

DEFICIT TO STIMULUS-CENTERED, LETTER SHAPE REPRESENTATIONS IN A CASE OF “UNILATERAL NEGLECT”

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Abstract—A brain-damaged subject is described whose pattern of performance in various reading tasks can be explained by proposing damage at a level of the word recognition process in which a representation with stimulus-centered, rather than retinal- or word-centered, coordinates is processed. Analysis of her reading performance as a function of topographical arrangement of letters, position of errors in the letter string, and the effects of letter spacing and of adding a prefix or suffix provide evidence not only for the existence of this level of representation (the letter-shape map in a model proposed by CARAMAZZA and HILLIS [3]), but also for specific assumptions about its functioning and structure.

CARAMAZZA and HILLIS [4] (see also RAPP and CARAMAZZA [20]), following the lines of a model of object recognition proposed by MARR [16] and MARR and NISHIHARA [17], and its extension to reading by MONK [18], proposed a model of word recognition based on the assumption that the information computed in the early stages of this process might be represented in terms of sets of representational primitives (such as visual features, letters, graphemes, or words) in different coordinate frames. The model assumes three levels of representation prior to lexical access: the first level of representation consists of a retino-centric, feature map; the second level consists of a stimulus-centered, letter-shape map; and the third level consists of a word- or object-centered, grapheme description. A schematic representation of this model is shown in Fig. 1. Support for each of the proposed levels of representation has come from the performance of neurologically impaired subjects with spatially-specific deficits (neglect). That is, the crucial data have come from brain-damaged subjects who in visual word-recognition (and other perceptual) tasks principally or exclusively make errors on one side of a given coordinate system—on the side opposite to the damaged hemisphere.

Evidence for the hypothesis that word recognition involves computing a representation with graphemes as primitives in a word-centered coordinate frame has been reported by CARAMAZZA and HILLIS [4, 5]. They described a subject with damage to the left hemisphere, N.G., who made reading errors only on the final letters of words (the “right” half of the word). She produced the same pattern of errors whether words were presented as a string of printed letters or as a series of spoken letters, indicating a deficit at a level of representation

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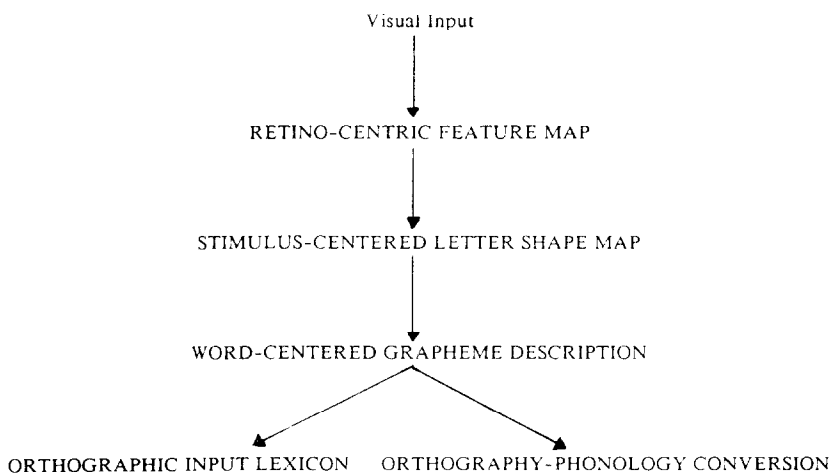


Fig. 1. Schematic representation of a model of early stages of the word-recognition process.

that specifies graphemes as primitives, rather than letters or visual features. This invariant pattern across modalities could not have resulted from impairment in computing a representation of the visual letter shapes. The affected representation was assumed to have word-centered coordinates because N.G.'s errors increased as a function of the number of graphemes from the center of the word in all word recognition tasks regardless of the topographic arrangement of the stimulus. In other words, her responses included a greater number of correct letters on the left of a long word than on the left of a short word. For example, she read *fable* as "fabric" (3 correct letters); whereas she read *banister* as "banish" and *familiar* as "family" (5 correct letters each). Thus, it was not the case that she correctly processed a limited number of graphemes on the left. Instead, it seems that she processed normally only about half of each centered representation. Her pattern of performance could not be explained by proposing impaired processing of representations with retinal or spatial coordinates because, as may be seen in Fig. 2, she made errors on the final letters of words (and not the physical stimulus) whether letters were printed or spoken, and whether words were printed normally (left to right), vertically, or in mirror-reversed print (right to left). The evidence from N.G. for impaired contralesional processing of a word-centered representation in word recognition is complemented by recent evidence for impaired contralesional processing of an object-centered representation in object recognition [6].*

There is also evidence from the performance of brain-damaged subjects for postulating the existence of an independent, stimulus-centered representation in word recognition. In marked contrast to the performance reported for N.G., subjects V.B. [7] and S.P. [26], for instance, made word-recognition errors that were restricted to letters on the impaired (in their case, left) side of the physical stimulus. However, neither subject made errors in recognition of orally spelled words or in reading of words printed vertically. Furthermore,

*N.G. also showed a right-sided deficit in computing an object-centered representation in non-lexical tasks, such as line bisection, drawing, copying [3], identifying the presence of 2 identical letters in a string of consonants [4], and in discriminating differences between abstract visual shapes like those used by DRIVER and HALLIGAN [5] (CARAMAZZA *et al.*, in preparation). These results show that the deficit in N.G. does not concern specifically the processing of graphemes, but any visually-based representation.

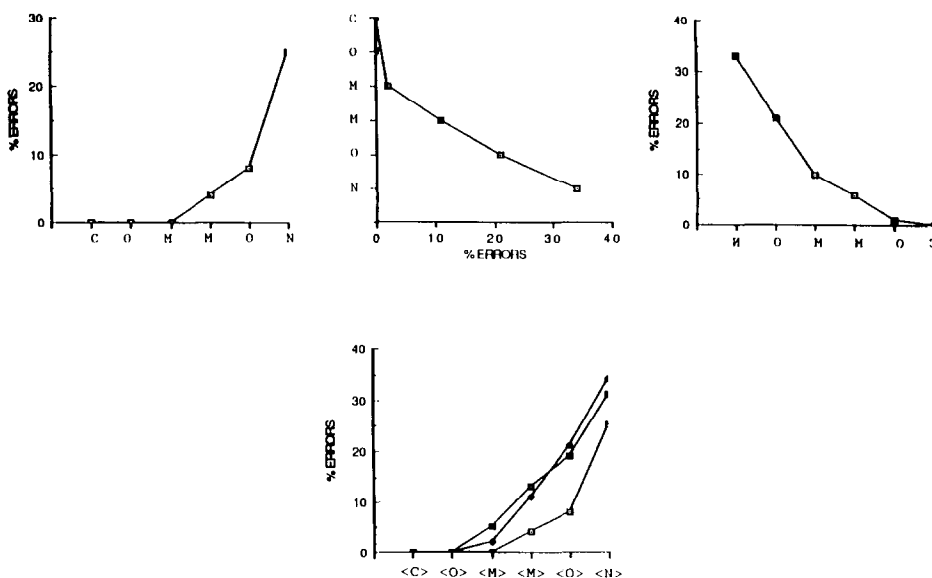


Fig. 2. N.G.'s reading performance in reading topographically transformed print. The top graphs report percentage of errors as a function of letter position in six-letter words. On the left is shown performance for standard, horizontally presented print; in the center is shown performance for vertically presented print; and on the right is shown performance for mirror-reversed print. The bottom graph shows performance as a function of position within a word for all three types of stimulus presentation conditions, regardless of physical location letters on the page.

the authors presented evidence that the problem was not specific to the processing of information in the left visual field: the subjects made errors on the left side of words even when these were presented in the right visual half-field. Thus, in tachistoscopic reading and in a task that required reading a word immediately after naming a red digit just to the left of the first letter, both subjects made errors on the left side (beginning) of words. For example, S.P. read *kill* as "hall" when the stimulus was presented to the right of a fixation point, and read *bat* as "eat" after she correctly named the preceding digit. KINSBOURNE and WARRINGTON [14] reported similar patterns of performance: left-sided errors in reading words even when these were presented in the right, intact visual field (ruling out a disruption at a retino-centered level), but accurate reading of vertical print (ruling out disruption at a word-centered level). Other brain-damaged subjects who make reading errors on the beginning of words only when this part of words is on the left side of the stimulus regardless of the visual hemifield in which it is presented have been reported by RIDDOCH *et al.* [23] and by BEHRMANN *et al.* [3]. The pattern of unilateral errors in word recognition in these subjects suggests an impairment in processing a representation with letters (or visual features) as primitives and spatial coordinates.

Other brain-damaged subjects have specific deficits in the perception of letter strings that can be explained by assuming damage at the level of a retino-centric and/or stimulus-centered representation. For instance, RAPP, BENZING and CARAMAZZA [19] describe a brain-damaged subject, C.S., whose reading and letter identification following a right hemisphere stroke can be explained by postulating reduced processing efficiency that increases as a function of distance to the left of fixation. Thus, C.S.'s identification of a target letter in a string of letters depends more on the position of the target in the visual field than on

its relative position in the string. In another case, RAPP and CARAMAZZA [20] showed that the performance by a brain-damaged subject, H.R., in recognizing strings of letters arrayed horizontally could best be explained by proposing a right-sided impairment in computing representations of visual stimuli with retinal coordinates *and* representations with spatial (stimulus-centered) coordinates. In a series of studies on the perception of a target letter in a string of letters presented for brief durations, H.R.'s performance was influenced both by absolute position of the target with respect to the visual field and relative position of the target within the stimulus (letter string). H.R. was slower to respond to a target letter presented in a given absolute position of the visual field when it occurred on the right side of a string of letters than when it occurred in the bottom, top, or left of a string of letters. On the other hand, she was slower to respond to a letter in a given relative position of the string when it was presented in the right visual field as opposed to the left visual field. An explanation in terms of retinal coordinates or spatial coordinates alone could not account for these data.

The results briefly reviewed here are substantially in agreement with predictions derived from the multi-level model of word recognition proposed by CARAMAZZA and HILLIS [4]. Thus, the performance of subjects such as N.G. [4, 5] (and possibly subject R.Y.T. [24]) is explained by assuming a spatially-specific deficit at the level of the word-centered, grapheme description; the performance of subjects V.B. [7], S.P. [26], J.B. [23], and some aspects of performance by H.R. [20] are explained by assuming a spatially-specific deficit at the level of the stimulus-centered, letter-shape map; and the performance of subjects such as C.S. [19] and some aspects of performance by H.R. are explained by assuming a spatially-specific deficit at the level of the retino-centric, feature map. Although the proposed model has sufficient structure to account for the principal features of the performance of patients with spatially-specific reading disorders, it remains underspecified in a number of crucial respects. Thus, for example, specific characteristics of the stimulus-centered, letter-shape map, such as whether the stimulus representation is "normalized" with respect to size of letters, spacing between letters, and so on, remain to be articulated and tested.

In this paper we describe a brain-damaged subject, R.W., whose pattern of performance in various reading tasks can be explained as resulting from damage at the level of the letter-shape map. Localization of her impairment in word recognition to this level of representation provided the opportunity to test specific assumptions about its functioning and structure. Specifically, we tested the hypothesis that the letter-shape map has stimulus-centered, rather than retinal- or word-centered, coordinates. Furthermore, through the analysis of her reading performance as a function of letter spacing we were able to address issues regarding the spatial characteristics of the letter-shape map. Most of the effects of various manipulations of stimuli on reading performance reported for R.W. have been previously recorded individually in patients with hemispatial deficits, but it was only the unique opportunity to record the effects together in a single patient that allowed us to localize her functional deficit to the letter-shape map and thus to test specific hypotheses about the structure of representations processed at this level.

CASE REPORT

Social and medical history

R.W. is 57-year-old, right-handed woman, who worked for the public school system, planning and serving meals, until she sustained a stroke 9 months before this investigation. She had completed 9th grade; by self-report she frequently wrote letters and read magazines before her stroke. She lives at home with her husband.

R.W.'s past medical history is unremarkable, except for a long history of mild hypertension. A CT scan the day

after her stroke was negative. On the same day, an EEG indicated seizure activity in the right hemisphere. Seizures were successfully controlled with Dilantin, and later with Tegretol. Four days after her stroke, a repeat CT scan revealed a large area of attenuation in the right parietal-occipital region. An MRI scan 1 week post-stroke showed damage in the same area.

At the time of the investigation R.W. presented with mild hemiparesis with slightly increased tone and reduced proprioception of both left extremities. Visual fields were full, but she showed left visual and tactile extinction. She also showed severe left hemispatial neglect on clinical evaluation. She walked independently and had resumed many household chores. However, she did not cook, because it was considered unsafe due to her tendency to "forget" that she had turned on burners on the left side of the stove. She was quite aware that she had problems responding to things on her left in many activities. For example, she reported that her husband always needed to turn her plate around after she had eaten food from the right side, since she was never aware of remaining food on the left side. As another illustration, she reported that three Christmas cards she had mailed had been returned to her because she had omitted the initial (left-sided) digits when copying the street address in each case.

Clinical evaluation of cognitive status

R.W.'s speech is fluent and grammatical, but tends toward excessive detail and frequent digressions. Prosody is normal, and she has no dysarthria or aphasia. Performance on the Wechsler Memory Scale [21] at 9 months post-stroke was within normal limits for her age on all subtests other than visual reproduction. Her reproduction of abstract designs, like her reproduction (and direct copying, see Appendix A) of drawn objects, showed gross omissions and distortions on the left side. Her attempts to bisect a 10 in. line deviated to the right 1–2 in. across separate trials. In a line cancellation task with 40 lines, R.W. omitted 8 lines on the far left and no lines on the right. She received a score of 8 out of 30 on the Hooper Visual Organization Test [9], which falls in the moderate range of impairment. On Raven's Coloured Progressive Matrices [17], she scored 18/36 (age-corrected score = 21, which is 2 S.D. below the mean); and she showed a right:left response bias of 2.6:1 (18:7). When asked to write, she began writing with a wide left margin on the page, which became progressively wider as she continued. Her writing also showed frequent perseverative letters and perseverative strokes (Appendix B), as described in greater detail below. In oral reading of arabic numbers, she omitted the initial digit in 11% of 4-digit numbers, 20% of 5-digit numbers, 40% of 6-digit numbers, and 50% of 7-digit numbers (all 3-digit numbers were correctly read). In oral reading of narrative she omitted the first 1–6 words on each line, with no apparent awareness that the resulting content was incoherent and ungrammatical.

EXPERIMENTAL INVESTIGATION

Reading performance

Over the course of the present investigation, R.W. was asked to read aloud more than 2000 words and pseudowords specifically designed to identify the effects on reading accuracy and error types of various orthographic and lexical dimensions of stimuli, topographic transformations of print (normal—horizontal, vertical, or mirror-reversed), location on page, and spacing between letters. Stimuli and scoring are described for each experiment separately. There were no time constraints on reading in any of the tasks.

Lexical effects

R.W. read aloud 216 words and 68 nonwords from the Johns Hopkins University Dyslexia Battery (GOODMAN and CARAMAZZA [9]) to determine the influence of lexical and orthographic parameters on reading performance. She also read an additional list of 96 words specially compiled for the purpose of determining the effects of ortho-phonological regularity on reading performance. On lists matched for frequency and word length there was no significant effect of grammatical word class: She correctly read 82% (23/28) of nouns, 75% (21/28) of adjectives; 68% (19/28) of verbs, and 70% (14/20) of functors. Neither was there a significant effect of concreteness: R.W. correctly read 81% (17/21) of concrete nouns and 86% (18/21) of abstract nouns matched for frequency and length in letters and syllables. Finally, there was no overall effect of length. On a list of words counterbalanced for length and frequency, 14/14 four-letter words and 13/14 words of each length from five to eight letters were read accurately. However, as discussed in greater detail below, the error rate for

individual letter positions did increase as a function of the number of letters from the center of the word, such that, for example, the error rate on the initial letter of words was significantly lower for shorter words than for longer words.

There was no overall effect of ortho-phonological regularity; R.W. correctly read 20/24 (83%) of three- to five-letter words, both with regular-consistent (e.g. *greed*) and with regular-inconsistent (e.g. *days*) spelling to pronunciation correspondences, 16/24 (67%) words with exceptional spelling to pronunciation correspondences (e.g. *says*), and 23/24 (96%) orthographically unique words ($X^2_3 = 5.79$; n.s.). Orthographically unique words—words with spellings of final vowel-consonant clusters that are unique to that word, such as *doubt*—were read more accurately than any of the other word types; the difference between orthographically unique words and exceptional words just reached significance ($X^2_1 = 4.03$; $P < 0.05$). Thus, words with no orthographic “neighbors”, and in particular those for which no other words share the letter sequence to the right of the first couple of letters, were very likely to be read correctly.

The main lexical dimension to influence significantly R.W.’s reading accuracy was word frequency. She correctly read 90% (125/139) of high-frequency words and 77% (107/139) of low-frequency words matched for word class and length ($X^2_1 = 7.53$; $P < 0.01$). Moreover, her incorrect responses were usually higher frequency words that shared all but the initial letters with the stimulus (e.g. *heir* → “their”; *oyster* → “sister”; *sleek* → “week”). On the combined lists of words (in regular print), the mean frequency of the misread stimuli was 57.3, and the mean frequency of the incorrect responses was 151.1 (paired *t*-test: $t = 1.923$; d.f. = 79; $P < 0.03$; mean difference between stimulus and response frequency = 94.9). She also tended to lexicalize nonwords, by reading them as words that shared all but the initial letters with the stimulus (e.g. *chench* → “french”; *reech* → “speech”; *kwine* → “wine”; *mushrame* → “frame”; *snoy* → “annoy”). R.W. was more likely to read words correctly than nonwords: she accurately read 75% (63/84) of words and 31% (21/68) of nonwords of the same length ($X^2_1 = 40.02$; $P \ll 0.0001$). Among nonwords, there was no significant difference between pseudohomophones (e.g. *hunnee*) and nonhomophones (e.g. *hannee*); they were 32 and 29% correct, respectively.

Error types

A total of 79% (302/382) of R.W.’s incorrect responses in reading words in standard format—i.e. printed horizontally, left to right—involved only the initial letters of the word. There were approximately equal numbers of insertions ($n = 90$; *rugged* → “drugged”; *member* → “remember”), deletions ($n = 88$; *broad* → “road”; *rewrite* → “write”), and substitutions of the initial letter or letters on the left end of words ($n = 94$; *paid* → “said”; *borough* → “through”). The remaining left-sided errors were mixtures of these types ($n = 30$; e.g. *sought* → “drought”; *proven* → “woven”). R.W.’s other errors included “don’t know” responses ($n = 11$) and visually similar words in which incorrect letters were not exclusively on the left ($n = 69$). The latter type of error usually involved the initial letters as well as other letters in the word (e.g. *strange* → “triangle”; *weights* → “height”; *greet* → “agree”; *severe* → “reverse”), but R.W. occasionally also made inflectional errors at the end of words (*emotion* → “emotions”).

Effects of format: standard vs topographically transformed print

On the JHU Dyslexia Battery (normal, left-right print), R.W. made 79 errors on 284 stimuli (28% errors). When the same stimuli were presented in the same font, in mirror-

reversed print, she made 23 (8%) errors ($X_1^2 = 36.15$; $P \ll 0.0001$). More importantly, her errors were markedly different in quality. Whereas the majority of errors in reading normal print occurred on the **initial** letters of the word or nonword, the majority of her errors in reading mirror-reversed print occurred on the **final** letters of the word or nonword (e.g. *severe* → “seven”; *though* → “thought”; *bole* → “bold”). In both cases, she made errors on the **left side of the physical stimulus**, since the initial letters of a normally printed word, but the final letters of a mirror-reversed word, are on the left side. Of her 23 errors in mirror reversed reading, 13 were final letter errors, three were other visually similar words (e.g. *province* → “providence”), and seven were “don’t know” responses. The fact that the initial letters were successfully processed in mirror-reversed reading, but not in reading normal print, might explain R.W.’s significantly higher accuracy in the former task. That is, the initial letters may be more informative with respect to word recognition than final letters. Alternatively, it could be that since R.W. seemed to spend more time on the less familiar task of mirror-reversed reading (although her responses were not timed), she was able to extract more information from the stimulus in this task.

In reading vertically printed words, R.W. made errors on 10% (18/167) of words. Of these errors, six occurred on the initial letters (e.g. *hose* → “nose”), 10 occurred on middle letters (e.g. *daze* → “doze”), and two occurred at the end of words (e.g. *your* → “yours”). Unlike errors in normal reading, her errors in vertical reading were most often substitutions of visually similar letters (e.g. h/n, b/d, a/o).

Conclusions regarding the level of deficit. There are several features of R.W.’s performance that are pertinent to determining the probable locus of damage underlying her reading impairment. These include the absence of lexical and orthophonological effects (aside from an effect of frequency),* the vast preponderance of left-sided errors for standard print, and the interaction of topographic arrangement of stimuli with spatial position of errors within words—errors occurred on the physical left side of stimuli: the beginning of words for print in standard display and the end of words for mirror-reversed stimuli. The spatially-specific nature of the impairment and the absence of lexical effects (aside from word frequency) on performance are consistent with a prelexical, visual processing deficit as the cause of the reading impairment. Furthermore, since the probability of an error as a function of letter position was determined by the relative physical location of the letters (and not their relative within-word position), we can rule out as a probable locus of damage a processing deficit at the level of word-centered, grapheme descriptions. Additional analyses of R.W.’s performance, reported below, further restrict the probable locus of damage to the stimulus-centered, letter-shape map.

Error rate as a function of letter position

R.W.’s error rate at each letter position for each word or nonword length (for which there was a sufficient number of stimuli tested) was determined. For this analysis, stimuli included all words and nonwords that were presented in the standard, horizontal format (including a

*It is possible that the frequency effect is attributable at least in part to her education level; i.e. that some of the low frequency words were never in her lexicon. We do not have norms for these lists for R.W.’s age, education, and geographic region (she went to school in rural North Carolina which at that time had a very different educational system from that of urban Baltimore). However, the fact that she correctly read all but 8% of the words when presented in mirror-reversed print indicates that she could, in fact, recognize nearly all of the words. Furthermore, the most significant finding for our account—that her error responses tended to be words that were higher in frequency than the stimulus words—pertained even to those words that were almost certainly familiar to her premorbidly (e.g. *paid* → “said”).

list of 650 words and 140 nonwords from the Johns Hopkins University Morphology Battery [1], for a total of 1789 stimuli. All 379 of her errors across positions (often there were errors in more than one position of the stimulus) were included in this analysis.* Each letter of the stimulus was assigned a position from the beginning of the string. The response was then compared to the target. A missing or incorrect letter in place of a letter in the stimulus was scored as a one point error in that position. Transposed letters (e.g. the *r* and *a* in *era* → “ear”) were scored as one/two point error in the position of each of the transposed letters. Inserted letters were scored as one/two point error in each letter position adjacent to the inserted letter. Percentages of errors at each letter position are summarized in Table 1. Two facts emerge from this analysis: (1) errors occurred virtually only on the left *half* of a stimulus; and (2) errors increased steadily as a function of the number of letters from the center of the word.

Table 1. R.W.'s percentage of reading errors at each position for centered letter string

Length	Letter position														
	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7
4					9	2	0			0					
5				14	7	1			1		0				
6			10	5	1			1		0		0			
7		11	6	4	1			0		0		0			
8	19	11	8	4	1			0		1		1			1

Total *n*: for four-letter strings = 508; five-letter strings = 321; for six-letter strings = 431; for seven-letter strings = 345; for eight-letter strings = 184.

Prefix and suffix effects

Another way of testing the hypothesis that errors increase as a function of the number of letters from the center of the stimulus word is to compare the error rates on the initial letters of specific words when they are presented in prefixed, unaffixed, and suffixed forms. To illustrate, if processing of the left side of the word were impaired, *latch* would have some probability of being read incorrectly as “catch”, “hatch”, “watch”, “witch”, “hitch”, etc. because *la-* is on the left half of the word. However, the *la* in *latch* would be less likely to be read incorrectly in the word *unlatch*, because it is closer to the center of the word. By the same token, the *la* in *latch* would be even more likely to be read incorrectly in the word *latched* than in the unaffixed word because in such cases it would be even further to the left of the center of the word. The effects should be the same when the added prefix or suffix yields a pseudoword (e.g. unroof). These expectations were assessed in an experiment with real and pseudo-affixed words.

Unaffixed stimuli consisted of 57 four-letter words that could be changed to a different word or words if either the first or last letter were changed (e.g. *trim* → *trip* or *grim*). These words were randomly presented with the same words to which a suffix had been added (e.g. *trimless*) in one case, and a prefix (*pretrim*) in the other. The critical dependent variable was

*“Visual” errors that did not appear to be attributable solely to her spatially specific deficit were included even though this inclusion could add “noise” to the analysis. This scoring method was used because any attempt to choose a criterion for including only “neglect” errors would prejudice the issue of the influence of the deficit on processing letters in various positions of words.

performance in reading the stem (e.g. *trim*) part of the stimuli in all three conditions. R.W. made one (2%) error on the stems in prefixed condition, seven (12%) errors in the unaffixed condition, and 25 (44%) errors in the suffixed condition ($X^2_2 = 35.15$; $P \ll 0.0001$). In other words, her errors on the stems decreased when the initial letters were closer to the center of the word and increased when the initial letters were further from the center of the word. For example, she read *hail* as "wail", but read the stem part of *nonhail* correctly; and she read *bark* correctly but read *barkless* as "sparkless". It was not that she made fewer errors on prefixed than on unaffixed words, but simply that her errors on prefixed words almost always involved the prefix part of the stimulus. For example, she read *clap* as "slap" and *disclap* as "misclap"; and she read both *mail* and *premail* as "mail". The results of R.W.'s reading are precisely the mirror image of the results obtained with the same stimuli read by our patient, N.G. [4, 5], who had a spatially-specific (neglect) deficit for the right part of words (Table 2).*

Table 2. Percentage of errors on four-letter words across three conditions for R.W. vs N.G. (results given in % error (No. of errors/57))

	R.W.'s stem errors	N.G.'s stem errors	R.W.'s affix errors	N.G.'s affix errors
Prefixed	2	37	28	2
Unaffixed	12	12	0	0
Suffixed	44	0	2	16

A similar experiment was carried out with real-word stimuli. On a list of 41 prefixed words and the same words with a suffix (e.g. *mistrust*, *mistrusting*), R.W. was more likely to make an error on the prefix when a suffix was also present. She misread 12% of prefixes in words that were not suffixed, and 27% of prefixes in words that were also suffixed (a difference that does not reach significance, probably due to the small number of stimuli). For example, she read *unpack* correctly, but read *unpacked* as "packed"; and she read *disloyal* correctly, but read *disloyalty* as "loyalty". These results provide further evidence that the probability of making an error on a given letter or letters increases as the letters occur further to the left of the center of the stimulus.

Conclusions regarding the distribution of errors. As in previously reported cases (e.g. Refs [4, 5, 7, 24]), R.W.'s errors in reading occurred principally on the contralesional side of the word. Furthermore, errors were virtually restricted to the left half of the word, and increased as a function of distance from the center. The latter two facts, together with the observation that errors are restricted to the physical, left half of the stimulus, indicate that the deficit concerns a stimulus-centered and not a word-centered representation.

Effects of location of word on page

R.W. read 72 words that were printed in nine columns across a horizontal (landscaped) 11 × 8.5 in. page. She initially omitted many words in the left column, but responded to them with prompts. She misread 1/8 words in columns 1–6 and 8; and made no errors on words in

*In this context, it is worth noting that R.W.'s only suffix errors occurred at the beginning of the suffix (e.g. *glumtion* → "plum-nation"), and N.G.'s only prefix errors occurred at the end of the prefix (e.g. *nonquiz* → "no-quit"), suggesting that in some cases the stimuli were parsed and treated as compounds.

columns 7 and 9. In a second task, she read 60 words that were randomly scattered across two pages. She again showed no difference in accuracy with respect to words on the left vs the right side of the page. Her error rates in reading words that fell into five columns, from left to right, were as follows: 17%, 18%, 19%, 0%, 17%.

Effects of spacing

Additional tests were designed to determine whether spatial extent as determined by spacing between individual letters of the word would affect reading performance. A set of 72 words that share all but the first letter with one or more words, such as *wicked* (which shares final letters with *licked*, *picked*, *ticked*, etc.) and *tumble* (which shares final letters with *humble*, *mumble*, *rumble*, *fumble*, etc.) was presented in three spacing conditions in mixed, random order: with no spaces (e.g. *rocket*), with two spaces between each letter (e.g. *r o c k e t*), and with three spaces between each letter (e.g. *r o c k e t*). For the entire set (combined word lengths) she made 6% errors when stimuli were presented with no spaces, 11% errors when there were two spaces, and 22% errors when there were three spaces between letters ($X^2_2 = 8.53$; $P = 0.01$). Nearly all of her errors in each of the conditions involved the initial letter of the words.

Since these words were selected to allow substitution errors on the initial letter in the presence of impaired processing on the left side of the word, it is especially informative to examine the percentage of errors on the initial letter as a function of the number of letters in the word and the spacing between letters. These data are presented in Table 3. R.W. showed increased error rates as a function of the number of letters from the center of the word in all three conditions **and** increased error rates as a function of the number of spaces between letters for each word length.* Thus, for example, her percentage of errors for the first letter of six-letter words **with two spaces** between letters (eight letters/spaces from the center of the word) was substantially **higher than** her percentage of errors for the initial letter of eight-letter words with no spaces (four letters/spaces from the center of the word). By contrast, her percentage of errors for six-letter words with **no spaces** between letters (three letters/spaces from the center) was **lower than** her percentage of errors for the first position of eight-letter words with no spaces. Consistent with the hypothesis that R.W.'s errors increased as a function of physical distance from the center of the word, it can be seen in Table 3 that initial letter accuracy decreased most precipitously as a function of word length in letters in the three-spaces condition, in which an additional letter results in the greatest increase in physical distance from the center of the word.

An additional list of words, consisting of 125 words, 4–10 letters in length, each with an embedded word on the right (e.g. *tenants*, *valley*) was presented in two conditions: with no spaces between letters and with two spaces between letters. R.W. made 11% errors in the no-spaces condition and 24% errors in the two-spaces condition ($X^2_1 = 6.21$; $P < 0.05$). Although most of her errors concerned the left part of the word, R.W. never produced the embedded instead of the stimulus word. Instead, her errors tended to be substitutions (*couch*→“pouch”; *braise*→“praise”) and/or insertions (*tripped*→“stripped”; *orange*→“arrange”; *ledge*→“pledge”) of letters on the left. Analyses of error rates as a function of

*Regrettably, we did not test R.W.'s reading of words with one space between letters, or reading of shorter or longer words with spaces between letters, which would have allowed a direct comparison between the number of spaces plus letters vs the number of letters only, from the center of the word. For example, the initial letter of a seven-letter word with no spaces is the same “distance” (in spaces/letters) from the center of a word as the initial letter of a four-letter word with one space between each letter.

Table 3. Percentage of errors on initial letter of words in three conditions

Word length	No spaces	Number of spaces between letters	
		2 spaces	3 spaces
5 letters ex.: tight →"might"	0%	6% t i g h t	10% t i g h t
6 letters ex.: willow →"pillow"	9%	26% w i l l o w	43% w i l l o w
7 letters ex.: fitness →"witness"	10%	30% f i t n e s s	50% f i t n e s s
8 letters ex.: canister →"banister"	18%	33% c a n i s t e r	100% c a n i s t e r

letters/spaces from the center of the word was not possible, since there were too few words of each length. However, it is clear that R.W.'s errors increased with increased spacing between letters, and this result does not appear to be due to a failure to process the complete letter string if spaces are present (since she did not seem to simply "skip" the initial letters and thereby produce the embedded word on the right).

Conclusions regarding the effect of letter spacing on reading. Two aspects of R.W.'s performance are of interest here: the fact that she was able to process words in all locations of the page, and the fact that the probability that she would misread a letter on the left half of a word was a function of its physical distance from the center of the word. The implication of the latter result, together with those that established that R.W.'s deficit concerns the stimulus-centered, letter-shape map, is that the letter-shape map retains relative physical distances in representing the word stimulus. We will return to this issue in the Discussion section.

Spelling performance

R.W. wrote to dictation 360 words and 34 nonwords, spelled aloud 42 words and 19 nonwords, and wrote the names of 52 pictured objects, in the Johns Hopkins Dysgraphia Battery [10]. She also transcribed 125 words and nonwords from upper to lower case or vice versa, both in direct copying and immediately after the stimulus was removed (delayed copy). All of her written responses except in transcribing to upper case were in script (her preference). She wrote with her right, dominant hand.

In all written spelling tasks (dictation, picture-naming, and transcribing tasks), R.W. made four types of errors: phonologically plausible spelling errors (e.g. "grew" → *grue*); phonologically implausible nonword responses that involved substitution, deletion, transposition or insertion of one or more letters (e.g. "language" → *langage*); perseverative letters (e.g. three e's together); and malformed letters with perseverative strokes (e.g. an m with four or more humps) or missing strokes (e.g. an uncrossed t). Some of the first two types of errors (phonologically plausible and implausible nonword responses) could simply reflect her poor premorbid spelling ability: R.W. often reported that she did not know how to spell a given word before her stroke. Consequently, we will only report aspects of her performance that

would not seem to reflect her limited premorbid spelling knowledge, such as the production of letter perseveration and missing stroke errors.

Malformed and perseverative letters

R.W. made 80/207 (39%) errors in forming six letters of the alphabet. She produced four letters that have inverted or upright “humps” in script—y, w, m, and u—with one or more extra humps, and omitted parts of two letters—t and i. The rates of her “perseverative” stroke errors on each letter were as follows: y—26% (7/27), w—32% (7/22); m—40% (10/25); and u—60% (31/52). These errors occurred in all positions of words, with approximately equal frequency (e.g. *borrow*, *about*, *jumpable*). They occurred in written naming (e.g. *comb*), delayed transcoding (e.g. *ENOUGH*→*enough*), and direct transcoding (e.g. *PURSUIT*→*pursuit*), as well as writing to dictation. However, in transcoding to upper case print, her only (possible) letter formation errors were substitutions M for N.

R.W. failed to cross 26% (12/45) of t’s on the left half of words, and 6% (5/80) of t’s on the right half of words ($X^2_1 = 8.55$; $P < 0.001$). She failed to dot 7% (3/41) of the i’s on the right half of words and 15% (8/52) of the i’s on the left half of words. Her significantly higher frequency of malformed letters on the left compared to the right (20/97 vs 8/121; $X^2_1 = 8.23$ $P < 0.01$) is the only identified instance of a left-right spatial bias in R.W.’s spelling to dictation.*

R.W. also made perseverative whole letter errors involving letters with “hoops”. Most (8/10) of these errors involved producing an extra letter in the context of double e’s or l’s (e.g. *keep*, *sheep*, *cheer*, *shall*, *million*). She also repeated two singleton o’s (*riot*, *lodge*).

Error rates across letter positions

Writing errors (of all types) as a function of letter position within a string for each word length were scored with the same method used for reading errors. The results are shown in Table 4. There clearly is no consistent pattern of increased error rate with respect to letter position. If anything, the initial letter seems to be relatively spared at all word lengths.

Conclusions from spelling. R.W., like the “left neglect” patient, V.B., reported by ELLIS *et al.* [7], made letter-formation and spelling errors that did not cluster toward the beginning of words. Her most frequent type of error involved repeated or missing strokes in forming letters, and only her failure to cross t’s occurred more frequently on the left than the right side of words. ELLIS *et al.* [8] have attributed a similar pattern of spelling errors in their patient V.B. to a failure of visual and kinesthetic feedback mechanisms in the presence of an attentional deficit, partly on the grounds that normal subjects make identical sorts of errors when asked to write with their eyes closed while tapping with their nondominant hand. Although it is fair to say that R.W.’s writing errors are not inconsistent with the account put

*Also, in copy transcoding tasks **only**, phonologically implausible errors occurred more often on the left than on the right side of words (31/50 on the left). Examples include: *BOKE*→*koke*; *MOMENT*→*conent*; *haygrid*→*gaygrid*; *reesh*→*FREESH*. A large percentage (76%; 50/66) of her error responses or 20% (50/250) of total responses, in copy transcoding tasks were phonologically implausible (e.g. *TEEBLE*→*sleele* in delayed copy transcoding; *brisk*→*BORISK* in direct copy transcoding), whereas only 14% (23/161) of her incorrect responses, or 6% (23/360) total responses, in spelling to dictation were of this type (of which many also had letter formation errors). Furthermore, in delayed copy transcoding, but not in any other spelling task, RW made one left-sided error that resulted in a word visually similar to the stimulus: *RIGID*→*frigid*. Thus, it is very likely that many of her left-sided errors in copy transcoding resulted from misreading the stimulus, rather than in written output.

Table 4. R.W.'s percentage of spelling errors at each position for centered letter string

Length	Letter position														
	Center														
	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7
4					2		11		8		14				
5				7		9		14		12		12			
6			6		17		10		25		13		17		
7		0		22		14		14		24		17		11	
8	6		24		12		6		29		18		9		3

Total *n*: for four-letter strings = 87; five-letter strings = 122; for six-letter strings = 36; for seven-letter strings = 27; for eight-letter strings = 17.

forth by Ellis and colleagues, it remains unclear the level of output representation at which the noted effects are supposed to take place.

R.W.'s remaining errors were either uncommon phonologically implausible misspellings, or errors that might be attributed to her relatively low educational background (phonologically plausible misspellings or "don't know" responses, particularly on low-frequency words), or to an additional deficit to the orthographic output lexicon. Because of this uncertainty, these errors were not considered further. Nonetheless, it is useful to note that her pattern of spelling performance is markedly different from that of ORF (Baxter and Warrington [2]) and patients we have previously reported (N.G. [4, 5]; H.H. [12]; H.B.; [11]), whose contralesional spelling and reading errors might be attributed to a spatially-specific deficit at the level of an internal representation common to both spelling and reading—the grapheme description level. Thus, R.W.'s spelling errors, which unlike her reading errors were not restricted to the contralesional side of words, cannot be assumed to arise from a spatially-specific processing deficit at the level of grapheme representations.

DISCUSSION

The principal results in the major part of the present investigation (reading) may be summarized as follows:

- (1) R.W. predominantly made reading errors on the left *half* of words, regardless of word length, with errors increasing monotonically as a function of distance from the center of the word. This fact implies that the damage concerns a level of representation with coordinates defined by the boundaries of the stimulus.
- (2) The format and type of stimulus input had a major effect on R.W.'s reading performance. Thus, although she predominantly made errors in the beginning (left side) of words in reading standard, horizontal print; she made roughly equal numbers of errors in all positions of words in reading vertically printed stimuli, and she made errors at the end (the physical left side) of words in reading mirror-reversed stimuli. Furthermore, she did not make spatially-specific errors in recognizing aurally spelled words. These facts rule out as a possible level of damage the grapheme description which, by hypothesis, is common to all reading tasks and aural spelling recognition; and, thus, we would expect similar patterns of spatially-specific errors in all these tasks. Instead, they indicate that the damage must concern a visually-based representation, as indicated

by the dissociation between reading and aural spelling recognition and by the fact that left-sided errors only occurred for horizontally arrayed letters (and not for vertically presented print). This conclusion is further supported by the fact that for standard, horizontally-oriented print her errors concerned the *beginning* of the word (the left side of the stimulus), but for mirror-reversed print her errors concerned the *end* of the word (the left side of the stimulus).

- (3) Adding a prefix to a word reduced the probability that R.W. would make an error on the stem, while adding a suffix increased the probability that she would make an error on the stem. These facts further imply that the level of processing impairment in R.W. concerns a stimulus- (or word-) centered representation.
- (4) R.W.'s reading performance was essentially unaffected by the physical location of words on a page, implying that she was not particularly impaired in processing information at a level where representations are coded by reference to retinal coordinates—the retino-centric, feature map. However, word length and spacing between letters had a major effect on her reading performance: she was more likely to make an error on the rightmost part of a stimulus the further it was from the center of the word, either in number of letters or in physical distance. The latter fact implies that R.W.'s processing deficit concerns a level of representation at which relative spatial distances are retained. Thus, the facts in (1)–(4) together imply that the stimulus-centered, letter-shape map retains the relative distances of the stimulus input.

It would seem, then, that the pattern of reading (and spelling) performance reported for R.W. is consistent with expectations derived from the model of visual word recognition proposed by CARAMAZZA and HILLIS [5] (see also RAPP and CARAMAZZA [20]), but poses a serious challenge to a somewhat similar model proposed by MONK [18].

In his model of word reading, MONK [18] distinguished between representations on the basis of whether the relative positions of information primitives (feature, letter shapes, graphemes, etc.) are specified with respect to retinal coordinates (position in visual field), spatial coordinates (position on page), word-centered coordinates (position in word), or sentence coordinates. R.W.'s pattern of errors in reading defies description in terms of these types of coordinate frames. Because there was no significant influence of the location of a word on the page on R.W.'s reading, her errors cannot be accounted for by impairment specific to position in the visual field or position on the page. Further, since the rate and spatial distribution of her errors were dramatically influenced by the orientation of the stimulus word (horizontal vs vertical and mirror-reversed reading), her pattern of performance cannot result from damage at a level at which word-centered, graphemic descriptions are computed. For in the latter case, the effects on performance would be expected to be invariant with respect to topographic transformations of a stimulus—that is, errors should occur at the end or beginning (depending on the side of brain damage) of a word regardless of the topographic arrangement of letters. Further, such damage would be expected to affect reading and spelling in qualitatively similar ways. Neither of these expectations were confirmed by R.W.'s performance. However, as argued above, her performance can be explained by proposing impaired processing of the left side of a representation with spatial coordinates differing from those discussed by Monk: *viz.*, coordinates with axes defined by the boundaries of the physical word (or pseudoword) stimulus—a stimulus-centered, letter-shape map as proposed by CARAMAZZA and HILLIS [5].

The conclusion that the letter-shape map has stimulus coordinates rather than retinal

coordinates might seem to be at odds with experimental evidence from normal readers cited by MONK [18] in support of his contention that representations with visual features *or* letters as primitives are specified in terms of retinal coordinates. Evidence came from two types of experiments. In the first, McCONKIE and ZOLA (1979) showed that reading of text presented in alternating case was unaffected when the case alternation shifted (e.g. CaSe→cAsE) during a saccade. In the second, RAYNER *et al.* [22] found that words presented in the parafovea primed subsequent identification of the word, even if the prime was in a different case. They concluded that information about letters, rather than simply about visual features, was integrated across saccades. However, this conclusion about “letters” clearly refers to graphemes rather than specific letter shapes, since letter shapes are different for different cases. Moreover, it is not clear that the results would require that the representations, that support such integration across saccades, would maintain retinal coordinates. Rather, it is more likely that the hypothesized integration occurs at a level where more abstract representations with stimulus- and/or word-centered coordinates are computed. Consistent with the latter hypothesis, results from eye movement-contingent displays showed that when peripheral letter string shared certain graphemes with the target that is eventually fixated, naming is facilitated more than if the peripheral string shared no graphemes. On the basis of these results, RAYNER *et al.* [22] concluded that representations with graphemes as primitives are used to integrate information from successive saccades. This hypothesis would account for the results of case alteration and cross-case priming, without requiring that representations of the letter string have retinal coordinates.

In short, none of the above results are inconsistent with the hypothesis that an intermediate representation of the letter shapes with stimulus-centered coordinates is computed in reading and used to activate the representations with graphemes as primitives and word-centered coordinates. In fact, what Monk discusses as a “word-centered” representation seems to be equivalent to what we have called the stimulus-centered representation. The evidence he presented for a word-centered representation—e.g. that omissions of letters are easier to detect than letter substitutions in proof-reading—might reasonably be interpreted as evidence for a stimulus-centered representation (of specific letter shapes) rather than as evidence for a word-centered representation (of graphemes).

The conclusion that the coordinates of the stimulus-centered representation are the boundaries of the physical word leaves open the question of **how** transformation of this representation to a word-centered graphemic description takes place. We have proposed that the letter-shape map retains the arrangement as well as the orientation of the letters in the physical stimulus, such that, for example, the initial letters of a mirror-reversed word are on the right side and oriented right to left. Is this representation then processed right to left in order to compute a graphemic description of the word? Unfortunately, our data do not speak to this issue, except in the sense that R.W.’s error performance can only be explained by assuming that the reversed orientation of all the letters in the letter-shape map is sufficient information for coding the right letter as the initial letter (and thus for processing the corresponding grapheme as the initial, left-sided segment of the graphemic description).

In the same vein we have assumed that the standard orientation of the letters in vertical strings results in processing the top letters as the initial graphemes of the word. Presumably, although we have no data to support it, if the letters in a vertical string were oriented bottom to top (so that the whole word would appear to be printed rotated 90 degrees counterclockwise from standard print), or if all the letters in a vertical array were upside down, the bottom letters would be processed as the initial graphemes. However, the only

prediction possible from our conclusions about the structure of the letter-shape map is that, irrespective of how the string is processed (top to bottom or bottom to top), the left side of the string is the left side of the representation at this level, the top of the string is the top of the representation, and so on. Hence, the presence of a left-sided impairment at the stimulus-centered level of representation should not substantially affect reading of any vertical array, regardless of the orientation of the letters or its position on the page.* Thus, although a vertical string of letters may be processed differently from a horizontal string of letters (top to bottom rather than left to right), we have presented evidence that the levels of representation computed in the word recognition process are identical in response to the two types of stimuli, and more specifically, that these levels of representation include one that is centered with respect to the boundaries of the physical stimulus.

In this discussion we have argued that a stimulus-centered, letter-shape representation is computed in the course of reading a word. In conjunction with contrasting patterns of performance that are consistent with damage to different levels of representation [4, 5, 20], this case provides additional evidence in support of the model of word recognition presented in Fig. 1. Some aspects of this model are also supported by patterns of reading performance by patients previously reported by [3], ELLIS *et al.* [7, 8], KINSBOURNE and WARRINGTON [14], and RIDDOCH *et al.* [23]. However, while several of the effects on reading performance shown by R.W. have been recorded individually in previous studies, analyses in earlier cases have not been designed to test hypotheses about the letter-shape map. Localizing R.W.'s damage in the word recognition process to a stimulus-centered representation permitted us to describe specific characteristics of such a representation. Thus, for example, we have suggested that the letter-shape map codes relative physical distances. Nonetheless, many important questions about the different levels of representation of letter strings computed in the reading process, such as how they are processed when reading vertical vs horizontal strings and their relation to the representations computed in object recognition, remain unanswered. This and previous reports of performance by patients with spatially specific deficits clinically classified as "unilateral neglect" indicate that the study of such patients provides a fruitful avenue for investigating these problems.

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REFERENCES

1. BADECKER, W. and CARAMAZZA, A. *The Johns Hopkins University Morphology Battery*. The Johns Hopkins University, Baltimore, MD, 1986.
2. BAXTER, D. M. and WARRINGTON, E. K. Neglect dysgraphia. *J. Neurol., Neurosurg., Psychiat.* **45**, 1073–1078, 1983.

*This conclusion is viable only on the assumption that the information available from each individual letter is sufficient to activate the corresponding grapheme. This assumption seems reasonable in the case of R.W., since she was 100% accurate in single-letter identification. We are also assuming that the page and the reader are aligned such that the left side of the stimulus is the left side of the reader. If the page and thus the stimulus (or the reader) is rotated independently, the coordinates of the stimulus change. Note, finally, that we would expect difficulty in reading vertical arrays in the presence of specific deficit in processing the bottom or top of the letter-shape map (or feature map).

3. BEHRMANN, N., MOSCOVITCH, M., BLACK, S. E. and MOZER, M. C. Perceptual and conceptual factors in neglect: Two contrasting case studies. *Brain* **113**, 1163–1183, 1990.
4. CARAMAZZA, A. and HILLIS, A. Levels of representation, coordinate frames, and unilateral neglect. *Cogn. Neuropsychol.* **7**, 391–455, 1990a.
5. CARAMAZZA, A. and HILLIS, A. Spatial representation of words in the brain implied by the studies of a unilateral neglect patient. *Nature* **346**, 267–269, 1990b.
6. DRIVER, J. and HALLIGAN, P. W. Can visual neglect operate in object-centered coordinates?: An affirmative single case study. *Cognitive Neuropsychology*, in press.
7. ELLIS, A. W., FLUDE, B. M. and YOUNG, A. W. “Neglect dyslexia” and the early visual processing of letters in words and nonwords. *Cogn. Neuropsychol.* **4**, 439–464, 1987a.
8. ELLIS, A. W., FLUDE, B. M. and YOUNG, A. W. “Afferent dysgraphia” in a patient and in normal subjects. *Cogn. Neuropsychol.* **4**, 465–486, 1987b.
9. GOODMAN, R. A. and CARAMAZZA, A. *The Johns Hopkins Dysgraphia Battery*. The Johns Hopkins University, Baltimore, MD, 1986a.
10. GOODMAN, R. A. and CARAMAZZA, A. *The Johns Hopkins Dyslexia Battery*. The Johns Hopkins University, Baltimore, MD, 1986b.
11. HILLIS, A. E. and CARAMAZZA, A. Spatially-specific deficit in processing graphemic representations in a case of “neglect dysgraphia”. Reports from the Johns Hopkins Cognitive Neuropsychology Laboratory, Baltimore, MD, 1991.
12. HILLIS, A. E. and CARAMAZZA, A. The effects of attentional deficits in reading and spelling. In A. CARAMAZZA (Ed.), *Cognitive Neuropsychology and neurolinguistics: advances in models of language processing and impairment*. Lawrence Erlbaum Associates, Hillsdale, NJ, 1990.
13. HOOPER, H. E. *The Hooper Visual Organization Test*. The Western Psychological Assn, Beverly Hills, CA, 1957.
14. KINSBOURNE, M. and WARRINGTON, E. K. A variety of reading disability associate with right hemisphere lesions. *J. Neurol. Neurosurg. Psychiat.* **25**, 334–339, 1962.
15. MCCONKIE, G. W. and ZOLA, D. Is visual information integrated across successive fixations in reading? *Percept. Psychophys.* **25**, 221–224, 1979.
16. MARR, D. *Vision*. Freeman, New York, 1982.
17. MARR, D. and NISHIHARA, H. K. Representation and recognition of the spatial organization of three-dimensional shapes. *Proc. R. Soc. Lond.* **200**, 269–294, 1978.
18. MONK, A. F. Co-ordinate systems in visual word recognition. *Q. J. exp. Psychol.* **37(A)**, 613–625, 1985.
19. RAPP, B. C., BENZING, L. and CARAMAZZA, A. Stimulus characteristics and visual neglect. Paper presented at TENNET II, Montreal, Canada, April, 1991.
20. RAPP, B. C. and CARAMAZZA, A. Spatially determined deficits in letter and word processing. *Cogn. Neuropsychol.*, 275–312, 1991.
21. RAVEN, J. *Coloured Progressive Matrices*. Lewis, London, 1962.
22. RAYNER, K., MCCONKIE, G. W. and ZOLA, D. Integrating information across eye movements. *Cogn. Psychol.* **12**, 206–226, 1980.
23. RIDDOCH, M. J., HUMPHREYS, G. W., CLETON, P. and FERY, P. Levels of coding in neglect dyslexia. *Cogn. Neuropsychol.* **7**, 479–517, 1990.
24. WARRINGTON, E. K. Right neglect dyslexia. A single case study. *Cogn. Neuropsychol.*, 193–212, 1991.
25. WECHSLER, D. *The Wechsler Memory Scale*. The Psychological Corp., New York, 1972.
26. YOUNG, A., NEWCOMBE, F. and ELLIS, A. Different impairments contribute to neglect dyslexia. *Cogn. Neuropsychol.*, 177–192, 1991.

APPENDIX A: R.W.'s DIRECT COPY OF A SCENE



APPENDIX B: EXAMPLES OF R.W.'s WRITING

Her verbalization of what she wrote: "Kid falling from a ladder . . . cookie spill from jar—I should have said **taken** from the jar—I was thinking of the water spilling from the sink. . . . I wrote 'overflow' and 'sink' . . . and 'doing dishes'." In the lower page: "[name and street number deleted], Bennett Rd., Balto., Md, 21221."

*Kid falling from ladder
 Cookie spill from jar
 overflow sink doing
 dishes*

*Bennett Rd
 Balto Md
 21221*