

We have previously described a patient, D.E.S., who showed symptoms of right neglect dyslexia following a left posterior artery cerebrovascular

accident (Greenwald and Berndt, 1999). Although right-handed, D.E.S. was similar to N.G. in that her auditory-verbal language was largely intact following the stroke. However, D.E.S.'s reading and spelling abilities were more severely impaired than were N.G.'s. D.E.S. showed frequency and imageability effects in her oral reading, but made very few (< 10%) semantic errors. There was no overall effect of word length. D.E.S. showed the characteristics of very severe "phonological dyslexia", although she demonstrated two unusual performance characteristics. First, she was *completely* unable to read pseudowords, and she did not produce the lexicalizations of pseudoword targets that are frequently seen in phonological dyslexia. Rather, she could not be induced to hazard a guess at pronunciation for pseudowords. Second, she failed to produce any verbal response to a large majority of presented words (> 50%), indicating only that she had no idea what the word was.

The majority of D.E.S.'s *spoken* errors while reading isolated words were visual/orthographic in nature (i.e., errors that shared at least half of the target's letters), and they overlapped targets in early letter positions (on the left). This positional pattern was maintained through rotation of the stimuli to vertical position, and also appeared in D.E.S.'s pronunciation of orally spelled words and in her oral spelling.

Despite the many similarities between D.E.S. and N.G., there are some important differences that argue against a spatial deficit as the cause of D.E.S.'s dyslexia. She did not show signs of clinical hemispatial neglect for non-language stimuli, and there was no discernible "neglect point" in her reading errors. In addition, she did not neglect words falling to the right sides of written sentences, nor did she neglect the right halves of isolated words in spoken word-written word matching tasks. Thus, she could consistently point to the correct written word in response to a spoken word such as "lamb", even if the written distractor were 'lamp'. However, she had great difficulty in matching a spoken word to a written word when the written distractor was a word with the same letters as the target in different order (e.g., 'stops'/spots or 'ladle'/lead). Because of these and other differences, we argued that the impairment giving rise to D.E.S.'s reading errors was not inattention to a word-centered *spatial* representation, but involved a language-specific deficit in the *ordinal* coding of letters (Greenwald and Berndt, 1999).

Because of the theoretical importance of the claim that D.E.S.'s neglect-type reading errors reflect impairments specific to reading, rather than to more general problems within the attentional system, we have continued to consider the possibility of nonlinguistic sources of her reading pattern. The clinical tests for neglect are coarse, and may not detect subtle deficits to contralesional

space. Here we report results from timed visual search tasks to provide more rigorous evidence concerning D.E.S.'s attentional system.

Another possibility to be explored is that D.E.S. has difficulty generating visual images for words. Coslett (1997) showed that neglect for visual images can occur independently of clinical hemispatial neglect. Although it is clear that D.E.S. is highly successful in attending to the right sides of written words in the spoken word-written word matching task, we have gone on to examine whether or not she shows any evidence of "neglecting" the right parts of visual word images. The follow-up study reported here was undertaken to examine her visual attention in more detail and to consider how a possible impairment to visual word imagery could relate to D.E.S.'s pattern of impairment to an ordinal graphemic code.

### CASE REPORT

D.E.S. is a 50-year-old (at the time of this testing) right-handed woman who suffered a left hemisphere posterior cerebral artery infarction in 1993 during heart surgery. Acute neurological evaluation revealed a right homonymous hemianopia as well as weakness in right upper and lower extremities. At the time of the current testing, D.E.S. continued to demonstrate these sensory and motor problems, and also showed the fluent speech, good auditory comprehension, intact repetition, mild anomia, and severe alexia and agraphia reported in previous testing (Greenwald and Berndt, 1999). A computed tomographic (CT) scan five months post-onset revealed a lesion involving the occipital gyrus and occipital pole, the lingual gyrus, and the posterior and medial temporal occipital gyri. Thalamic involvement was suggested by the right hemiparesis, but was not visualized on the scan.

D.E.S. is a native speaker of American English with 12 years of formal education. Prior to her stroke, she was a homemaker with a few years of semiskilled factory work. D.E.S. reported no signs of developmental dyslexia and described her premorbid reading and spelling abilities as average. She compensates well for the hemianopia and right weakness, and continues to function independently.

### Language Retesting

In order to determine that D.E.S.'s reading pattern had not changed substantially during the hiatus between the previous and current testings, we re-administered a subset of the words and pseudowords that D.E.S. had previously attempted to read. In order to sample widely among the large number of stimuli employed in the initial testing, words were selected to include those she had previously had difficulty reading, along with those

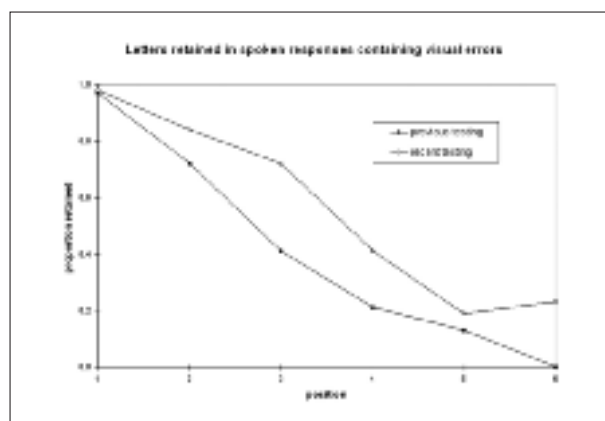


Fig. 1 – Proportion of letters retained in visual errors at each serial position in previous testing ( $n = 35$ ) and in recent testing ( $n = 30$ ).

she had read more easily. A total of 186 words were selected from the original list to include frequency-matched nouns high and low in imageability ( $n = 40$  each), grammatical function words ( $n = 50$ ), and a set of frequency and imageability-matched short and long words ( $n = 28$  each). She also attempted to read a set of 25 CVC pseudowords.

Performance on this subset of items was very similar to her previous performance. She continued to be completely unable to read pseudowords or nouns low in imageability. Although word reading accuracy was somewhat better in recent (.31) than in previous (.26) testing, her error patterns remained unchanged. She produced many "no response" errors in the previous testing (.54 of all responses, .74 of errors) and more recently (.44 of all responses, .64 of errors). As in the earlier testing, her most frequent type of *spoken* error (.65) was visual/orthographic, sharing 50% of target letters in the same relative order. The remaining portion (.35) of spoken errors included 8 orthographically related responses that did not meet the criteria for visual errors (e.g., pupil → pool), two unrelated words, and three morphological, one semantic, one visual-then-semantic and one phonological error.

Most importantly for present purposes, the visual/orthographic errors produced in the recent testing still showed a clear "right neglect" positional effect favoring retention of left-most letters (as shown in Figure 1). For the same items in the previous testing, there was a similar proportion of visual errors out of all spoken errors (.60), showing the same positional effect. This finding will be followed up in more detail below.

### Clinical Tests for Neglect

D.E.S. had performed normally on letter cancellation, line bisection, and blindfolded search tasks in previous testing. To provide a more comprehensive clinical assessment for hemispatial

neglect, we administered three additional clinical tests. D.E.S. performed normally on the Bells Test (Gauthier et al., 1989), a visual search task that requires detection of targets in a cluttered array. She also performed normally in the Part/Whole Drawing task described by Marshall and Halligan (1993), reproducing all segments of both drawings without error. She also performed well on a "space bisection" version of the line bisection task, where she was required to bisect the empty space between two lines. Over five trials, her bisections were shifted very slightly (3.8%) toward the right side, i.e., in the direction opposite to what would be expected if she were neglecting right space. Thus, we were again unable to detect any problem with allocation of attention into right space using clinical tests administered in free vision.

#### TIMED VISUAL SEARCH TASKS

A failure to find evidence of neglect on clinical tests such as those described above may reflect insensitivity of such tests to subtle attentional deficits. Several studies have found evidence of attentional impairments in patients using more sensitive measures even when clinical tests have failed to indicate neglect (Coslett, 1997; Posner et al., 1984). We administered a sensitive attentional test that has previously uncovered evidence of neglect in patients with right hemisphere lesions who performed well on line bisection and other clinical tests (Coslett et al., 1995; Stark et al., 1996). The task is a modification of an experiment developed by Treisman and Souther (1985, Experiment 1) to explore the factors influencing attentional allocation in visual search tasks. The experiment was divided into a preattentive, "feature present" condition, where the target possessed a feature that the distractors did not, and an attentional, "feature absent" condition, where the target lacked a feature that the distractors possessed. In their experiment, Treisman and Souther (1985) used a circle as the main stimulus and a line as the feature, making stimuli that looked like Os (feature absent) and Qs (feature present). The reaction time to detect the target in each array of distractors was measured for each subject. Their findings indicated an asymmetry between the two conditions. The detection time for the "feature present" condition was independent of the size of the array, while reaction times were longer in the "feature absent" condition for larger arrays. It was argued that the "feature present" condition required only preattentive (parallel search) processes, while the "feature absent" condition required attentive (serial search) processes.

If D.E.S. has difficulty attending to right space, her ability to detect targets on the right side of the array should be diminished compared to her ability

to detect targets on the left, especially in the attention-demanding "feature absent" conditions. To investigate whether the source of any right-sided effects reflected problems in right space or problems on the right side of the stimulus, the visual search task was administered twice: first using the standard administration in which the array appears symmetrically around a central fixation point, and second with the entire array appearing to the left of fixation. If D.E.S. has difficulty deploying attention to the right sides of stimuli (a 'stimulus-centered' attentional impairment), she should have difficulty with the right sides of the arrays regardless of where they fall in space.

#### Materials

The stimuli consisted of image arrays that were created in Mac Draw Pro and sized using Adobe Photoshop. The arrays consisted of circles with or without vertical lines intersecting at the 6 o'clock position. Figures with the line are referred to as "feature present" (Qs) and figures without the line are "feature absent" (Os). Two array sizes were used, with either nine ( $3 \times 3$ ) or 15 ( $5 \times 3$ ) cells. The size 9 arrays (3.8 cm  $\times$  3.8 cm) were designed such that they would contain six figures and three empty spaces, all in randomly determined positions. The size 15 arrays (5.0 cm  $\times$  3.8 cm) were designed in a similar fashion such that there were 12 figures and 3 spaces. For each array size, there were four array types: a feature-present-target was present (a target Q in a field of Os), a feature-present-target was absent (all Os with no target Q), a feature-absent-target was present (a target O in a field of Qs) and a feature-absent-target was absent (all Qs with no target O). The possible target positions were predetermined to lie either along a vertical edge of the array or in the center. For each of these possible target positions, three template arrays were made using randomly generated positions to determine which positions would have figures and which positions would be empty. This yielded 21 total template arrays. Each of these templates was then used in each of the four conditions. Thus, each target position was sampled three times in each condition.

#### Procedures

The experiment was run in Psyscope on a Macintosh PowerBook G3. D.E.S. received one condition, with all four types of arrays, including an instructional block, a practice block of 24 trials and two experimental blocks of 42 trials each. The instruction block had four horizontal strings of Os and Qs, one for each of the array types. The patient was instructed to study the strings and observe the difference between a string with a target and a string without a target. The practice block consisted



of a subset of experimental trials presented in a randomized order. The experiment consisted of all 21 template arrays in each of the four array types, yielding 84 trials which were split into two administration blocks of 42 trials each. The layout of the trials consisted of a prompt to start the trial, a centrally located fixation cross with a duration of 2000 msec, and the presentation of the array, during which D.E.S. was required to continue fixating on the central point. In both the practice block and the experimental blocks, the patient was to respond by pressing a button only to those arrays that contained a target. If a response was not made, the array disappeared after 4000 msec.

The experiment was conducted first with the arrays presented symmetrically around the central fixation. The two central administration blocks were interspersed with other, unrelated testing and presented in separate sessions. Approximately four weeks after conclusion of the central administration testing, the experiment was repeated with the arrays falling to the left of center. The experimental conditions were the same with the exception that in the left-administration condition the array was presented to the left of the fixation point with the right edge of the array located in the center of the screen. Again, two blocks of the experiment were interspersed with other tasks and presented in separate sessions. In both administration conditions, D.E.S. was required to maintain central fixation. A second examiner seated across from the subject monitored eye movement. Trials containing gross eye movements were eliminated from the analysis.

### Results

Control data for this task are taken from Stark et al. (1996), who tested 14 normal adults aged 60 to 69. Consistent with the results of Treisman and Souther (1985), these results indicate a significant effect of array size only in the attentive (target absent) condition and no effect of side (right, left) of target.

#### Central Administration

Overall accuracy on the task was very high. D.E.S. produced no false positives, but did miss on four trials, all in the attentive (feature-absent target) condition. Three of the missed targets were on the left, and one was on the right. In order to keep the number of data points in each condition equal, we removed four data points for targets that were in mirror image positions of the four missed targets. Mean reaction times across the accurate conditions are shown in Figure 2.

Separate repeated measures ANOVAs were performed on the correct reaction time data for each condition (attentive, preattentive) with target side and array size as independent variables.

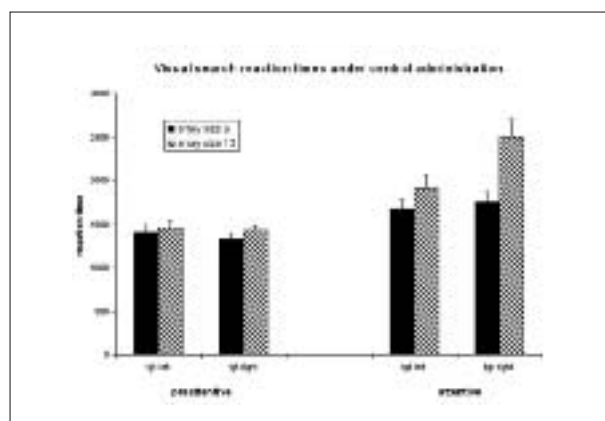


Fig. 2 – Mean response times for preattentive (feature-present target) and attentive (feature-absent target) conditions for D.E.S. in visual search task, central administration condition.

Although her latencies were greater than those of the controls, D.E.S. performed similarly to normal subjects with respect to the existence of the asymmetry between the attentive and preattentive conditions. There was a significant effect of array size in the attentive condition [ $F(15) = 9.024$ ,  $p = .009$ ], but not in the preattentive condition [ $F(17) = 0.392$ ,  $p = .540$ ]. Control subjects show no asymmetry with respect to target side. For D.E.S., however, there was a marginally significant effect of target side in the attentive condition [ $F(15) = 3.554$ ,  $p = .079$ ], with targets on the left (mean = 1850 msec) being detected more quickly than those on the right (mean = 2156 msec), and there was a significant interaction of array size  $\times$  target side [ $F(15) = 5.58$ ,  $p = .032$ ]. She showed no significant effect of target side in the preattentive condition [ $F(17) = 1.457$ ,  $p = .244$ ] and no interaction. These results indicate that D.E.S. does not exhibit any sign of a preattentive deficit, but that there may be some attentional disturbance resulting in a disadvantage to her right side in the larger array. However, if such a deficit does exist, it affects only response latency; there were no effects on accuracy as a function of side of the targets, even though D.E.S. was maintaining central fixation.

#### Left Field Administration

Again, D.E.S. produced no false positives. In this format, there was one missed trial (on the left) and one trial with gross eye movement (on the right). Again, the number of data points was kept constant for each condition by removing trials with mirror image target positions to the two omitted trials.

A repeated measures ANOVA was performed on the data from this presentation in the same manner as for central administration. Figure 3 shows the mean reaction times for each variable in each condition of the left visual presentation format. There was a significant effect of array size in the attentive condition [ $F(16) = 7.164$ ,  $p = .017$ ] as

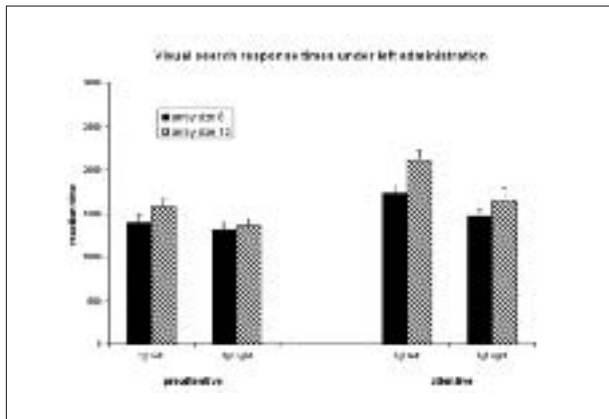


Fig. 3 – Mean response times for preattentive (feature-present target) and attentive (feature-absent target) conditions for D.E.S. in visual search task, left field administration condition.

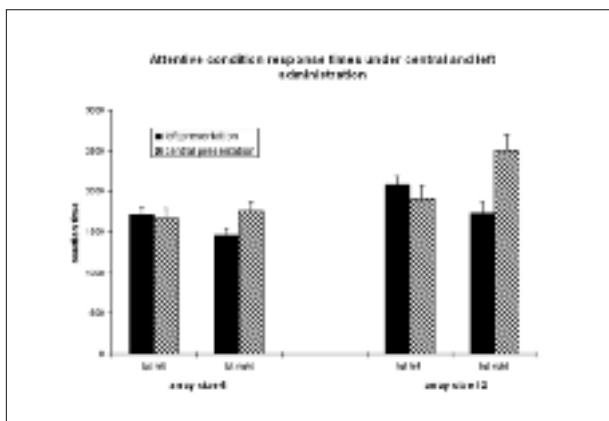


Fig. 4 – Mean response times for each array size, central vs. left field condition, for D.E.S. in the attentive conditions of the visual search task.

well as in the preattentive condition [ $F(16) = 6.604, p = .021$ ]. There was no effect of target side in the attentive condition [ $F(16) = 2.94, p = .106$ ], and no interaction of target side with array size.

To determine if the differences in performance between the two presentation formats in the attentive condition were significant, we performed a repeated measures ANOVA for each size array with the data from the two presentation formats pooled together, using target side and presentation format as the independent variables. Figure 4 shows the mean reaction times for each variable for each array size in the attentive condition. This analysis yielded no significant effects for the size six array. For the size twelve array, there were no main effects of presentation format [ $F(15) = 2.132, p = .165$ ] or of target side [ $F(15) = 1.142, p = .302$ ], but there was an interaction [ $F(15) = 8.224, p = .012$ ]. As shown in the figure, this interaction reflects the fact that in central administration response times were faster on the left (mean = 1924 msec) than on the right (mean = 2555 msec), while for the left-field presentation condition times were faster on the right (mean = 1845 msec) than on the left (mean = 2095 msec). We attribute the somewhat slowed reaction times to

the left in the left presentation condition to the increased distance of left targets from fixation in the left-field presentation condition.

### Summary and Discussion

D.E.S.'s overall accuracy in both presentation conditions was very high, indicating that she could identify targets on both sides of the array with about equal proficiency. Response latencies in the central administration condition also mirror the normal results in terms of distinguishing preattentive from attentive processes, i.e., she shows no effect of array size when detecting the "pop out" feature-present target, but does show an array size effect on the feature-absent target trials that require serial deployment of attention. Unlike normal subjects responding to central administration of the array, however, D.E.S. showed somewhat longer latencies to detect targets in the attentive conditions when they appeared on the right side of fixation in the large array. Although this finding might be taken as evidence for an attentional impairment to right space, it seems unlikely that this latency difference could be responsible for her right "neglect dyslexia". That is, she was equally successful identifying even the difficult feature-absent targets on both sides of the array during the same period that she produced many reading responses with errors limited to the right sides of words. These findings raised the question of whether presentation of word stimuli to the left of fixation would attenuate the positional errors in words, similar to its effects on the reaction time disadvantage on the right in the visual search task.

### LEFT VISUAL FIELD PRESENTATION OF ORAL READING

To address this possibility, we re-tested D.E.S.'s oral reading using a computerized presentation format in which the words fell to the left of midline.

### Materials and Procedures

The 186 word stimuli described in the Language Retesting section above were readministered on the computer using Psyscope. The stimuli were presented to the left of fixation such that the right edge of each word was located at the center of the screen. Again, D.E.S. was required to fixate centrally throughout the entire trial, and eye movements were monitored.

### Results

A Chi-Square analysis on proportion correct in the two presentation conditions revealed that D.E.S.'s performance with left visual field

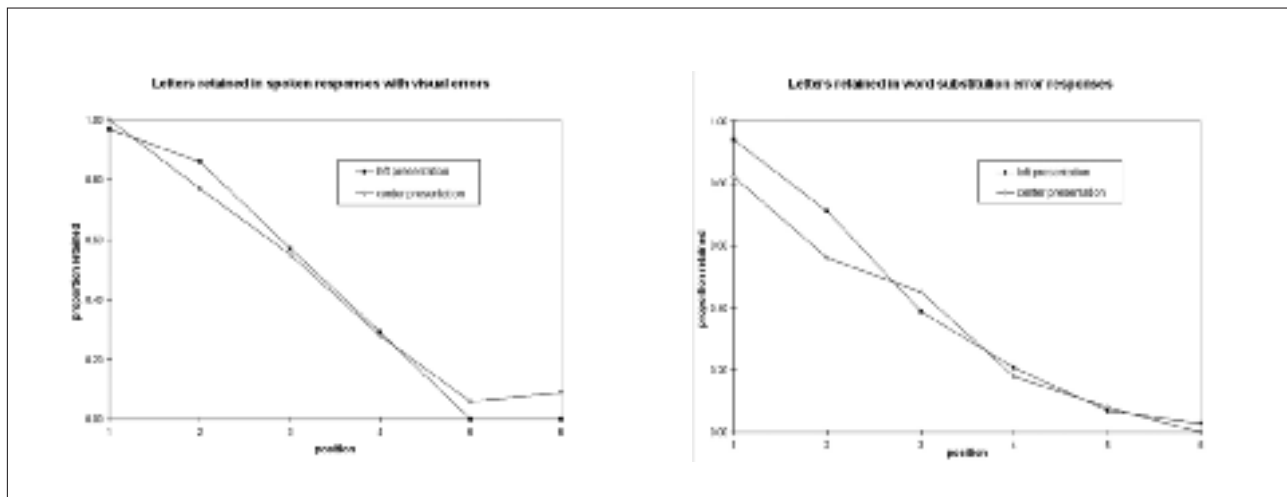


Fig. 5 – Proportion of letters of target word retained in visual errors (left panel) at each letter position for left presentation ( $n = 38$ ) and central presentation ( $n = 30$ ) and for all word substitution error responses (right panel) for left presentation ( $n = 62$ ) and central presentation ( $n = 45$ ).

presentation did not differ significantly from that for the central presentation [.39 and .31 correct, respectively;  $X^2(1) = 2.31$ ,  $p = .13$ ]. In left compared to central administrations, D.E.S. made slightly more visual errors, though this difference was not significant [.35 of total errors with left and .23 with central administration;  $X^2(1) = 3.08$ ,  $p = .08$ ]. This is likely due to the fact that D.E.S. made significantly fewer “no response” errors in left compared to central conditions [ $X^2(1) = 15.6$ ,  $p = .0001$ ]. A comparison carried out on spoken errors revealed that the proportion of visual errors *out of spoken errors* was almost identical for the two presentations [.28 and .24 respectively;  $X^2(1) = .151$ ,  $p = .64$ ]. Moreover, her pattern of “neglect” errors was unaffected by the shift to left presentation. Positional analysis revealed that D.E.S. exhibited a positional gradient with left field presentation that was very similar to that found in the central presentation format. Figure 5 shows that this correspondence of positional effects across the two presentation conditions was not only clear in her visual errors (in which targets share at least half their letters), but also was apparent in all spoken error responses (which included perseverations and unrelated word responses).

### Summary and Discussion

The results presented above indicate that D.E.S. does not demonstrate the patterns associated with retinocentric or stimulus-centered inattention to spatial representations when reading. By default (in the Hillis and Caramazza, 1995, model), this suggests a disruption at the “word-centered” (or ‘object-centered’) representation, which is argued to be a more abstract word or object representation that is independent both of position in space and orientation of the visual stimulus. However, this abstract representation is argued to be spatially coded, such that the “neglect” is to the right (or

left) sides of a canonical representation of the word. We have previously argued against this interpretation for D.E.S. on the basis of her excellent performance of spoken word/written word matching tasks with distractors that differ on the right sides of words (e.g., lamb/lamp). However, it is possible that this level of performance was accomplished with the help of top/down information provided by these tasks, including semantic and syntactic cues. We devised tasks in which the patient’s response required consideration of the *form* rather than the meaning of the letters constituting spoken words, i.e., which required the generation of a visual image of letters and words for a correct response, to address this concern. The assumption is that the generation of a visual image from spoken stimuli generates a spatial word representation, unlike the ordinal code generated when trying to read written words.

### IMAGERY TESTING

It has been demonstrated that a double dissociation exists between visual perception and visual imagery (Coslett, 1997). In his study, Coslett (1997) described a patient who showed no signs of clinical neglect, yet demonstrated neglect when reporting an imagined scene. According to Bisiach and colleagues (Bisiach and Luzzatti, 1978; Bisiach et al., 1979), this phenomenon may be attributed to a deficit in generating or maintaining a spatially-encoded representation of one side of an image. If D.E.S. had this type of deficit, it could affect her reading. We therefore wanted to test her ability to generate images for objects and words and to determine if she demonstrates any disadvantage making judgments about what is on the right side of the image she had generated. We administered three imagery tasks: a clock setting task, a letter imagery task and a word imagery task.

### *Clock Setting Task*

We devised an imagery task in which D.E.S. was required to generate a mental representation of a clock set to a given time and to draw that image. Given that D.E.S. had shown no perceptual-motor impairment, any deficit in her ability to do this task would point to an image generation impairment.

### *Materials and Procedures*

Clock times were selected such that there were symmetrical pairs with respect to the hour hand, while keeping the minute hand constant. D.E.S. was given four practice trials and 12 experimental trials. She was presented with one sheet of paper at a time, each with a time typed at the top in digital format, e.g. 12:15. Underneath the digital representation, D.E.S. was to draw clock hands which represented that given time. She was to do this without the outline of the clock or the numbers on the face of the clock. The practice stimuli consisted of a pair of even hour times and a pair of half past times. The experimental stimuli consisted of three groups of four: even hour times, "half past" times, and "quarter past" or "quarter of" times.

### *Results*

D.E.S. showed some minute hand/hour hand confusion, but only in the sense that one hand was not always the right length with respect to the other hand, or both hands were of equal length. However, she was able to articulate correctly, when questioned, which hand was the hour hand and which was the minute hand. All of her hand positions fell on or within one position of the target position, assuming no movement of the hour hand as the minute hand progresses. Overall, her performance on the clock hand drawings suggests that D.E.S. does generate adequate mental images and does not neglect the right side of them.

### *Letter Imagery Task*

To test the hypothesis that D.E.S. was not able to form an accurate mental representation of letters and words, or that she was neglecting parts of a generated image, we devised another imagery task in which she was required to generate images of lower case letters in isolation.

### *Materials and Procedures*

All of the lower case letters in the alphabet were separated according to whether or not they were "extenders", i.e., a letter with some part extending above or below the body of the letter. Examples of extenders are b, d, k, g, j, etc. D.E.S. was presented with the entire lower case alphabet within a set of lines to assure that she understood

the concept of an extender. She was then presented with a baseline condition in which individual letters were presented without the lines, and she was asked to say "yes" if the letter was an extender and "no" if it was not. D.E.S. was then presented with an imagery condition in which she heard a spoken letter name and again was asked to say "yes" if the letter was an extender and "no" if it was not. She was then presented with a production condition in which she was presented with a letter name orally and was required to write the letter in lower case.

### *Results*

D.E.S. showed an adequate understanding of the concept of an extender when presented with the entire alphabet within a set of lines. She then correctly identified 15/16 extenders in the baseline condition, mistaking an "l" for an "i" and erroneously labeling it as a non-extending letter. She next accurately labeled 16/20 letters in the imagery condition. All of her errors were failing to say "yes" to an extending letter. Finally, of the same 20 letters used in the imagery condition, she correctly produced 18 of them in lower case. The two errors were letters that were also mislabeled in the imagery condition. This performance suggests that D.E.S. is able to generate an image of isolated letters with a fair amount of accuracy.

### *Word Imagery Task*

Since D.E.S. showed a reasonable level of ability to "picture" the form of letters and make judgments about them, we tested whether or not that ability was affected by the side of the words on which the extender letters appeared. We selected words that contained extending letters on either their right or left sides. Example words with extenders include "bar" and "hammer" (left) as well as "cry" and "around" (right). If D.E.S. is inattentive to the right sides of a spatially arrayed image of letters comprising words, she should make more errors on the extender judgments when those letters fall at the ends of words.

### *Materials and Procedures*

We eliminated the letters for which D.E.S. did not generate an accurate image based on the previous testing, and presented her with the same baseline, imagery and production conditions for words. In the baseline condition, D.E.S. was presented with words on the computer screen and was asked if they contained an extender. In the imagery condition, she was presented with words orally ( $n = 24$ ) and was asked if they contained an extender. Words for this condition were selected from the set of words D.E.S. was able to read accurately. The set was balanced for length (3, 4, 5



or 6 letters) and presence of an extender. There were eight words with an extender on the left, eight with an extender on the right, and eight with no extending letter. As writing is difficult for D.E.S., she was asked to orally spell the words for the production task.

### Results

In the baseline condition, D.E.S. was able to label correctly every word as having an extender or not. In the imagery condition, she correctly labeled 16/24 words as to the presence of an extender. She missed four extenders and erroneously said yes to four words that did not contain an extender. Of the extenders she missed, three words had extending letters on the left side. In the production condition, D.E.S. was able to spell correctly only 7/24 words, all of which were three letter words. Of these seven words, D.E.S. had correctly labeled six of them in the imagery condition. This finding suggests that for some words, D.E.S. was able to generate a correct image and to use that to spell. However, for those words she was unable to spell, we were concerned that she may have been guessing in the imagery condition rather than generating an image. Therefore, D.E.S. was tested in the imagery condition two more times during separate sessions to assess item consistency. On the second and third presentation of the stimuli, D.E.S. labeled correctly 16/24 and 15/24 words, respectively. Of these 24 words, two thirds were consistently labeled, regardless of their accuracy, in all three presentations. Her accuracy of 49/72 over all three presentations was significantly different from chance at the  $p < .01$  level (Binomial Test).

These results suggest that for most of the words, D.E.S. does generate some kind of mental image, though not always correctly, from which she is making her judgments. Thus, evaluation of her responses should reveal any neglect of these generated images. Over all three presentations of the imagery condition, D.E.S. missed 15 of the 48 words with extender letters, only five of which were on the right side of the word. Of her consistently correct responses, five had extenders on the right, while only two had extenders of the left. These findings suggest that though D.E.S. has some difficulty generating correct word images, there is no evidence that she is neglecting the right side of the spatially-encoded image. It should be noted that D.E.S.'s ability to translate between letters and sounds sublexically was virtually abolished; thus, her performance in these tasks was very likely based on generation of a whole word image. On the assumption that the generation of a visual image from a spoken word involves spatial encoding of a "word-centered" representation, these results support our contention that D.E.S.'s oral reading difficulties, which were not mirrored in the imagery task, arise from some other source.

### GENERAL DISCUSSION

The purpose of our investigation was to carry out additional testing on the performance of a patient with severe phonological dyslexia, who makes frequent neglect-like errors on the ends of words when reading aloud. Following up on a previously published study (Greenwald and Berndt, 1999), we demonstrated first that D.E.S.'s basic patterns of performance had not changed since the prior testing. Her overall accuracy was consistent with her previous performance, as were the types of errors she produced. Most importantly, there was no change in her tendency to produce orthographically related responses in which an incorrect word is produced that overlaps the target in early (left-most) letter positions.

We showed that D.E.S. continues to perform well on a variety of clinical tests for hemispatial neglect, and we assessed her performance using a more sensitive attentional test. D.E.S. showed the normal distinction between attentive and preattentive processing in this task, and accurately identified both left- and right-sided targets in both the preattentive and attentive tasks. However, she was somewhat slower to detect right compared to left-sided targets in the attentive, large array condition, even though she made virtually no errors. To investigate the nature of the latency difference, we altered the format of presentation so that the entire display fell left of midline. In this format, she showed no disadvantage on the right side of the array.

In light of this attenuation of a possible attentional disadvantage to the right when the stimulus was moved to the left, we compared oral reading of the same words in central and left field presentation. Moving the word stimuli to the left of midline had absolutely no effect on performance; positional scoring of her errors resulted in data that were virtually identical in left and central presentation conditions. Taken together, these results indicate that the positional errors in D.E.S.'s reading performance are not a manifestation of either neglect of right space or poor sensory processing secondary to her right visual field impairment. Based on her improved performance on visual search when the arrays were moved into her left visual field, it also appeared that her impairment was not "stimulus-centered".

However, it has been suggested that neglect of an internally generated "word-centered" spatial representation – a kind of mental image – could underlie neglect dyslexia (Hillis and Caramazza, 1990). Thus, we investigated D.E.S.'s ability to generate and attend to internal (spatial) object-centered representations of verbal and non-verbal stimuli. D.E.S. was able to give consistent responses to two thirds of the word stimuli. This suggests that she was not guessing and that she was frequently able to generate an image from

which she could make her judgments. Though her responses were not always correct, she showed no tendency to be more accurate for words probing the left versus those probing the right sides of words.

Taken together, these results support the argument that at least some cases of right neglect dyslexia have a different underlying cause from left neglect dyslexia, which may be related to the typical spatial neglect often found in patients with right hemisphere damage. As Ellis et al. (1993) point out, the errors made by patients with right neglect dyslexia are not simply the mirror image of those made by patients with left neglect dyslexia. Because of qualitative differences in the symptoms of right neglect dyslexic patients, and their frequent failure to show general spatial neglect, Ellis et al. (1993) termed this type of dyslexia "positional dyslexia".

Greenwald and Berndt (1999) suggested that the oral reading impairment in such patients is related to disruption of an ordinal code that is generated during an early stage of visual word recognition. This code is hypothesized to be abstract enough to support both reading (which typically relies on visual-spatial input) and spelling (which requires serial processing). Importantly, this abstract ordinal code allows translation between visual-spatial codes and temporal-phonological codes for oral reading. Based on a wide range of results involving D.E.S.'s spelling and the pronunciation of orally spelled words, as well as reading, it was hypothesized that this more abstract "ordinal" code is associated with letter position in the retrieval of orthographic representations. An impairment in the generation of this ordinal graphemic code from print was argued to be the source of left-position errors for D.E.S. and some similar patients with right "neglect dyslexia".

In fact, some impairment to this code may occur frequently when patients have left hemisphere lesions. We have recently analyzed the visual errors of seven patients with left hemisphere lesions and aphasia who showed a left-to-right positional gradient of target/response letter retention, similar to that demonstrated by D.E.S. and other reported patients with right neglect dyslexia (Berndt et al., 2005). These patients would not typically be referred to as neglect dyslexics, since they produced non-trivial numbers of other types of errors (e.g., semantic) when reading. The one symptom common to all of them, aside from right-neglect-like errors in word reading, was severe difficulty with sublexical print-to-sound translation (i.e., reading pseudowords).

Our account of this pattern, which may occur in a wide range of patients with left hemisphere damage, is that the ordinal graphemic code normally represents letters ordered in a graded fashion, with strongest activation for early letter positions. We have developed a computational

model to test the feasibility of this idea, in which lexical activation from print is expressed as a gradient across letter nodes, with highest activation of the first letter and gradual fall-off across later positions (Whitney and Berndt, 1999). This model has allowed us to hazard an explanation for some conflicting word naming results from the normal literature about the relative activation of letters in different positions. Although there is considerable evidence that initial letter positions enjoy enhanced processing by normal subjects performing speeded tasks, there is conflicting evidence about the status of final position letters. Some studies report an enhancement *only* for initial positions (e.g., Grainger and Jacobs, 1991; Hellige et al., 1995; Montant et al., 1998), while other studies have also shown increased activation for final positions compared to internal letters (Hammond and Green, 1982; Perea, 1998). In our model, activation falls off across letter nodes from first to last, but final position letters show an increase in activation relative to internal letters because they are not subject to lateral inhibition coming from letters to the right. The studies cited above with conflicting findings on final letter positions differ in terms of the duration of stimulus input, with shortest input durations associated with no enhancement for final positions. Activation of final positions in our model is diminished in conditions of degraded stimulus input (short input durations), or reduced input letter activation (possible in dyslexic patients). Thus, our simulations of right neglect dyslexia using the model showed enhanced processing only for initial letter positions.

One other factor that may influence patient performance is difficulty with sublexical print-to-sound translation. All seven patients showing right neglect dyslexia in our recent study were very poor at reading pseudowords, and D.E.S. could read aloud no pseudowords. Peressotti and Grainger (1995) have suggested that the serial generation of sublexical phonological information early in normal written word recognition could play an important role in establishing positional encoding in letter strings. On the assumption that any sublexical contribution to our patients' reading would be abnormal, we "lesioned" the computational model by adding noise to the word nodes, representing aberrant input from impaired sublexical translation.

Damage to the ordinal graphemic code may generally result in oral reading patterns with relative sparing of letters in positions that are the most highly activated in the normal case, i.e., early letter positions. Without normal sublexical support, those positions without high pre-existing levels of activation (middle and end positions) may not reach activation levels that can support correct lexical access. Our explanation of D.E.S.'s "neglect" errors in reading thus has little to do with neglect in the classic sense but with impairments to

components that are necessary for normal oral reading.

**Acknowledgements.** This study was supported by a research grant from the National Institute on Deafness and Other Communication Disorders (R01-DC00699). The authors are grateful to Anne N. Haendiges and Charlotte C. Mitchum for assistance in the conduct of this study and preparation of the manuscript. They also thank D.E.S. for her continued good humor throughout the testing.

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(Received 7 September 2004; reviewed 10 February 2005; revised 11 October 2005; accepted 10 November 2005; Action Editor Roberto Cubelli)