Brain (1990), **113**, 1163–1183

PERCEPTUAL AND CONCEPTUAL MECHANISMS IN NEGLECT DYSLEXIA

TWO CONTRASTING CASE STUDIES

by M. BEHRMANN,[1,2] M. MOSCOVITCH,[1,3] S. E. BLACK[2] *and* M. MOZER[4]

(*From the* [1]*Department of Psychology, Erindale College, and* [2]*Sunnybrook Medical Centre, University of Toronto, and* [3]*Rotman Research Institute, Baycrest Centre for Geriatric Care, Toronto, Canada, and the* [4]*Institute of Cognitive Science, University of Boulder, Colorado, USA*)

SUMMARY

The contribution of peripheral, data-driven effects is contrasted with conceptual, 'top-down' effects to the reading performance of 2 subjects with neglect dyslexia following a single right hemisphere lesion. Several tasks were administered, manipulating the physical, lexical or morphemic properties of the stimuli in an attempt to establish whether the attentional deficit disrupts reading at an early or late stage of processing. Both subjects were impaired at detecting elementary stimulus features on the left side of the display but were even more impaired at identifying conjoined features. One subject's performance was influenced by structural manipulations which altered the low-level representation of the stimulus. The other was less affected by structural changes of the stimuli but was influenced by the lexical and morphemic status of the words. This apparent double dissociation is interpreted as arising from a graded attentional deficit at a single locus, early in the reading process where low-level information is detected. When the deficit is not severe sufficient information may be picked up and may interact with higher order lexical knowledge to offset partially the peripheral malfunction. For a severe attentional deficit, top-down knowledge is not engaged as insufficient information is processed on the left-hand side. This hybrid view of attention provides insight into the mechanisms underlying neglect dyslexia and bears on the role of attention in normal visual processing.

INTRODUCTION

Visual neglect following lesions of the right hemisphere in previously literate adults can result in reading impairments independent of aphasia. These impairments may manifest themselves in different reading tasks: the left side of an open book may be ignored, the beginning of lines may be omitted during text reading and/or the beginning letters of single words may be omitted (Friedland and Weinstein, 1977; Caplan, 1987). These deficits, which have come to be subsumed under the heading 'neglect dyslexia', were mentioned in several early papers (Gilliatt and Pratt, 1952; Kinsbourne and Warrington, 1962; Leicester *et al.*, 1969) but have received little in-depth discussion until recently. Evidence from the few detailed studies available remains contradictory with regard to the mechanisms underlying neglect dyslexia. While most people accept

Correspondence to: M. Behrmann, Department of Psychology, Erindale College, University of Toronto, Mississauga, Ontario L5L 1C6, Canada.

that an attentional deficit underlies the disorder, the nature of this impairment remains unclear. Heilman *et al.* (1985, 1987), for example, have argued that the brain lesion results in reduced arousal of one hemisphere. Sensory information which appears on the contralesional side is not adequately processed, giving rise to neglect. An alternative explanation put forward by Kinsbourne (1987) is that the attentional balance between the hemispheres is disrupted following a lesion. This produces a failure to attend to contralateral information, coupled with an exaggerated focus to the ipsilesional side. The outcome of this deficit is that a gradient of attention exists both within and across the visual fields. Consequently, for patients with right hemisphere lesions in whom the gradient provides more optimal attention on the side of the lesion, stimuli appearing on the right have a processing advantage, leading to left-sided neglect.

In order to understand better the nature of the attentional deficit following brain damage, several studies have set out to define the elementary operations of attention in relation to neural systems and then to relate these operations to processes such as visual pattern recognition (Posner and Presti, 1987; Posner, 1988; Posner and Petersen, 1989). The purpose of the present research was also to examine the role of attention in cognitive processing by investigating acquired neglect dyslexia in adults who were premorbidly literate. More specifically, the aim was to assess at what stage in the reading process the attentional deficit has its impact, namely, whether the disruption arises early or late in cognitive processing. Early disruption suggests that the impairment occurs before stimulus identification, that is, low-level representations are degraded or filtered. In contrast, late disruption implies that the attentional impairment plays a role once the stimulus has been processed to a high level and has been identified as a token of a specific category or type (Pashler and Badgio, 1987).

The issue of level of attentional selection has generated controversy for several decades in the cognitive psychology literature and continues to be of theoretical concern. The earlier literature on this issue reflected two opposing viewpoints, with Broadbent's (1958) early filtering theory at one end and the late selection theory of Deutsch and Deutsch (1963) at the other. Recently, it has been argued that early and late selection loci need not be mutually exclusive and a hybrid view of attentional selection has been proposed (Pashler and Badgio, 1987; Mozer, 1988). Evidence from neuropsychological studies on neglect dyslexia is pertinent to this ongoing controversy and may shed light on the attentional operations in normal visual spatial proccessing.

Proponents of an attentional disruption at peripheral stages of processing have attributed the deficit in neglect dyslexia to the abnormal distribution of visual attention in the early stages of reading. The left side of the stimulus is attenuated and registration of the features is impeded. Kinsbourne and Warrington (1962), for example, described 6 subjects with parietal lobe lesions who neglected the left side of words on bedside and tachistoscopic presentation and concluded that the reading disorder arises from 'a pathological alteration in perceptual processes' (p.344). This peripheral explanation is supported by V.B., a subject with neglect dyslexia (Ellis *et al.*, 1987), who produced a high number of left-sided neglect errors on words and nonwords. Since words and nonwords were equally affected, Ellis *et al.* (1987) concluded that the damage arose peripherally, before lexical status became a relevant factor and words made contact with their existing orthographic representations in the word-form system.

These peripheral explanations have been questioned by studies which have shown that neglect is not simply restricted to reading or to the visual modality but occurs across modalities. Several patients have been described who perform poorly on tasks such as oral spelling and/or writing (Baxter and Warrington, 1983; Barbut and Gazzaniga, 1987; Caramazza and Hillis, 1990). As errors are observed in different modalities, the deficit must arise in a mechanism which is common to all these modalities and which is centrally located at a high level in the processing system.

A further set of findings suggests that peripheral and central factors need not be mutually exclusive but may interact to produce neglect dyslexia. Several researchers have demonstrated that stimuli may be differentially affected depending on their lexical status. For example, some patients missed the first few letters of nonwords but not of words (Sieroff *et al.*, 1988; Brunn and Farah, 1990) or, for Chinese patients, neglected parts of pseudoideograms but not of genuine Chinese characters (Tzeng and Hung, 1989). Various explanations have been offered to account for the differential sensitivity of stimulus types. On one account, stimuli such as words or ideograms which have pre-existing lexical representations do not require the deployment of attention. Instead, they have privileged and direct access to their phonological and semantic codes (LaBerge and Samuels, 1974). Unfamiliar nonwords, on the other hand, rely on a serial attentional scan for readout of information and are, therefore, subject to the attentional disorder. An alternative account is that attention is always deployed, irrespective of stimulus type. When attention is disrupted, features of words and nonwords are not efficiently registered. The superiority of words over nonwords arises through interaction with 'top-down' knowledge. Words are boosted by their pre-existing lexical representations, which feed back down and enhance word perception (as proposed in the Interactive Activation Model of word recognition (McClelland and Rumelhart, 1981)). Because nonwords do not receive the advantage of such top-down support, they are more impaired. This latter interaction theory suggests that we cannot understand the attentional deficit solely in terms of peripheral factors since top-down processing may override a primary attentional disorder. While the primary problem is one of attention, its manifestation may be affected by stimulus variables such as lexical status. In these instances, neglect dyslexia reflects an interaction between a data-driven, bottom-up deficit and top-down, conceptual knowledge.

The peripheral or data-driven theory and the central, conceptual theory have dominated the neglect literature while less emphasis has been given to the interactive view. The study of reading and neglect dyslexia is potentially a valuable technique for understanding the mechanisms underlying neglect and for evaluating possible interactions. Written stimuli can be systematically varied along physical parameters (number, size and spacing of letters) to reflect bottom-up effects and along linguistic dimensions (lexicality and morphology) to demonstrate the operation of higher order top-down influences. Simply stated, if the attentional deficit occurs at an early stage, then performance would be affected by the physical dimensions or low level features of the stimulus. For example, words which have too many letters or are too widely spaced may be impaired relative to shorter words if the attentional 'spotlight' (Eriksen and Yeh, 1985) only illuminates a restricted region of space. If, however, the attentional disruption arises at later stages of processing, then we would predict that higher cognitive variables (such as lexical status or morphological composition) would influence subjects' performance since this information is accessed only at advanced stages of processing. Such predictions allow us to compare the contribution of data-driven bottom-up effects with top-down, conceptual effects and to examine combinations of early and late attentional selection in an interactive framework. In this study, we compared and contrasted the performance of 2 patients with neglect dyslexia on a number of experiments designed to test the above predictions.

CASE HISTORIES

Two subjects, both right-handed and English-speaking, demonstrated hemispatial neglect on bedside testing following a single right hemisphere stroke. Both subjects were mildly dysarthric and showed motor impersistence on lateral gaze and other actions. Neither subject demonstrated aphasia nor diffuse cognitive impairment consistent with dementia.

Case 1

H.R., a 61-yr-old male, was initially admitted to hospital in July 1986 with hemiplegia, left hemisensory loss and a left homonymous hemianopia. Before his stroke, he lived at home with his wife and was reported to be functioning normally. He was employed as a tinner in a steel and electronics plant but had held numerous other jobs in the past. He had completed 10 yrs of schooling. He was studied during a readmission to hospital in October 1987 for reassessment. At this time, he was still wheelchair-bound and exhibited a spastic left hemiplegia, significant left sensory loss and a complete left homonymous hemianopia on testing to confrontation with hand movements. He was mildly anosognosic, denying the extent and implications of his deficits. He scored 52 on a standardized stroke scale (Adams *et al.*, 1987) in which a score above 50 indicated a severe deficit. On the WAIS-R, H.R. had a low average full scale IQ with a verbal IQ in the average range and a performance IQ in the bottom twentieth percentile. His memory quotient on the Wechsler Memory Scale fell in the average range and was consistent with his verbal IQ score. His digit span was 6 forwards and 3 backwards. Speech was fluent, grammatical and without paraphasias. Auditory comprehension was normal. A CT scan in October 1987 revealed a patchy but extensive right middle cerebral artery territory infarct (*see* fig. 1, top row). At the time of testing, he was alert and cooperative and required minimal assistance in activities of daily living.

Case 2

A.H., a 70-yr-old male, was admitted to hospital in April 1987 and testing was initiated within 1 month of onset of his stroke. At the time of his stroke, he was a retired insurance agent who was an active member of the local golf club and was serving as chairman of its board. He had completed 13 yrs of formal schooling. His score on the Adams *et al.* (1987) standardized stroke scale was 28 (moderate 20–50). He had a complete left homonymous hemianopia on testing to confrontation with hand movement, and mild left-sided weakness and sensory loss, but was ambulatory. Standardized neuropsychological assessment 2 months after his stroke revealed marked impairment in visuomotor tracking (Trail Making test), constructional praxis (Rey-Osterreith Complex Figure) and visual-perceptual skills (Read Visual Closure test). On the WAIS-R, he had a low average verbal IQ, but his performance IQ was in the bottom tenth percentile. Performance on the Wechsler Memory Scale-Revised was impaired due to mild verbal and severe non verbal memory deficits. Left hemispatial neglect and decreased attention and concentration were evident throughout the testing session. A.H.'s CT scan revealed an infarct in the right middle cerebral artery territory involving the basal ganglia, deep white matter and the temporal and parietal cortex (*see* fig. 1, bottom row).

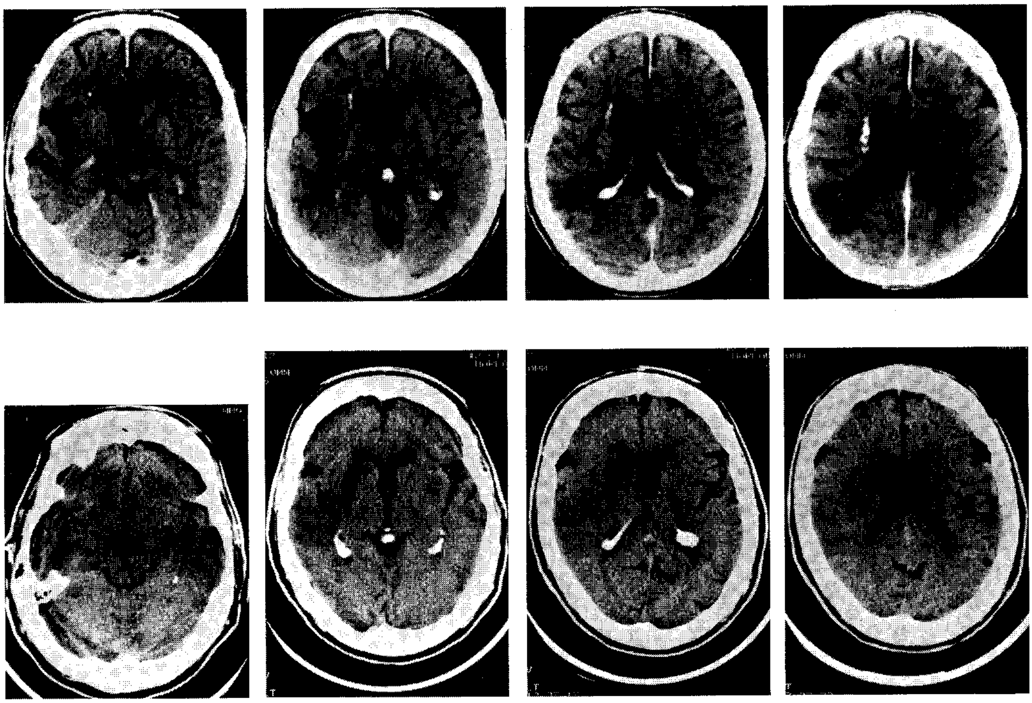

FIG. 1. *Top row*, CT scan for subject H.R. revealing a right middle cerebral artery infarct, involving the parietal and frontal areas, as well as the basal ganglia. *Bottom row*, CT scan for subject A.H. revealing right middle cerebral artery infarct, involving the basal ganglia, deep white matter and temporal-parietal cortex.

INITIAL INVESTIGATIONS

Bedside testing for hemispatial neglect

Both subjects demonstrated general left-sided neglect, not restricted to any one modality. All visual testing was carried out in the subjects' intact right field (neglect of the left-most stimulus within the intact field is often reported). On testing to confrontation with hand movement, H.R. and A.H. both showed extinction of the contralateral stimulus on double simultaneous stimulation in the intact visual field, a not uncommon finding which has previously been taken as support that neglect is not simply a product of a sensory disturbance (Gazzaniga and Ladavas, 1987). Extinction of the contralateral stimulus was also observed on auditory and tactile testing. Both subjects showed neglect on spontaneous drawing and copying of figures such as a daisy and a clock. The results of the line bisection, line cancellation (Albert, 1973), letter and symbol cancellation tasks (Mesulam, 1985) are presented in Table 1. Although both subjects exhibited severe neglect on bedside testing, A.H. performed particularly poorly. He only attended to the extreme right side and, therefore, omitted material even to the right of the midline of the page.

TABLE 1. RESULTS OF H.R. AND A.H. ON BEDSIDE SCREENING FOR HEMISPATIAL NEGLECT

Tasks	*H.R.* *(No. neglected)*	*A.H.* *(No. neglected)*
Line cancellation: 21 lines	11 on left 0 on right	7 on left 0 on right
Letter detection: 60 letters, ordered presentation	2 on left 0 on right	30 on left 15 on right
Symbol detection: 60 symbols, random presentation	15 on left 0 on right	30 on left 25 on right

Reading

Sixty single words of 3–7 letters in length and 60 matched pronounceable nonwords were presented individually in upper case to the subjects' intact right field on an Apple IIE computer for oral reading. The stimuli were presented horizontally on one occasion and then vertically on a second. Strings of 3–6 digits were also presented in horizontal format. Oral reading of text was assessed using Caplan's (1987) paragraph in which the starting position of the left-hand margin is varied from line-to-line.

There was no evidence of neglect on vertical words (accuracy 84% and 80% for H.R. and A.H., respectively) whereas performance on horizontal single word, text and digit reading, revealed a predominance of left-sided neglect errors. In addition to the within-word errors on Caplan's paragraph test, A.H. and H.R. both neglected left-sided information on 70% and 71% of the lines, respectively.

In an attempt to increase the corpus of errors for subsequent analysis, the horizontal words were re-presented to the subjects under limited viewing conditions. The subjects were trained to maintain central fixation and this was monitored using a video camera. Since A.H.'s performance remained unchanged with brief exposure, all subsequent testing was conducted under unlimited viewing time. H.R., however, produced many more errors at 500 ms and this exposure duration was selected for him for all further testing.

Cross-modality testing for central effects

In order to assess whether neglect was restricted to reading or whether it also affected other modalities, oral and written spelling were examined.

Spelling single words to dictation. Twenty high-frequency English words of regular and irregular orthography (3–7 letters in length) were dictated to the subjects for writing. A.H. wrote all words correctly. H.R. made 6 errors, a result which is in keeping with his educational background. For our purposes, it is relevant that none of the spelling errors involved the beginning or left-sided letters of the word.

Oral spelling single words. Fifteen high-frequency words (3–5 letters in length) were read aloud individually to the subjects for oral spelling. A.H. spelled all words correctly and H.R. spelled 11 words correctly. As in written spelling, no errors involved the left side of words.

These findings suggest that neglect of the left side of words does not arise at a central locus, common to all modalities. Instead, it is domain specific, affecting only words the subjects see, but not those they spell or write.

EXPERIMENTAL INVESTIGATIONS

Testing was carried out on a Macintosh Plus computer and 9 inch diagonal, high resolution, 512×342 pixel bit-mapped display screen using Psychlab software (Bub and Gum, 1988). In all cases, a central fixation point appeared 500 ms before the stimulus. Stimuli were presented in bold black 24-point font on a white background. All experiments were self-paced and responses were recorded manually for error analysis. Subjects were seated at a distance of 50 cm and the visual angle subtended by the stimulus was 2.3°, 3.4° and 4.6° for 3, 5 and 7 letter words, respectively.

Experiment 1: Manipulations of physical stimulus features

These experiments were designed to examine the effect of manipulating the physical dimensions of the stimulus on reading performance. If low-level manipulations such as stimulus orientation (horizontal *vs* vertical) or word length were shown to have an effect on performance, then we might conclude that the neglect dyslexia seen in these patients arises at an early stage of processing. Ellis *et al.* (1987), for example, showed that their subject neglected the left side of space (defined as left from the viewer's perspective) and was sensitive to the physical orientation of the stimulus. Performance on vertical words was superior to that of horizontal. Errors were made on the left side irrespective of whether the stimuli were presented in normal forward order (e.g., PLANE → 'lane') or backwards (e.g., LRAEP → 'pear'). These findings suggest that V.B.'s neglect arose at a low level of processing and was related to the left side of external space rather than to the left side of the internal representation of the word.

Preliminary evidence from our initial investigations suggested that our subjects' neglect was also operating with respect to the left side of space since performance was significantly better when the stimuli were presented in vertical rather than horizontal orientation. The following tasks were constructed to examine in more depth the influence of physical parameters of the stimulus on reading performance. The effect of stimulus extent in the horizontal plane was evaluated in two conditions. In one, length was altered by increasing the number of letters in the stimulus; in the other, the number of letters was held constant but the horizontal area covered by the stimulus was manipulated.

Number of letters

In order to evaluate the effect of stimulus length, a list of 210 words of 3–9 letters and 70 matched orthographically legal and pronounceable nonword foils was presented for oral reading. The mean frequency of occurrence was controlled across word lengths, ranging between a mean of 237 and 269 per million (Francis and Kučera, 1982). In order to minimize a possible lexical bias, the subjects were instructed that both words and nonwords would appear in the list. Table 2 shows the accuracy of report across the different word lengths. (Nonword foils were not analysed, but *see* Experiment 2 for investigation of role of lexical status on performance.)

H.R. read 65.1% (range 54–79%) and A.H. 75.3% (range 67–82%) of the words correctly. Word length did not have an effect on performance for H.R. ($r = 0.11$, $P > 0.5$) but a significant effect of length was seen in A.H.'s data ($r = 0.86$, $P < 0.01$) with reading accuracy decreasing as the number of letters increased. The majority of error responses contained approximately the same number of letters as the target word, suggesting that both subjects had some awareness of the stimulus length. In H.R.'s case, 67% of the errors were of the same length as the target and an additional 24% were either one letter longer or shorter than the target. Similarly, 53% of A.H.'s responses were of identical length to the target and all his remaining responses were either a letter shorter or longer than the target. A more detailed error analysis is provided later on.

TABLE 2. OVERALL READING ACCURACY FOR H.R. AND A.H. ACROSS VARYING WORD LENGTHS

Word lengths (no. of letters)	*Percentage correct*	
	H.R.	*A.H.*
3	79	80
4	55	82
5	67	76
6	54	75
7	70	77
8	62	70
9	69	67
Total	65.1	75.3

Discussion. These data indicate that the subjects differed in their sensitivity to the stimulus dimensions with A.H. being much more affected by word length than H.R. Both subjects, however, possessed rudimentary information about the length of the word, as indicated by the length of the error responses. These findings are consistent with the previous descriptions of patients who tended to substitute information on the left, thereby preserving word length (Kinsbourne and Warrington, 1962; Ellis *et al.*, 1987). From these results it appears as though A.H. was influenced by the physical features of the stimulus. It is not clear, however, whether the critical variable is the number of letters in the stimulus or the amount of horizontal space taken up by the stimulus since they are confounded in this task. Before considering why our 2 subjects were different, we attempted to separate out these dimensions.

Stimulus extent

In this experiment, the horizontal extent of the stimulus was varied independently of the number of letters. Two lists of words were constructed for oral reading and were run in two conditions. (1) Regular: 150 words of 3–5 letters were presented starting in the character space immediately next to the fixation asterisk (e.g., *ACE). The stimulus appeared 500 ms following the fixation point in the experiment; (2) Spaced: the same words were presented next to fixation but with a single character space between letters so that the visual angle subtended by these words exceeded that of the regular condition (e.g., *A C E).

There was no significant difference in H.R.'s performance across the two conditions (McNemar test n.s.), confirming the prediction that horizontal extent, produced either by increased letters or visual angle, did not influence his neglect dyslexia. For A.H., however, horizontal extent was a significant determinant of reading accuracy. Performance on the regular condition words was superior to that on the spaced condition (McNemar's test $\chi^2 = 6.8$, $P < 0.01$). An effect of increasing number of letters was also observed in the spaced condition: A.H. correctly read 77% of 3 letter words, 55% of 4 letter words and 33% of 5 letter words, confirming the previous finding of a word length effect. A.H.'s deterioration in performance with increasing horizontal extent was further confirmed in an additional manipulation. Words of 3–5 letters were presented immediately next to fixation but without a space between the letters. Instead, the letters were 'stretched' so that they covered the horizontal extent as the words in the spaced condition, for example, DOG. Performance on the stretched condition was not significantly different from that on the spaced condition (McNemar's test n.s.) but was significantly worse than that on the regular condition (McNemar's test $\chi^2 = 4.3$, $P < 0.05$).

Discussion. These findings demonstrate that H.R.'s neglect dyslexia was less affected by length manipulations than A.H.'s. A.H.'s sensitivity to various alterations of the physical parameters of the stimulus indicates that his attentional deficit impaired the extraction of low-level information from the left side of space. This was not the case for H.R.; although performance was not perfect, the attentional deficit did not prevent the stimuli from being processed at a higher level. An error analysis, consisting of errors produced in response to word and nonword targets, was conducted to provide further details about the information which the subjects were able to extract for later processing.

Error Analysis. The analysis (*see* Table 3) included the error responses from several experiments in which the regular presentation format was used and in which both subjects participated. This included experiment 1 (number of letters and stimulus extent) plus the near condition of Experiment 4 (discussed later)). A corpus of 101 errors for A.H. and 128 for H.R. was collected. Errors, made in response to word and nonword targets, were classified as follows.

1. Left-sided word neglect errors. These are errors in which the response is a real English word and in which the right side of the target and the response are identical but no common letters appear to the left of a 'neglect point' (following Ellis *et al.*, 1987). An example might be FEATHER → 'heather' where the neglect point falls to the left of the 'e'. This is a stringent criterion since it excludes errors such as 'flashing' for 'fishing' because of the shared 'f'. We have adopted a particularly conservative criterion (as did Ellis *et al.*, 1987), to protect against false positives, since at this stage we do not have a good understanding of the mechanism producing the errors.

TABLE 3. DISTRIBUTION OF ERROR RESPONSES FOR WORD AND NONWORD TARGETS FOR A.H. AND H.R.

Error types	*Percentages* H.R. (n = 128)	*Percentages* A.H. (n = 101)
Neglect errors		
Word responses	63	32
Nonword responses	15	29
Total	78	61
Other errors		
Word responses	9	7
Nonword responses	13	32
Total	22	39
Neglect errors (collapsed across word and nonword responses)		
Substitution	56	40
Addition	10	2
Deletion	12	19
Total	78	61

2. Left-sided nonword neglect errors. These are neglect responses as defined in (1) above but the response is a nonword rather than a word, for example, FEATHER → 'meather'.

3. Other word errors. These are real English words which do not meet the criterion for inclusion in (1) as in the example cited above (FLASHING → 'fishing').

4. Other nonword errors. These are nonwords or neologisms which are visual errors of mixed visual and neglect errors (e.g., OVER → 'iven') in which letters of the target appear on both the left and right of the response.

The neglect errors were analysed further in terms of letter substitutions (letters replaced to the left of the 'neglect point', e.g., TRACE → 'grace'), letter deletions (initial letters of word omitted, e.g., FARM → 'arm') and letter additions (additional letters attached to the left of the target, e.g., AMPLE → 'sample').

The error responses reveal qualitatively different patterns of performance for the 2 subjects (collapsed across all error types $\chi^2 = 11.5$, $P < 0.05$; collapsed across neglect error types $\chi^2 = 7.6$, $P < 0.05$). H.R. produced a preponderance of real word responses (overall 70%), most of which were left-sided neglect errors (63%). He produced relatively few addition and deletion errors while substitution errors made up the majority of his neglect responses. The tendency to lexicalize was less marked in A.H. who produced a relatively high proportion of nonword responses (overall nonword responses 61%) often resulting from a substitution or a deletion response, for example, CAB → 'ab' and RIDE → 'de'. The presence of neologistic nonword errors is unusual in neglect dyslexia and, as we argue later, may have something to do with the severity of the underlying deficit.

Experiment 2: Contribution of lexical knowledge

Having established that both subjects were affected to some extent by the physical dimensions of the stimulus with A.H. being by far the more affected of the two, we then proceeded to examine the effects of higher-order knowledge on reading performance.

Several previous studies have reported that words are less subject to neglect than nonwords (Sieroff *et al.*, 1988; Brunn and Farah, 1990, and E. Sieroff, personal communication, 1989) although there are instances when this does not occur (Ellis *et al.*, 1987). If a distinction between words and nonwords were observed in our subjects, it would be reasonable to conclude that top-down knowledge of lexical identity was exerting an effect on behaviour. Aside from examining the lexical effects of stimuli, we also examined whether certain psycholinguistic dimensions occurring within the class of words also influenced performance. It has been suggested that patients with neglect dyslexia tend not to violate the morphemic structure of words but rather to break words along meaningful boundaries (e.g., CLEVER → 'lever' or 'ever' but not 'ver'; Friedland and Weinstein, 1977), indicating sensitivity to high-level psycholinguistic information. Morphemes are the smallest free-standing units of language that contain unique meaning (e.g., the word 'cow' contains a single morpheme whereas the word 'cowboy' contains 2 morphemes). The following experiments were therefore designed to assess whether the subjects adhered to morphemic boundaries. If this were so, it would indicate that neglect was implicated at a late stage of processing once this high-level morphemic information was recovered.

Lexical status effects

A list of 216 stimuli of 3–7 letters in length of which half were words (e.g., MOUSE) and half nonwords (e.g., POARD) was presented for oral reading. H.R. read 63% of words and 8% of nonwords correctly and A.H. read 42% of words and 3% of nonwords accurately. The proportion of neglect errors (out of total number of errors) as a function of lexical status is shown in fig. 2.

H.R. produced significantly more neglect errors (Fisher's exact test $P = 0.028$) on nonwords than on words, whereas A.H. did not show a difference in performance as a function of lexical status (Fisher's exact test n.s.).

Discussion. The results demonstrate a word superiority effect for both subjects with better preservation of words over nonwords in terms of overall accuracy of report. This effect was more marked for H.R. who also showed a greater tendency to produce neglect errors in response to nonwords rather than to words. It is important to note, in this context, that A.H. also performed better on words than on nonwords but that the type of error response was equally distributed across target type. The implications of this will be discussed later.

Morphemic effects. These experiments contrasted the effects of neglect on reading words that contained a free-standing morpheme on the right (e.g., pea*nut* or f*arm*) from words that did not (e.g., pis*tol* or e*ast*). The sets of stimuli for assessing these effects were as follows. (1) Compound words: a list of 50 compound words and 50 control noncompound words, matched for length, syllable structure and frequency was presented to the subjects. Compound words contained an embedded word on the right (e.g., 'nut' as in pea*nut*) whereas control words did not (e.g., pistol). (2) Embedded words: 216 words and nonwords were

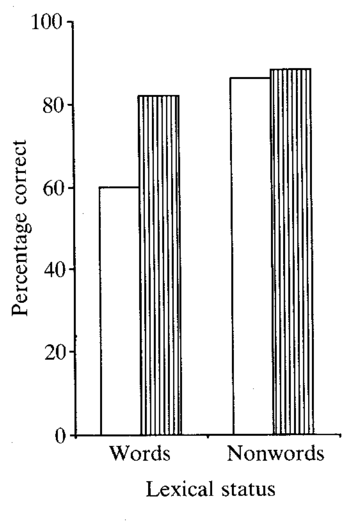

FIG. 2. Proportion of neglect errors as a function of lexical status for A.H. and H.R. Open areas = H.R.; striped areas = A.H.

selected for presentation. Half of the words and nonwords contained morphemes embedded on the right-hand side (e.g., 'arm' as in f*arm* and g*arm*) whereas the other half did not (e.g., 'ast' as in e*ast* and w*ast*). The length of the embedded morpheme ranged from 3 to 5 letters and the total length of the stimuli ranged from 4 to 8 letters. Overall accuracy on compound/control and embedded/nonembedded is presented in Table 4.

TABLE 4. PERCENTAGE OVERALL ACCURACY FOR H.R. AND A.H. ON EXPERIMENTS EXAMINING HIGHER-ORDER EFFECTS

	H.R.	*A.H.*
Compound words	43	74
Noncompound words	40	68
Embedded words	36	15
Nonembedded words	33	30

Neither subject showed any significant difference in overall accuracy on compound versus control words and on embedded versus nonembedded words (Fisher exact test n.s.). Of greater interest is the relation between error type and the presence of a free-standing morpheme on the right of a stimulus. Table 5 shows the error distribution on the above two lists. Errors classified as 'right-sided word' refer to the reporting of the right-hand morpheme (on compound and word/nonword stimuli) and to the right-hand syllable on control and nonembedded words (e.g., COWBOY → 'BOY' (right-hand morpheme) and PISTOL → 'TOL' (right-hand syllable). 'Other responses' include any other type of error.

TABLE 5. DISTRIBUTION OF ERROR TYPES FOR H.R. AND A.H. ON HIGHER-ORDER EXPERIMENTS (PERCENTAGES)

	H.R.		*A.H.*	
Error types	*Compound*	*Noncompound*	*Compound*	*Noncompound*
Right-sided response	65	7	0	0
Other responses	35	93	100	100
	Embedding	*Nonembedded*	*Embedding*	*Nonembedded*
Right-sided response	36	3	24	30
Other responses	64	97	76	70

H.R. produced more right side errors on the compound and the embedded words than on the noncompound and nonembedded words (Fisher exact test compound/noncompound: $\chi^2 = 34.9$, $P < 0.01$; embedded/nonembedded: $\chi^2 = 16$, $P < 0.01$). There was no significant difference in the number of right-sided responses versus other responses for A.H. on either the compound/noncompound or the embedded/nonembedded list (Fisher exact test compound/noncompound: n.s.; embedded/nonembedded: n.s.).

Discussion. If the right side of a word constituted a free-standing morpheme, H.R. tended to produce the morpheme. If it did not, he tended to report a word of approximately the same length as the target stimulus, neglecting (usually substituting) the left side of the word. This differential distribution of errors depending on whether a right-sided morpheme appears in the stimulus is taken as support for H.R.'s sensitivity to the morphological composition of the word. Although we have shown that A.H. was sensitive to the lexical status of the item, he was not sensitive to the morphemic boundaries of words and this may account for his numerous neologistic responses.

The findings thus far suggest that both subjects were influenced by the lexical status of the target item (more marked in H.R.), indicating that top-down knowledge played a significant role in performance. Even when information appearing on the left was attenuated, higher-level knowledge played a role in reading performance. One well-accepted explanation of the word superiority effect is that existing lexical representations feed down and enhance the perception of the target item; that is, top-down knowledge interacts with low-level processing and helps to overcome the effect of reduced exposure of the stimulus (McClelland and Rumelhart, 1981). The interaction between an early attentional deficit and lexical knowledge is compatible with the present results. In the next experiment, we examined the potency of top-down knowledge in assisting the recovery of low-level information.

Further investigation of morphemic effects

In this experiment, we examined other conditions in which pre-existing lexical knowledge might boost or enhance the uptake of low-level stimulus information. In particular we were interested in knowing whether the pre-existing unified lexical code would be strong enough to provide top-down support for words even when the component morphemes were no longer physically continuous (e.g., COW BOY). A well-documented finding in the neglect literature is that with simultaneous bilateral presentation of two noncontiguous stimuli, subjects neglect the contralesional stimulus even when it appears in the intact visual field, a phenomenon known as extinction. When a single word is presented which subtends the same visual angle as the 2 shorter words, extinction is less likely to occur, indicating that physical contiguity is an important variable in the extinction phenomenon (Sieroff and Michel, 1987). In addition to spatial contiguity, the lexical status of the stimulus has also been shown to be an important contributing factor. Sieroff *et al.* (1988) found that their subject was more likely to neglect the contralesional stimulus when the stimuli were nonwords rather than words, suggesting that top-down lexical influences play a powerful role in reading over and above that played by spatial contiguity.

In the following experiment, we examined whether this interaction between higher-order effects and extinction would also apply to stimuli within the class of words. We selected 100 items made up of 2 morphemes which either formed a compound word (e.g., COW BOY) or did not (noncompound, e.g., SUN TAX) and examined the contribution of spatial contiguity and morphemic relatedness to reading performance. All stimuli were presented for oral reading in H.R.'s intact visual field in the following conditions. (1) Contiguous: the compound and noncompound pairs of morphemes were presented with the morphemes physically adjacent to each other and immediately to the right of a fixation point (*) (e.g., COWBOY and SUNTAX). (2) Non contiguous: the 2 morphemes appeared immediately to the right of a central fixation point but were separated by a single space (e.g., SUN TAX and COW BOY). (3) Contiguous joint presentation: the 2 morphemes were physically adjacent but were separated by a number sign, e.g., SUN # TAX and COW # BOY.

We anticipated that H.R. would report both members of the pair more often when the stimuli were contiguous (as in Sieroff *et al.*, 1988) than when they were noncontiguous and that performance on the contiguous joint condition would fall somewhere between the two. Further, since H.R. was shown to be sensitive to morphemic factors on a previous experiment, we predicted that he would also be affected by the identity of the stimuli. We thus expected performance on the compound stimuli to be better than that on the noncompound pairs, irrespective of physical contiguity. Finally, we predicted that if higher-order information were sufficiently strong, both members of the compound pair would be reported when noncontiguous although not as often as when they were contiguous. The results, shown in Table 6, reflect the percentage of words in which H.R. reported both morphemes of the stimulus, i.e., where no extinction occurred.

There was a statistically significant effect of condition ($\chi^2 = 12.2$, $P < 0.05$) with both morphemes reported most often on the spatially contiguous condition, followed by the joint and then the noncontiguous condition. In addition to the effect of spatial contiguity, a statistically reliable effect of stimulus type was observed with both morphemes of the compound word being reported more often than those of the noncompound words (collapsed across all three conditions, $\chi^2 = 18.1$, $P < 0.05$). This suggests that the

TABLE 6. PERCENTAGES OF BOTH MORPHEMES REPORTED BY H.R. ON THE MORPHEMIC EXTINCTION EXPERIMENT

	Conditions		
Stimuli	*Physically contiguous (e.g., COWBOY)*	*Noncontiguous (e.g., COW BOY)*	*Joint contiguous (e.g., COW#BOY)*
Compound	59	28	48
Noncompound	14	12	9

top-down support of an existing lexical representation increases the probability that H.R. reported the left-sided morpheme. Within the noncompound words, there was no significant difference of mode of presentation (χ^2 n.s.), with the left side being frequently extinguished in all conditions. On compound words, however, there was an effect of mode of presentation with performance on the contiguous condition and joint contiguous condition being equivalent (χ^2 n.s.) but being significantly different from the noncontiguous condition (collapsed across joint and contiguous; $\chi^2 = 12.9$, $P < 0.01$).

Discussion. These results confirm the prediction that the unified lexical code which underlies the paired morphemes of compound words helps to resist extinction of the left-sided stimulus. These findings also provide further support for the contribution of stored lexical knowledge to H.R.'s reading performance. The interaction between distribution of attention and lexical status of the stimulus was also observed in a study of normal subjects by Sieroff and Posner (1988) who modulated the effects of attention by using a digit which appeared prior to the stimulus and cued subjects either to the beginning or the end of the target. Noncompound words (e.g., YARDBACK) benefited from the attentional cueing as did nonwords, whereas compound words (e.g., BACKYARD) did not. These results, like ours, suggest that compound words are processed differently from noncompound words.

In all the above experiments, we have shown that our 2 neglect dyslexic subjects, A.H. and H.R., demonstrated significantly different patterns of performance. One possible explanation for the discrepancy in their behaviour is that there existed a fundamental difference in the nature and severity of the attentional deficit, thereby giving rise to different patterns of reading performance. It may be, for example, that A.H.'s attentional disorder is so severe that he can only pick up some information on the left-hand side (producing a word superiority effect) but that this information is insufficient to activate all forms of top-down knowledge. To substantiate this claim, we attempted to establish how much information A.H. and H.R. were able to process from the left of the stimulus.

Experiment 3: Spatial attention testing

Current theories of attention (Treisman and Gelade, 1980; Posner, 1988; Treisman and Gormican, 1988) distinguish between two modes of processing. One mode involves the detection of the presence of a simple feature among disparate features; for example, when one object differs in orientation from the background, the item 'pops out' of the visual display. Detection of the 'oddball' feature is conducted automatically and in parallel and, according to some views, does not require attention although attention is engaged after the information is processed (Posner and Presti, 1987; Treisman and Gormican, 1988). Attention is mandatory, however, for the second mode of processing when two or more features must be conjoined to distinguish the object from the background, for example, when colour and form are both needed to locate the disparate object or when letter position and identity must be conjoined as in reading. The theoretical distinction between the two modes of processing is derived from experimental work with normal subjects and it is not clear how this might operate in the case of attentional deficits. It may be that even if the simple feature detection is attention-free, the pick-up of low-level features may be impeded if the deficit is severe enough. Employing a similar distinction, Riddoch and Humphreys (1987) showed how simple feature detection was relatively intact with 3 subjects suffering from unilateral neglect but that serial or conjoined processing was impaired.

We predicted that both subjects would show better performance on the left of the display compared with the right, irrespective of the task. Like Riddoch and Humphreys (1987), we predicted that performance on the simple feature task would be better than on the conjoined task for both subjects but that A.H. might be more affected than H.R. on the latter task. In other words, even though both subjects have a deficit in attention, the locus and degree of interference may differ. The tasks were as follows.

Simple feature detection task

A total of 120 horizontal strings of 6 letters appeared on the screen after the appearance of a central fixation point and a 500 ms delay. On half the trials the letters were all alike (e.g., *AAAAAA) and on the other half, a different letter appeared in the array with its position systematically varied across trials (e.g., *ACAAAA). The subjects were required to judge whether all the letters were the same or not. Accuracy of 'oddball' detection by character position was calculated.

Conjunction of features

A total of 120 horizontal strings of 6 different upper case letters appeared on the screen for oral report after the central fixation point and 500 ms delay (e.g., MXRTBG). Accuracy of report by letter position was calculated. As on previous tasks, A.H. performed both tasks at unlimited exposure duration whereas H.R. received the stimuli at 500 ms exposure duration.

A 3-way ANOVA was conducted with tasks (simple and conjoined) and positions (using all serial positions as individual points) as within-subject variables and subjects (A.H. and H.R.) as the between variable (*see* fig. 3). There was a significant main effect of task ($F(1,16) = 5.04$, $P < 0.04$), supporting the finding by Riddoch and Humphreys (1987), and of position ($F(1,16) = 8.03$, $P < 0.02$) as we had predicted. The main effect of subject was not significant ($F(1,16) = 2.4$, $P < 0.15$) but there was a significant interaction between subject and task ($F(1,16) = 7.18$, $P < 0.04$) as evident from the superior performance displayed by A.H. on the conjoined task in positions 4–6 relative to H.R.

Discussion. H.R.'s overall performance on the simple task was superior to that on the conjoined task, with the left side being impaired relative to the right equally on both tasks. Information was being picked

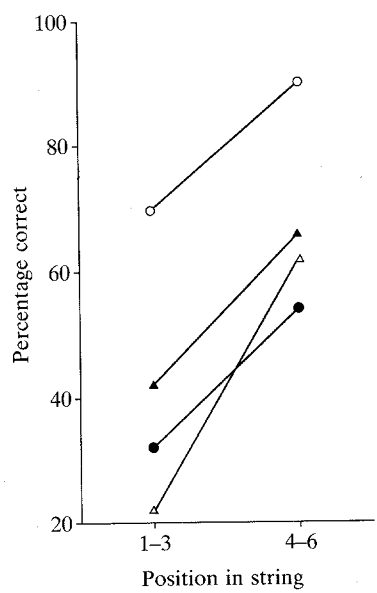

FIG. 3. Percentage correct letter report as a function of position of target on simple and conjoined feature detection task. Open circle = H.R., simple; filled circle = conjoined; filled triangle = A.H., simple; open triangle = conjoined.

to an equal degree in both tasks but when attention was required to conjoin the information, the task became more difficult.

A.H.'s difficulty in the simple feature detection task for material on the left-side of space, already more pronounced than H.R.'s was exaggerated on the conjoined task. In the right-most positions, A.H. was able to perform the simple and conjoined tasks equally well. This implies that basic feature information was not being picked up well on the left-hand side of the array and when that information was used for conjunction of features, the deficit became even more apparent. This inability to encode information on the left was not the result of a primary sensory loss (visual field defect) but was attributable to a fundamental attentional deficit, as will be demonstrated later in Experiment 5.

These data are compatible with the suggestion that A.H. cannot make use of top-down knowledge since he cannot assemble a reasonable representation of the visual stimulus. H.R. is able to take advantage of stored lexical knowledge which is then used to assist in the interpretation of the stimulus.

The serial position curves for both subjects (*see* fig. 3) support the view that information appearing on the right is processed better than information on the left. This is consistent with the view that attention is distributed as a gradient across the field with the lowest level of activation on the left (Kinsbourne, 1987; De Renzi *et al.*, 1989). If this hypothesis is indeed correct and performance is simply a function of where the stimulus appears along the gradient of attention, then moving the stimulus into a more optimal attentional region should result in improved performance for both subjects. The next experiment corroborated this prediction.

Experiment 4: Location effect

A list of 60 words of 3–5 letters (mean frequency 239 per million; Francis and Kučera, 1982) and 20 nonword foils was presented in two different locations, starting either immediately next to fixation (near condition; visual angle 2.3°–3.4°) or starting at the fourth character position to the right of the fixation point (far condition; visual angle 4.6°–5.7°). Care was taken to ensure that the stimuli were still within the range of good visual acuity. We predicted that performance should be superior in the far condition, i.e., when stimuli fell in a more optimal region of attention.

The results revealed significantly better performance for both subjects in the far condition as compared with the near presentation. H.R. reported 17/60 words correctly when they appeared next to fixation and 27/60 words correctly when they were further over into right hemispace (McNemar's test $\chi^2 = 4.5$, $P < 0.05$). A.H.'s behaviour followed a similar trend, although the effect of location was not as strong. He reported 24/60 words correctly next to fixation and 32/60 correctly in the more displaced location (McNemar's test $\chi^2 = 3.6$, $P < 0.10$).

Discussion. Both subjects showed superior performance when the stimuli appeared further over into right hemispace, lending support to the hypothesis of a gradient of attention. These results are also consistent with the general finding in the neglect literature that the severity of neglect decreases as one moves even a small distance further into ipsilesional hemispace (Heilman and Valenstein, 1979; Butter *et al.*, 1988). The general explanation for this finding is that the amount of neglect is decreased when the stimuli are presented in an area of optimal attention, i.e., further to the right along the gradient.

The gradient explanation has been used previously to account for neglect dyslexia (Kinsbourne and Warrington, 1962) and our data provide empirical evidence which corroborates this attentional hypothesis. Our finding suggests that the fundamental deficit is clearly one of visual spatial attention but depending on the location of the stimulus along the attentional gradient, more or less information may be neglected during reading.

Experiment 5: Manipulation of attention

In view of the fact that A.H. picked up so little information on the left-hand side, it may be tempting to ascribe his neglect of the left side to a primary sensory or perceptual deficit. If this were indeed the case, the above results would have no bearing on the issue of selective attention. To exclude this possibility, we designed a task to demonstrate that A.H. can be cued to attend to the left. We expected that when his gradient of attention is shifted so that stimuli appear in a more optimal region, he would be able to report more information appearing on his previously neglected side. This would effectively exclude a primary sensory deficit as an explanation for his impaired performance. In addition, we expected that if our interpretation is correct, then A.H. like H.R., would then show sensitivity to morphemic boundaries. In other words, when attention is operating more efficiently, the low-level information would be picked up and the opportunity for top-down support and lexical enhancement would be provided.

Fifty trials of 2 morphemes separated by a single character space were presented to A.H. for unlimited viewing time to the right of a central fixation point. In half of the trials, the 2 morphemes formed a compound word (e.g., *COW BOY) whereas in the other half the 2 morphemes were unrelated (e.g., *SUN TAX). The trials were presented in two conditions. (1) Baseline condition: A.H. was instructed merely to read the 2 words on the screen. (2) Attentional manipulation: A.H. was instructed to report the left-sided word first followed by the right-sided word. Karnath (1988), in a similar task using nonverbal material, showed that reducing information analysis on the right side by instructing subjects to attend to the left, provoked a covert shift of attention to the left side. A.H. was instructed to maintain central fixation throughout.

In the baseline condition A.H. reported both words correctly in only 2 out of 50 trials whereas he reported both words correctly on 28 trials when attention was manipulated. Of these 28 trials, 21 were from the list of compound words whereas the remaining 7 were unrelated morpheme trials.

Discussion. The improvement observed on the manipulation task suggests that A.H. is able to pick up information from the contralesional side if he consciously directs his attention to the left. His neglect dyslexia, therefore, cannot be attributed to a primary visual problem which precludes processing of left-sided information. While his attention may be automatically directed to the right, he can voluntarily shift it to detect information on the left. No obvious shifts in eye movements accompanied his performance and the orientation to the left may therefore be attributed to a covert attentional shift. The fact that A.H. was able to attend to material appearing on the left, when cued to shift his attention consciously in that direction, supports the claim that attention may be voluntarily directed to the neglected side either by a cue (Riddoch and Humphreys, 1983) or by task instructions (Karnath, 1988). Furthermore, the increased probability of reporting both morphemes when they form a compound word suggests that lexical knowledge plays a critical role in performance. Thus when the stimuli appear in a region where the attentional gradient is sufficiently high to allow a critical amount of information to be processed, an interaction with stimulus type emerges. Even when the information on the left was somewhat attenuated, higher-level morphemic knowledge therefore assisted in recovering information when the 2 morphemes formed a compound word but not when they were unrelated. As for H.R., then, A.H. did demonstrate an interaction between a low-level attentional deficit and higher-order knowledge provided that sufficient information was picked up from the left to activate the top-down knowledge.

GENERAL DISCUSSION

The goal of this paper was to document the locus of breakdown of attention in visual processing of verbal material and to describe the effect of the attentional deficit on the reading performance of 2 subjects with neglect dyslexia. Both subjects possessed intact central representations of words as evidenced by their ability to spell orally and to write correctly. Their left-sided neglect only became manifest on reading single words and text. The modality-specific nature of the impairment is consistent with the view that attention is disrupted peripherally rather than in a central mechanism or 'conceptual space' (Barbut and Gazzaniga, 1987) which is common to all modalities.

Although both subjects exhibited some disruption of visual attentional processing, a more detailed examination of their performance revealed what appears to be a double dissociation. On the one hand, A.H. was susceptible to structural manipulations (such as length and horizontal extent) which altered the low-level representation of the word. This indicates that the attentional disruption is data-driven and stimulus-bound, supporting the view that attentional selectivity takes place early in the system. H.R. did not demonstrate these low-level effects. Instead, he was influenced by the lexical and morphemic status of the stimuli, thereby supporting the hypothesis that attentional selectivity takes place late in the system once the stimuli have been identified and their psycholinguistic features have been accessed.

This apparent double dissociation of physical low-level versus lexical higher-order effects may be taken as evidence for separate patterns of breakdown, one affecting early processing and the other affecting later processing. This account fragments the neglect dyslexia syndrome and posits two separate loci of breakdown. While this fragmentation account captures some of the data, it cannot account for all of the findings. For example, in addition to high-level factors, H.R. also showed some sensitivity to the physical parameters of the stimulus as his performance was influenced by the orientation and location of the item in the visual field. Furthermore, A.H. was not affected only by low-level stimulus dimensions but also by the lexical status of the items as evident by his word superiority effect. The paradox thus becomes apparent—a clear separation into perceptual versus conceptual effects does not suffice and an alternative explanation is required.

We offer one possible explanation for these apparently contradictory findings. Our explanation depends on the assumption that the symptoms shared by the subjects differ in degree. In proposing a unitary framework, we have taken the evidence from both subjects in tandem. While the effects of conceptual factors and low-level manipulations were most noticeable in H.R. and A.H., respectively, we assume that both types of effects were operating in both subjects but that the overt symptoms of one or the other were obscured or masked, depending on the extent of the attentional deficit.

Attention which is disrupted early does not affect information processing in an all-or-none fashion but is unevenly distributed as a gradient from left-to-right. Features appearing on the left are picked up poorly but may often be sufficient to activate top-down knowledge. This higher-order knowledge is brought to bear on the encoded information, enhancing and improving performance and giving rise to higher-order effects. This interaction between an early deficit and existing knowledge was less obvious for A.H. whose attentional gradient was very steep. Thus information on the left was so poorly registered that it could not trigger the existing lexical and morphemic representations. When the information was shifted into a more optimal region of the attentional gradient (Experiment 4), top-down effects became apparent. H.R.'s attentional gradient was less severe, allowing higher-order effects to be readily observable. In the context of a unitary explanation, the critical distinction between our subjects, then, is in the severity of the attentional disturbance or the slope of the attentional gradient (Experiment 3). A.H. and H.R. are thus parametric variations of the same basic attentional disruption which appears at an early processing stage. Depending upon its severity, the attentional deficit may or may not give rise to interactions with later processing stages. Any simple explanation of peripheral versus central or early versus late attention, therefore, cannot suffice.

A model to explain both subjects' deficits could operate as follows. H.R.'s primary attentional deficit results in decreased attention to the left-hand side but information from the left, although much attenuated, is still processed. A 'clean-up' operation, which has access to the stored representations of words, then takes the perceptual data and constructs the most consistent and plausible interpretation of the incoming information. Thus words are read better than nonwords, right-sided morphemes are reported when possible, and compound words are preserved relative to two unrelated morphemes. A.H.'s primary attentional deficit is more severe, affecting even the detection of fundamental features. Since the clarity of the perceptual data is diminished, the 'clean-up' operation may be compromised so that he cannot benefit much from interactions with higher-order knowledge.

A model with these essential features and functions has been developed by Mozer (1987, 1988). This connectionist model, MORSEL (multiple object recognition and attentional selection), is a parallel distributed processing model capable of recognizing multiple words appearing simultaneously on its 'retina'. The network consists of a letter and word recognition modules through which activations from the 'retina' are propagated. MORSEL also has a module in which higher-order lexical and semantic information is stored. Critical to our account is the fact that MORSEL has an attentional mechanism that controls the amount and sequential order of information flowing through the system. An 'attentional spotlight' is constructed across some region of the 'retina' facilitating preferential processing of sensory information from that area.

If attention is distributed as a gradient from left-to-right (as in neglect), the rightmost information will always have an advantage over the left-sided information. Information on the left will also be processed but in a more probabilistic fashion. If this left-sided 'unattended' information is sufficiently activated, it may engage higher-order knowledge which feeds down and assists in the recovery of the attenuated left-hand side. Such a 'clean-up' mechanism may not be possible if insufficient left-sided knowledge is propagated forwards, that is, if the gradient is too severe. MORSEL is an implemented, working computational model and, in the past, has been able to account for a broad range of empirical psychological phenomena. Using a 'lesioned' version of MORSEL in which the attentional mechanism has been selectively 'lesioned' (Mozer and Behrmann, 1990), we have successfully simulated the behaviours of A.H. and H.R. The results of these simulations suggest that manipulations of the severity of the attentional gradient can account for the differences in performance between subjects.

The findings from both the clinical and the simulation studies indicate that neglect dyslexia is a heterogeneous phenomenon. Our assertion, however, is that the heterogeneity arises not from different loci of breakdown but from the severity of the attentional disorder. In one case, the disorder leads to what appears to be a low-level deficit and in the other, to a more complex pattern that is receptive to higher-order lexical influence. In this formulation, both manifestations of the disorder arise from a single cause, an uneven distribution of attention within the retinal frame.

It is possible, therefore, that a unitary explanation can account for and resolve the individual differences and discrepancies that exist in the literature. The patient of Ellis *et al.* (1987) demonstrates effects which are similar to those of A.H. in that the disorder occurs early in the reading process. Sieroff *et al.* (1987), on the other hand, describe top-down effects which are more in keeping with H.R.'s pattern than A.H.'s disorder. We suggest then that a detailed analysis of neglect dyslexia in all subjects may highlight the commonalities rather than the differences. The differential results shown by A.H. and H.R. have bearing on the role of spatial attention in normal visual processing. Disruption of attention at an early stage need not affect processing in an all-or-none fashion. The pick-up of low-level information may be impeded but the information that does get through can be combined with knowledge of stored representations so that perceptual information may be accurately recovered. The dichotomy of early and late selection and of pre- and postidentification procedures may be an over-simplification of the way in which attention functions in visual processing. We suggest that a 'hybrid' view may be a closer approximation to reality (Pashler and Badgio, 1987; Mozer, 1988).

ACKNOWLEDGEMENTS

The authors wish to thank Doug Martin for his assistance in the collection of the data. This research was supported by grants from the Sunnybrook Medical Centre Research Trust Fund, the Ontario Mental Health Foundation, the Medical Research Council, the James S. McDonnell Foundation and grant A8347 from the Natural Sciences and Engineering Research Council. M.B. was supported by a Postgraduate Scholarship from the NSERC. The authors also thank Dr Morris Freedman of the Behavioural Neurology Unit, Baycrest Centre for Geriatric Care, for referring one of the patients to us.

REFERENCES

ADAMS RJ, MEADOR KJ, SETHI KD, GROTTA JC, THOMSON DS (1987) Graded Neurologic Scale for use in acute hemispheric stroke treatment protocols. *Stroke*, **18**, 665–669.

ALBERT ML (1973) A simple test of visual neglect. *Neurology, Minneapolis*, **23**, 658–664.

BARBUT D, GAZZANIGA MS (1987) Disturbances in conceptual space involving language and speech. *Brain*, **110**, 1487–1496.

BAXTER DM, WARRINGTON EK (1983) Neglect dysgraphia. *Journal of Neurology, Neurosurgery and Psychiatry*, **46**, 1073–1078.

BROADBENT DE (1958) *Perception and Communication*. London: Pergamon Press.

BRUNN JL, FARAH M (1990) The relation between spatial attention and reading: evidence from the neglect syndrome: *Cognitive Neuropsychology*. In press.

BUB D, GUM T (1988) Psychlab Software. Montreal: McGill University.

BUTTER CM, MARK VW, HEILMAN KM (1988) An experimental analysis of factors underlying neglect in line bisection. *Journal of Neurology, Neurosurgery and Psychiatry*, **51**, 1581–1583.

CAPLAN B (1987) Assessment of unilateral neglect: a new reading test. *Journal of Clinical and Experimental Neuropsychology*, **9**, 359–364.

CARAMAZZA A, HILLIS AE (1990) Levels of representation, co-ordinate frames and unilateral neglect. *Cognitive Neuropsychology*. In press.

DE RENZI E, GENTILINI M, FAGLIONI P, BARBIERI C (1989) Attentional shift towards the rightmost stimuli in patients with left visual neglect. *Cortex*, **25**, 231–237.

DEUTSCH JA, DEUTSCH D (1963) Attention: some theoretical considerations. *Psychological Review*, **70**, 80–90.

ELLIS AW, FLUDE BM, YOUNG AW (1987) 'Neglect dyslexia' and the early visual processing of letters in words and nonwords. *Cognitive Neuropsychology*, **4**, 439–464.

ERIKSEN CW, YEH Y-Y (1985) Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance*, **11**, 583–597.

FRANCIS WN, KUČERA H (1982) *Frequency Analysis of English Usage*. Boston: Houghton Mifflin.

FRIEDLAND RP, WEINSTEIN EA (1977) Hemi-inattention and hemisphere specialization: introduction and historical review. *Advances in Neurology*, **18**, 1–31.

GILLIATT RW, PRATT RTC (1952) Disorders of perception and performance in a case of right-sided cerebral thrombosis. *Journal of Neurology, Neurosurgery and Psychiatry*, **15**, 264–271.

GAZZANIGA MS, LADAVAS E (1987) Disturbances in spatial attention following lesion or disconnection of the right parietal lobe. In: *Neurophysiological and Neuropsychological Aspects of Spatial Neglect. Advances in Psychology*, No. 45. Edited by M. Jeannerod. Amsterdam, North-Holland, pp. 203–213.

HEILMAN KM, VALENSTEIN E (1979) Mechanisms underlying hemispatial neglect. *Annals of Neurology*, **5**, 166–170.

HEILMAN KM, WATSON RT, VALENSTEIN E (1985) Neglect and related disorders. In: *Clinical Neuropsychology*. Second edition. Edited by K. M. Heilman and E. Valenstein. New York and Oxford: Oxford University Press, pp. 243–293.

HEILMAN KM, BOWERS D, VALENSTEIN E, WATSON RT (1987) Hemispace and hemispatial neglect. In: *Neurophysiological and Neuropsychological Aspects of Spatial Neglect. Advances in Psychology*, No. 45. Edited by M. Jeannerod. Amsterdam: North-Holland, pp. 115–150.

KARNATH H-O (1988) Deficits of attention in acute and recovered visual hemi-neglect. *Neuropsychologia*, **26**, 27–43.

KINSBOURNE M (1987) Mechanisms of unilateral neglect. In: *Neurophysiological and Neuropyschological Aspects of Spatial Neglect. Advances in Psychology*, No. 45. Edited by M. Jeannerod. Amsterdam: North-Holland, pp. 69–86.

KINSBOURNE M, WARRINGTON EK (1962) A variety of reading disability associated with right hemisphere lesions. *Journal of Neurology, Neurosurgery and Psychiatry*, **25**, 339–344.

LABERGE D, SAMUELS SJ (1974) Toward a theory of automatic information processing in reading. *Cognitive Psychology*, **6**, 293–323.

LEICESTER J, SIDMAN M, STODDARD LT, MOHR JP (1969) Some determinants of visual neglect. *Journal of Neurology, Neurosurgery and Psychiatry*, **32**, 580–587.

MCCLELLAND JL, RUMELHART DE (1981) An interactive activation model of context effects in letter perception. Part 1. An account of basic findings. *Psychological Review*, **88**, 375–407.

MESULAM M-M (1985) *Principles of Behavioral Neurology*. Philadelphia: F. A. Davis.

MOZER MC (1987) Early parallel processing in reading: a connectionist approach. In: *Attention and Performance XII: The Psychology of Reading*. Edited by M. Coltheart. Hillsdale, NJ: Lawrence Erlbaum, pp. 83–104.

MOZER M (1988) *A Connectionist Model of Selective Attention in Visual Perception*. Proceedings of the Xth Cognitive Science meeting, Montreal. Hillsdale, NJ: Lawrence Erlbaum.

MOZER MC, BEHRMANN M (1990) On the interaction of spatial attention and lexical knowledge: a distributed connectionist model of neglect dyslexia. *Journal of Cognitive Neuroscience*. In press.

PASHLER H, BADGIO PC (1987) Attentional issues in the identification of alphanumeric characters. In: *Attention and Performance XII: The Psychology of Reading*. Edited by M. Coltheart. Hillsdale, NJ: Lawrence Erlbaum. pp. 63–81.

POSNER MI (1988) Structures and functions of selective attention. In: *Clinical Neuropsychology and Brain Function: Research, Measurement and Practice*. Edited by T. Boll and B. Bryant. Washington, DC: American Psychological Association.

POSNER MI, PRESTI DE (1987) Selective attention and cognitive control. *Trends in Neurosciences*, **10**, 13–17.

POSNER M, PETERSEN SE (1989) The attention system of the human brain. Technical report 89-3. Institute of Cognitive and Decision Sciences, University of Oregon.

RIDDOCH MJ, HUMPHREYS GW (1983) The effect of cueing on unilateral neglect. *Neuropsychologia*, **21**, 589–599.

RIDDOCH MJ, HUMPHREYS GW (1987) Perceptual and action systems in unilateral visual neglect. In: *Neurophysiological and Neuropsychological Aspects of Spatial Neglect. Advances in Psychology*, No. 45. Edited by M. Jeannerod. Amsterdam: North-Holland, pp. 151–181.

SIEROFF E, MICHEL F (1987) Verbal visual extinction in right/left hemisphere lesion patients and the problem of lexical access. *Neuropsychologia*, **25**, 907–918.

SIEROFF E, POLLATSEK A, POSNER MI (1988) Recognition of visual letter strings following injury to the posterior visual spatial attention system. *Cognitive Neuropsychology*, **5**, 427–449.

SIEROFF E, POSNER MI (1988) Cueing spatial attention during processing of words and letter strings in normals. *Cognitive Neuropsychology*, **5**, 451–472.

TREISMAN AM, GELADE G (1980) A feature-integration theory of attention. *Cognitive Psychology*, **12**, 97–136.

TREISMAN A, GORMICAN S (1988) Feature analysis in early vision: evidence from search asymmetries. *Psychological Review*, **95**, 15–48.

TZENG O, HUNG DL (1989) Brain processes and reading Chinese. In press.

(*Received February 17, 1989. Revised September 8, 1989. Accepted September 15, 1989*)