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Rehabilitation for Pure Alexia: Efficacy of Therapy and Implications for Models of Normal Word Recognition

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In an attempt to remediate the deficit in letter processing thought to underlie pure alexia or letter-by-letter reading, a therapy programme was implemented with SI, a 46 year-old woman with pure alexia following a posterior cerebral artery infarction. Prior to the intervention programme, SI's reading and letter processing abilities were characterised in detail, and baseline measurements were taken to rule out spontaneous recovery or fluctuations in her performance. A nine-week, intensive therapy programme was designed to alter SI's report of single letters as a function of serial position in a string from the observed linear function to a more normal M-shaped curve. This involved training SI to apprehend and report the identity of the letter in the final position of a string as string length was increased and exposure duration was decreased. Whereas SI's ability to recognise the final letter improved significantly on post-therapy measures, there was no significant transfer to her word reading performance. The word length effect—increase in reaction time with increasing word length—remained unchanged from pre- to post-therapy, although the intercept shifted downwards. These results raised questions about the relationship between processes involved in single letter report and word reading in normal processing. Findings from rehabilitation studies such as this are not only useful in determining the efficacy of particular intervention techniques but, importantly, shed light on the mechanisms underlying normal cognitive behaviour.

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INTRODUCTION

Cognitive neuropsychology aims to extend our understanding of the normal cognitive system by studying the behaviour of patients who have sustained brain damage that selectively affects performance in a particular cognitive domain. Through detailed observation of the way in which performance on various tasks is differentially impaired and/or preserved, theoretical insights about the mechanisms underlying normal cognition may be obtained. Whereas most of the research in cognitive neuropsychology focuses on characterising the steady-state behaviour of neurologically impaired patients, research in cognitive development and knowledge acquisition has shown that studying change can lead to increasingly precise theories about the mechanisms subserving cognitive behaviour (Siegler & Crowley, 1991; Siegler & Engle, 1994). In recent years, in cognitive neuropsychological research, there has also been a growing emphasis on studying change as a valuable source of evidence for understanding the processes underlying normal cognitive behaviour. This emphasis has come about largely through the implementation of theoretically guided treatment studies that have explored the re-acquisition of impaired cognitive skills in brain-damaged patients.

One major goal of these therapy studies is to use evidence from remediation research to test out particular hypotheses about the organisation of the normal cognitive system. For example, implementing a therapy programme to retrain process X, and noting that it generalises to process or domain Y but not to process or domain Z, can provide important constraints on theories of normal behaviour (Behrmann & Byng, 1992; Byng, 1988; Byng & Coltheart, 1986; Howard, 1986; Howard & Hatfield, 1987; Wilson & Patterson, 1990). A second goal of these therapy studies has been to study the patient's behaviour in detail and to develop better therapy procedures: Successfully determining the mechanism underlying the patient's deficit leads to increasingly efficient and effective therapy, and provides a systematic basis for remediation. Failures to improve performance following intervention have also proven informative, allowing us to delimit the range of patients for whom a particular approach is valuable. On the one hand, then, theoretical models of normal processing have constrained and guided the development of better remediation programmes for adults following brain injury. On the other hand, the outcomes of these intervention studies themselves have contributed to our knowledge of how normal processing functions.

While treatment studies of this sort have proven relatively successful in accomplishing these two main goals—one more practical, the other more theoretical—they have also been subject to criticism. Much of the criticism stems from the fact that the types of models used in cognitive neuropsychology are often insufficient for developing theory-based treatment approaches. The absence of detail regarding the computations and representations necessary for carrying out a particular task (Plaut, in press) and the lack of a theory of remediation for predicting the nature and direction of change (Caramazza, 1989; Hillis, 1993) seriously curtail the utility of this approach. In this paper, we take these criticisms into consideration and develop a therapy procedure based on established data from normal performance. We make specific predictions about the expected change in performance following therapy and employ testing procedures sensitive enough to detect differences relative to an established pre-intervention baseline. Specifically, we focus on the remediation of impaired letter processing in single word recognition in a patient, SI, who has remarkably few other neurobehavioural impairments. Prior to implementing the rehabilitation programme, we explore in detail the nature of SI's letter and word recognition disorder and compare her behaviour to performance curves obtained from normal subjects. By examining how she differs from the standard pattern of performance, we devise a therapy plan to re-align her letter detection performance with the normal pattern and predict that this will have direct consequences for other, related cognitive processes such as single word reading. At the conclusion of therapy, we examine whether there is any improvement in letter processing and, if so, whether this change really does have direct benefits for her reading performance.

Word reading deficits are the single type of cognitive deficit that has received the most attention in cognitive neuropsychology, and the bi-directional relationship between intervention studies and models of normal cognition is perhaps best exemplified in the treatment of acquired reading deficits or acquired dyslexia. To provide some perspective on the current study, we need to place SI's reading deficit in the broader context of these other studies of acquired dyslexia. There are many different forms of acquired dyslexia, roughly divided into those in which the deficit affects processing prior to the derivation of a "word form" or orthographic representation of the input string (*peripheral dyslexias*) and those in which the impairment arises at more conceptual stages of processing once an orthographic representation is attained (*central dyslexias*) (see Shallice, 1988). Most of the theoretically motivated cognitive intervention studies have dealt with dyslexias of the central type, with emphasis on retraining the ability to convert graphemes into phonemes (Berndt & Mitchum, 1994; de Partz, 1986; Hillis, 1993) or to access meaning or semantics directly from orthography (Coltheart & Byng, 1989; Scott & Byng, 1988; Weekes & Coltheart, in press). There are only a few studies that have explored the effects of intervention in patients with peripheral dyslexia or reading deficits at the early stages of reading during which the visual input is encoded and analysed. The next section describes one particular form of peripheral dyslexia, pure alexia, which is the pattern shown by patient SI. We describe the symptomatology and then summarise the existing studies designed to treat this deficit.

Pure alexia, or letter-by-letter reading, is characterised by disproportionately slow, but generally accurate, reading of single words and text in the absence of other marked neurobehavioural impairments in premorbidly literate adults. The hallmark of pure alexia is the word length effect: an increase in reaction time (RT) as the number of letters in a string increases. Letter-by-letter readers may require up to three or four seconds to name even common three-letter words, and for each additional letter, reading time is slowed incrementally (Patterson & Kay, 1982; Warrington & Shallice, 1980). Pure alexic patients can identify words that are spelled aloud to them and can spell words they cannot read. This deficit is usually associated with lesions to the left occipital lobe although it was originally suggested that a second lesion, involving the splenium of the corpus callosum, was necessary to produce this reading problem. Original accounts of pure alexia proposed that visual information could not access left hemisphere language areas because first, information could not be processed by the damaged left occipital cortex and second, visual information arriving at the preserved right visual cortex could not be transmitted to the left hemisphere because of the splenial lesion (Damasio & Damasio, 1983; Dejerine in Bub, Arguin, & Lecours, 1993). More recently, however, there have been many reports of patients with pure alexia who have only a single lesion, usually involving the left occipital lobe, following an infarction of the posterior cerebral artery (Behrmann, Black, & Bub, 1990). Although the reading problem is the most marked deficit in pure alexia, additional problems such as memory loss and colour agnosia may also be associated with it. Despite the fact that pure alexia was one of the first neurobehavioural deficits to be documented scientifically in the elegant case studies by Dejerine in 1891 and 1892 (Bub et al., 1993), it is still often overlooked in the rehabilitation setting (Marks & De Vito, 1987).

When pure alexia is diagnosed, perhaps the best explored method for its rehabilitation is the Multiple Oral Rereading (MOR) technique, initially developed by Moyer (1979). This technique requires the patient to read the same short text passage daily for approximately one week, after which time a second passage is given for a week and so on. This repetitive practice with the same text has proved successful both with pure alexic patients as well as with patients with more central forms of dyslexia (Moyer, 1979; Moody, 1988). In a recent study, for example, Tuomainen and Laine (1991) evaluated the single word and text reading speed of three patients with pure alexia all of whom completed a MOR rehabilitation programme. The most interesting result from this study is that, while text reading improved for some patients, their performance on lists of single words did not. Based on these results, Tuomainen and Laine (1991; see also Tuomainen & Laine,

1993) argued that the increase in text reading speed may be attributed to "top-down" processes that provide syntactic and semantic constraints and thereby facilitate the processing of single words. The benefit obtained from the MOR method, therefore, comes not from the direct alteration of the impaired functional system per se; rather, word processing is facilitated by virtue of the concurrent context.

A quite different approach to remediation with a pure alexic patient which also does not affect the putative functional lesion but nevertheless has yielded beneficial results is one in which kinesthetic facilitation accompanies reading. Kashiwagi and Kashiwagi (1989) had their Japanese patient copy characters while reading them aloud. After some time, the copying was phased out and reading practice continued. Following this training, improvement was observed in reading aloud but the change was restricted to the familiar (which had been copied) and not the unfamiliar symbols. Based on these findings, the authors suggested that kinesthetic images of characters, probably mediated by the intact right hemisphere, contributed to the improvement in reading. A more recent study which also involves kinesthetic feedback was carried out by Nitzberg Lott, Friedman, and Linebaugh (1994). They trained their pure alexic patient, TL, to trace letters onto the palm of his hand while naming them aloud. This training with single letters was particularly critical given that TL was impaired even in single letter visual identification. Following this tactile-kinesthetic intervention, TL showed a 50% improvement in the reading of trained items. Of even more interest is that he also showed a 40% increase in reading untrained words, demonstrating the effectiveness of the treatment programme.

As is evident, both the MOR procedure and kinesthetic facilitation produced positive and encouraging results for patients with pure alexia. In both cases, however, the damaged mechanism itself was not the focus of therapy. Rather, alternative, compensatory procedures were exploited to retrain word recognition. It remains an open question, therefore, whether pure alexia can be rehabilitated by a more direct approach in which the underlying impairment that gives rise to the overt reading deficit is treated. This would be consistent with the cognitive neuropsychology view in which the goal is to identify specifically and remediate that component of the cognitive system that is impaired. Identifying the deficient cognitive component, however, in the case of pure alexia has not been simple, and many differing interpretations have been proposed to explain the linear relationship that exists between reading latency and string length. One class of explanations, which has gained most acceptance recently, is that the damage affects early stages of processing during which visual arrays are encoded (see Arguin & Bub, 1994a, for review). The high proportion of visual errors in letter-by-letter readers (Karanth, 1985), the massive effect of case alternation on reading speed (Bub & Arguin, in press; Warrington

& Shallice, 1980) and the interaction between word length and degraded visual input (Farah & Wallace, 1991) lend support to this view. Recent studies have suggested that, because of this fundamental problem in pattern recognition, letter processing is slowed relative to normal performance (Behrmann & Shallice, in press; Reuter-Lorenz & Brunn, 1990) and that, consequently, only a single letter can be identified at any one time (Arguin & Bub, 1993; Kay & Hanley, 1991). This problem in letter analysis, in some views, is not restricted to the processing of alphanumeric symbols but is part of a more widespread pattern of impaired visual perceptual processing (Farah & Wallace, 1991; Friedman & Alexander, 1984; Rapp & Caramazza, 1991; Sekuler & Behrmann, in preparation). The consequences of this fundamental perceptual deficit, however, may be most evident in the processing of orthography, as letter identification requires fine discriminations across many similar letters produced in a variety of different fonts and handwriting.

Because letters can only be identified singly at any one time, usually starting from the left and proceeding to the right, the position of the letter in the string affects performance substantially. For example, Kay and Hanley (1991) found that their pure alexic patient, PD, showed a marked drop in the accuracy of single letter report as a function of serial position across a four-letter string. Whereas accuracy of letter report for position one was approximately 80%, performance on the fourth letter had dropped to below 20% (Kay & Hanley, 1991, Fig. 2, p. 257), irrespective of whether the string was a word, a pseudoword or a random set of letters. Similarly, Howard (1991) showed a strong effect of serial position in a string on the probability of correct letter report in two cases: Patients PM and KW reported 48% and 85% of the first letter in a four-letter string, but accuracy dropped to 18% and 5% respectively for the final letter. In contrast with this dramatic drop-off across the string, single letter report studies with normal subjects frequently yielded M-shaped serial position curves with best performance on letters at both ends and in the middle of the array, and poorest performance in the intermediate locations (Bouma, 1987; Mason, 1975, 1982). The benefit for items at the end of a string has also been demonstrated by Merikle, Coltheart, and Lowe (1971) who showed that items in the centre, but not at the ends, of a string are adversely affected by the presence of a mask. These *end-effects* cannot be accounted for by sensory explanations nor by the retinal location of the items: The advantage still obtains even when the string is centred over the fovea and the end letters are furthest from fixation (Mason, 1982). Furthermore, the benefit for end letters applies irrespective of string length. Interestingly, however, this advantage for end letters is not always seen and instead, applies only to strings of familiar (e.g. English letters) but not unfamiliar symbols (e.g. Greek letters). Together, these findings suggest that explanations based on lateral inhibition from neighbouring letters or from limitations in perceptual analysis are insufficient. Rather, the results suggest that because the initial and final elements are salient and indicate word length for letters, they are given preferential weighting over other letters (Mason, 1982).

An immediate question that comes to mind is: What is the relationship between the M-shaped letter detection curves and whole word recognition in normal subjects? Although normal subjects show these M-shaped curves for single letter report, most models of word recognition assume that all the visual elements are processed simultaneously and spatially in parallel (e.g. McClelland & Rumelhart, 1981). This conclusion is based on the finding that normal readers show minimal effects of word length on naming RT when words are presented in free-field (usually foveally) and are not distorted in any way (see Henderson, 1982, for overview of these studies). The M-shaped curve, however, is not necessarily inconsistent with parallel processing: It may be the case that normal subjects adopt a strategy whereby the end letters are given additional weighting during the process of parallel activation of all letters. The assumption in the pure alexia research, however, has been that patients are forced to use a serial process of letter identification because they cannot use parallel letter recognition processes to drive word recognition. The product of this compensatory serial process, then, is the monotonic linear relationship between word length and reading latency (Howard, 1991).

SI, the subject of this study, demonstrates a linear function for recognising letters in a string as a function of serial position and shows the typical and expected word length effect in reading. The goal of the therapy approach adopted in this study, therefore, is to alter her processing strategy and to align her letter report performance more closely with that of normal subjects. Specifically, this entails retraining her to adopt a strategy in which the first and last letters of a string are apprehended together rather than in serial order. The hypothesis is that if the processes involved in letter identification are related to those used in word recognition, improving the former would have positive consequences for the latter. For SI, then, if the sequential compensatory process were to be altered through therapy, and replaced with a function that more closely approximated the normal M-curve, the effect of word length on single word reading should be minimal, as is the case for normal readers.

METHOD

Subject

The subject of this study, SI, is a 46 year-old, right-handed, English speaking woman who was born in Edinburgh, Scotland, and immigrated to Canada at the age of 15. She received a Grade 13 education and was a part-time computer programmer and analyst. SI is a diet-controlled diabetic and had a mitral valve replacement in 1989. In February 1991 she experienced a sudden right quadrantanopsia (which still persists), a severe headache and some memory loss. She did not lose consciousness and presented with no other focal neurological deficits. A SPECT scan done at that time showed a large left parieto-occipital perfusion deficit and a normal right hemisphere. A MRI scan in October 1991 revealed a high signal area in the left occipital-temporal region indicating an infarction of the posterior cerebral artery and involving the hippocampus, fusiform and lingual gyri. A second, smaller lesion of the middle cerebral artery affecting the parietal region was also noted. The scans indicate two separate ischaemic events that occurred at the same time (see Plates 1a and b). Prior to the start of this intervention study, in December 1991, SI scored 95/100 on the Reading Comprehension Battery for Aphasia, a test designed to evaluate a person's functional reading skills. Her performance on the Functional Communication Subtest was six correct out of ten items. Despite this high level of overall accuracy, the total time taken for SI to complete the test, summed over the ten subtests, was 23 minutes, substantially longer than is normal for someone of her intelligence and education. At this time, SI believed that her reading difficulties were a function of her quadrantanopsia and was distressed to find out that this was not the case: Even when the written material was presented in her intact left field, her reading was still slow and laboured. In contrast to her reading deficit, SI's spontaneous speech was fluent and comprehension was good. Mild word finding difficulty was detected on the Boston Naming Test (Goodglass, Kaplan, & Weintraub, 1983) where she scored 48/60 correct and an additional nine points with phonemic cueing for a total of 57/60 (normal performance for matched controls is 54.4, SD 3.5). SI was not aphasic as determined by her quotient of 99.2 on the Western Aphasia Battery (Kertesz, 1982), a score considerably above the normal cut-off of 93. On the WAIS-R she obtained a verbal score of 104, a performance score of 98 and a full scale score of 101. Her score on the Wechsler Memory Scale "Revised" was 97, indicating a mild memory deficit.

SI's relatively isolated reading deficit in the absence of other marked neurobehavioural deficits is consistent with the diagnosis of pure alexia. Although SI had enjoyed reading prior to her stroke and described herself as a "speed reader", she no longer read for pleasure post-morbidly. She could not provide us with any examples of her premorbid writing but reported that her spelling was excellent. When she was tested in January 1992, however, she made several spelling errors, most of them phonologically plausible renditions of the target. For example, she wrote SIEVE as "syv", CHAOS as "caos", CIRCUIT as "circut" and SEIZE as "sceaze". The coexistence of surface dysgraphia, in which words with irregular sound-spelling correspondences are given a regular form of spelling, with pure alexia has been reported in several cases (Friedman & Hadley, 1992; Patterson & Kay, 1982).

SI participated in an occupational therapy programme between July 1991 and January 1992, but this was terminated prior to the implementation of her reading therapy which started in January 1992. At this time, she was unable to return to work but was involved in volunteer work at a nearby secondary school. SI was strongly motivated to participate in this study.

Design of the Study

The design of the study was a single-subject time series approach in which a pre-treatment baseline was obtained followed by the introduction of the intervention procedure. After a nine week therapy period in which SI was seen twice a week for approximately 90 minutes a session, an in-depth post-therapy evaluation was conducted to determine the extent of change in her performance. We first characterise the nature of the reading deficit in detail and then report the data from the pre-intervention experimental baseline tests. Following that, we describe the therapy procedure and finally, we present the results from the post-therapy testing and compare her performance to the pre-intervention baseline.

The experiments reported here were administered by means of Psychlab software (Bub & Gum, 1988) run on a Macintosh Plus computer. The identical procedure was adopted for most experiments and any deviations from this standard procedure are described where pertinent. Stimuli were presented in bold, black, upper case, 24 point Geneva font on a white background, and SI sat at a distance of approximately 40 cm from the screen. Each stimulus was preceded by a central black fixation point which remained on the screen for 500 msec. and was followed by a 1000 msec. delay. The exposure duration of the stimulus was varied according to the task. All stimuli were presented in SI's intact left visual field with the final character of the word occupying the position immediately to the left of fixation. The visual angles subtended for stimuli of 1, 3, 5 and 7 characters in length were 1°, 1.5°, 2.4°, and 3.6° respectively. On tasks requiring an oral response, reaction time (RT) was measured by a voice activation key, while on tasks requiring a key press, RTs were measured from the keyboard. Control data were collected using the identical procedures from a single age- and education-matched female subject, BR, who had no history of neurological illness.

Pre-therapy Assessment

In this section, we describe SI's performance on a range of tests developed to characterise her letter and word recognition abilities.

Letter Naming

Single letter identification is obviously a crucial skill required for word reading, and abnormalities in this process may contribute directly to letter-by-letter reading. Many patients with pure alexia, however, show preserved single letter identification provided that they have sufficient time to process the individual letters (Arguin & Bub, 1993; Behrmann & Shallice, in press; Kay & Hanley, 1991; Reuter-Lorenz & Brunn, 1990). This experiment examines whether SI was able to identify single letters, when presented alone or in two- or three-letter arrays for brief exposure durations.

Material and Procedure. A list of 30 randomly selected single letters was presented for identification. Each letter was presented individually for 17 msec. (the briefest possible exposure time subject to screen refresh limits), and SI was instructed to name it out loud. Following this, 30 two- (e.g. H A) and 30 three-letter (e.g. F M A) arrays of random letters with a single character space between them, were presented individually for identification with two-letter arrays at 50 msec. and three-letter arrays at 100 msec. exposure. Accuracy of letter report was again recorded.

Results and Discussion. SI was able to report the identity of single letters presented alone or in two-letter arrays with 100% accuracy. She was able to identify correctly 83% (75/90) of letters presented in three-letter arrays. Of the 15 letters misidentified, 12 (80%) occupied the third position in the array. These results suggest that single letter identification is generally good even under rather brief exposure durations and that when errors do occur, the majority are on letters occupying the final position of the string.

Naming Latency

Material and Procedure. To examine SI's reading of single words prior to therapy and to establish that she shows the expected word-length effect, a list of 120 words, 40 of each of three, five and seven letters were selected. Half the words were high (>20 per million, mean 87, SD 79) and half low in frequency (<20 per million, mean 6.5, SD 5.2) (Francis & Kuçera, 1982). The mean frequency across the list was 52 with a standard deviation of 70. Half the words were concrete and half abstract. The words were presented individually to the left of fixation for an unlimited time until a response was made. RT and accuracy were recorded. The control subject, BR, completed this experiment under the identical conditions.

Results and Discussion. BR made no errors in reading while SI made two errors (PAT → "pot" and CANDLES → "candies"), both of which involved the substitution of a single letter. Reading latencies for BR, the control subject, and SI are shown in Fig. 1 for words of three, five and seven letters in length along with the lines of best fit.

A one-way ANOVA with word length as a between-subjects factor and trials as a random factor, conducted separately for the two subjects, revealed no significant increase in RT with word length for BR but a significant effect for SI [$F(1, 116) = 11.63$, $P < 0.001$]. The line of best fit for SI has a slope of 178.5 msec. for each additional letter while for BR, the slope is 15.3 msec. per additional letter. SI's increase in RT with increasing string length is consistent with the pattern of letter-by-letter reading.

Lexical Decision

Material and Procedure. The 120 words used in the naming latency experiment were matched with a further 120 orthographically legal and pronounceable nonwords constructed by changing one or two letters of their corresponding words (e.g. APE–AFE, BRIBE–BLIBE). The 240 strings were presented individually in the centre of the computer screen for

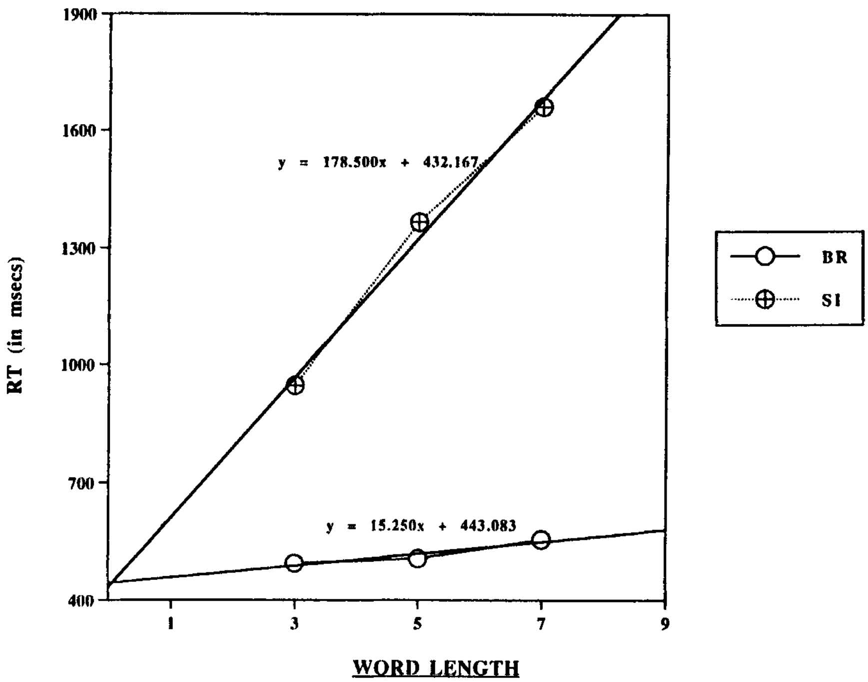

FIG. 1. Reaction time for naming aloud words of increasing length for SI and control subject, BR. The lines of best fit are included for each.

an unlimited time. SI and BR were instructed to use two fingers of the dominant right hand to indicate their responses. The "," was used to indicate "yes" and the "." to indicate "no". Accuracy and RT were recorded.

Results and Discussion. BR made a single error on a three-letter word whereas SI made 21/240 (9%) errors with 16 of the errors occurring on three-letter nonwords. Lexical decision latencies for correct "yes" and "no" responses for BR and SI are shown in Fig. 2 along with lines of best fit for the "yes" responses.

A two-way ANOVA with string type (word, nonword) and length (3, 5, 7) was conducted for BR and SI separately. Whereas BR shows no increase in RT to make either "yes" or "no" responses with an increase in string length, SI's decisions are slowed with additional letters, particularly when she has to make "no" responses [$F(1, 205) = 9.3$, $P < 0.005$]. Main effects for string type [$F(1, 205) = 8.2$, $P < 0.05$] and for length [$F(1, 205) = 69.4$, $P < 0.0001$] were also significant for SI with the mean

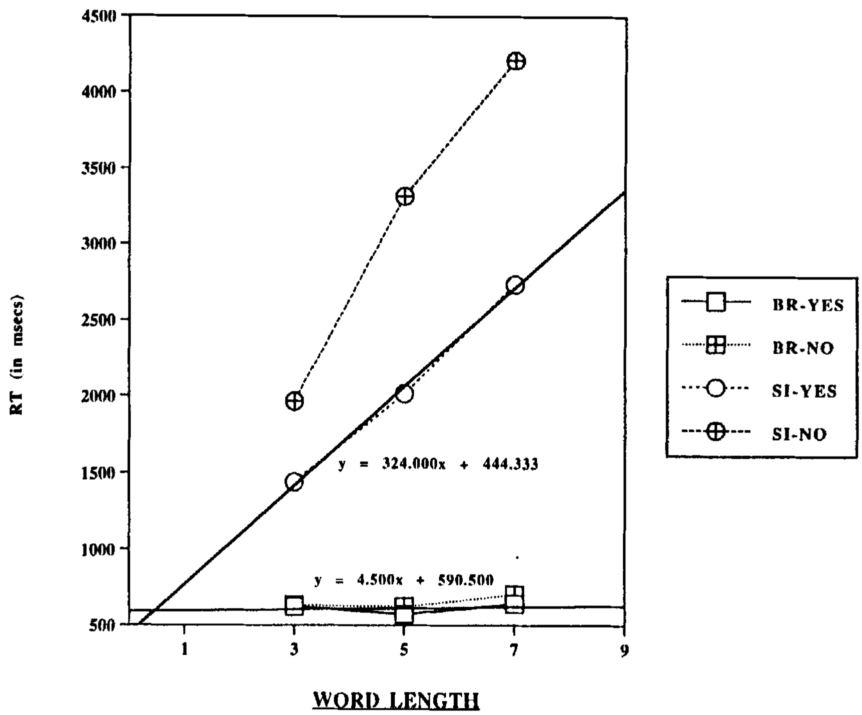

FIG. 2. Reaction time for "yes" and "no" lexical decision responses for SI and control subject, BR, as a function of increasing word length. The lines of best fit are included for "yes" responses.

for "yes" and "no" responses being 2133 and 3995 msec. respectively and the means for three-, five-, and seven-letter words being 1703, 2666, 3473 msec. respectively. The slope of the best fit curve for the "yes" responses was 324 msec. for SI and only 4.5 msec. for BR, consistent with the minimal increase in RT in lexical decision tasks in normal subjects (Henderson, 1982). SI's increase in RT in lexical decision for strings of increasing length, and the interaction with string type, is typical of that seen in most letter-by-letter readers (Behrmann et al., 1990; Behrmann & Shallice, in press; but see Bub & Arguin, in press for a different pattern).

Summary of the Pre-therapy Assessment

The findings from the naming latency and lexical decision experiments reveal the hallmark feature of letter-by-letter reading, the monotonic increase in RT with additional letters even though individual letter recognition, tested under fairly lenient conditions, is generally good. The slopes of the increase in RT for each additional letter is comparable to that of other patients with pure alexia (Shallice, 1988) and exceeds the normal increase in the RT performance of normal subjects for words that are placed in the left visual field (Bruyer & Janlin, 1989; Bub & Lewine, 1988; Young & Ellis, 1985).

Establishing a Pre-therapy Baseline

Having established that SI is indeed a letter-by-letter reader, we describe additional experiments designed to examine her letter and word processing performance in greater depth prior to therapy. Because the goal of the therapy procedure with SI is to facilitate the adoption of a more parallel, rather than serial, procedure, we document SI's sequential letter processing as a function of serial position in an array. We also report data from additional naming latency experiments in order to examine further SI's reading performance prior to intervention. Such a pre-therapy baseline is essential to determine whether there is any spontaneous recovery or fluctuation in her behaviour over time. If no change in performance is documented without intervention and the baseline is stable, it is more likely that changes observed post-therapy are attributable to the remediation procedure per se rather than to some non-specific spontaneous fluctuation in behaviour.

Measure of Sequential Processing

This experiment was designed to document SI's processing ability for letters as a function of their serial position in a string. Specifically, the goal was to ascertain whether SI processed strings "ends-in" in random letter strings as is the case for normal subjects (Mason, 1982) or sequentially as is the case for many patients with pure alexia (Howard, 1991; Kay & Hanley, 1991).

Material and Procedure. A single target letter appeared on the left of the screen (three spaces to the left of fixation) for 250 msec., following the presentation of a foveal fixation point. After a 500 msec. interval, a string of five random letters appeared centred over the position three spaces from fixation so that the final letter appeared next to the fixation location. For example, the target "V" appeared followed by the string "PSXVL". SI was instructed to decide whether or not the target letter was present in the string and to indicate her response using two keys "," and "." for present and absent responses respectively. Of the 150 trials, the target was present on 100, with equal probability of occurrence over the five letter positions in the string. The target was absent on the remaining 50 trials. Both accuracy and reaction time to detect the presence of the letter was measured.

Results and Discussion. Overall, SI was correct on 134/150 trials, with most errors (only 12/20 correct) occurring on position three of the string. Figure 3 shows the RT as a function of serial position for trials on which the target was present for SI and BR. The control subject, BR, shows the expected M-curve with fastest RT for the two end positions, followed by the middle position. The times are somewhat slower than those usually obtained for normal undergraduate subjects (Mason, 1982) but this is probably because BR is older than these younger subjects. In contrast to this M-shaped curve, SI's RTs form a mostly linear pattern, increasing across the array at the rate of 283 msec. per additional letter. Of note is that SI's RT is slowest for those items which occupy positions closest to fixation, consistent with the finding that retinal position does not significantly affect serial order effects (Mason, 1982). SI's base RT (and intercept), even for letters in the first position, is slowed relative even to BR. This slowing in RT is a common finding in patients with brain damage.

Ends-in Processing for Words and Nonwords

In the previous experiment we showed that SI's letter processing is sequential in a random letter string, as reflected in the linear increase in RT with serial order. There is reason to believe, however, that if the display is a word, this may have some special effects on letter processing (McClelland & Rumelhart, 1981; Wheeler, 1970). To determine whether SI also processes legal letter strings sequentially, in this experiment, we compare her ability to report the first and last letters (position 1 and n) of word and random letter strings of increasing length. Based on the findings of serial processing in the previous experiment, we predict that letter 1 will be

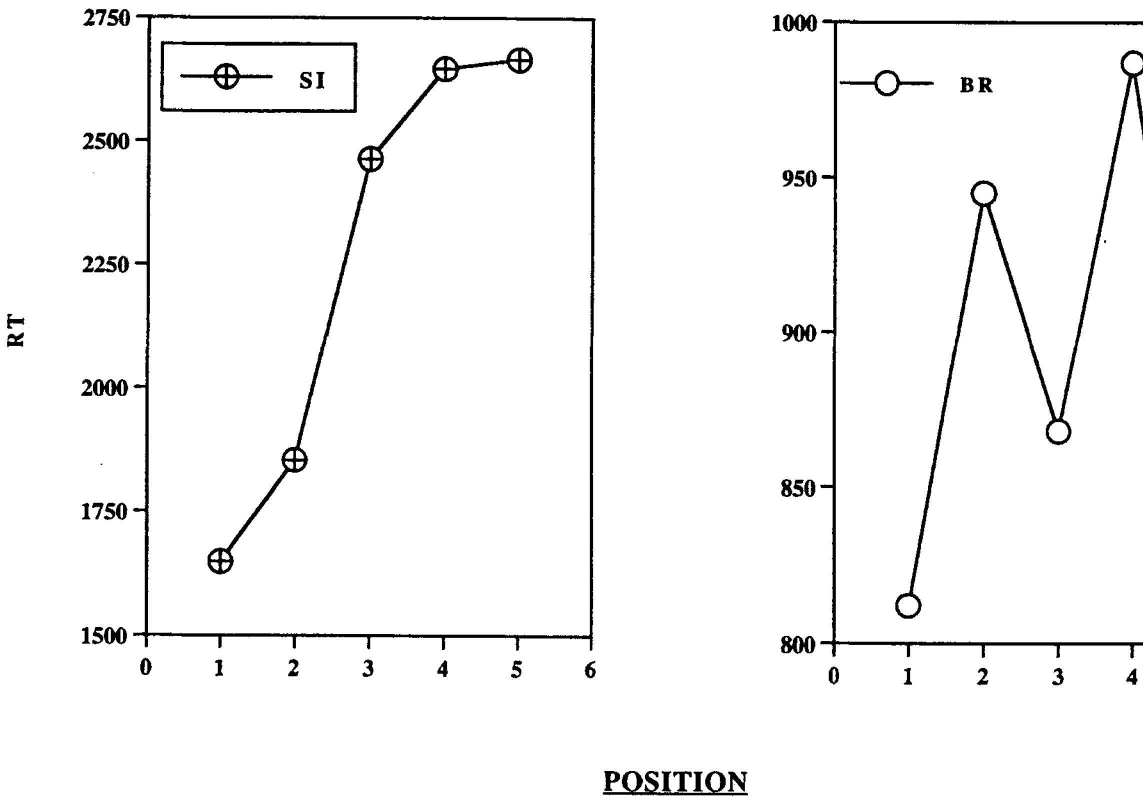

FIG. 3. Reaction time for SI and BR to detect presence of target letter as a function of serial position in a nonword strin
Y-axes differ for the two subjects.

reported better than letter n irrespective of word length. Since some, but not all, patients with letter-by-letter reading show a word superiority effect (WSE) and are more accurate in reporting letters in words than in nonwords (Bub, Black, & Howell, 1989; Kay & Hanley, 1991; Reuter-Lorenz & Brunn, 1990), we might observe a difference in report of letter 1 and letter n when they are drawn from words compared to when they are drawn from nonwords.

Materials and Procedure. Fifteen words and 15 random letter strings (e.g. NDFME), each of 3, 4, 5, 6, and 7 letters in length (N = 150), were selected. The words were matched for frequency, with a third of the trials falling below 20 per million, a third between 30–90 per million and a third over 110 per million for each word length (Francis & Kuçera, 1982). The stimuli were centred over a point located in the fourth character position from fixation in the left visual field to allow for centring of words of seven letters in length. SI was instructed to report the first and last letters (e.g. AE in ATHLETE or AE in ATHMATE). The stimuli were presented blocked and SI reported first 1/*n* of words (N = 75 trials) and then 1/*n* of nonwords (N = 75 trials). The items were presented to SI's intact left field at a preset exposure duration at which accuracy of report of the first and last letter was 60%. The duration was calculated on a practice set of 30 nonwords of varying lengths. The exposure selected for SI was 100 msec. Two testing sessions were necessary to complete this experiment.

Results and Discussion. The number of letters, both 1 and n, reported correctly for words and nonwords is shown in Table 1. The trials per word length are too small to obtain reliable effects and thus the data are collapsed across length. Overall, words are reported better than nonwords ($\chi^2_1 = 7.01$, $P < 0.005$) and the first letter is identified better than the last ($\chi^2_1 = 51.3$, $P < 0.0001$). Interestingly, there is an interaction such that letter 1 is reported equally well for words and nonwords ($\chi^2_1 = 0.23$, $P > 0.5$) but letter n is reported better for words than for nonwords ($\chi^2_1 = 4.3$, $P < 0.05$).

TABLE 1
Number Correct Letter Report for Letters 1 and n as a Function of String Type Pre-therapy

Words		*Nonwords*		
Letter 1	*Letter n*	*Letter 1*	*Letter n*	*Total*
74	57	72	39	242

As expected given the serial order effect, letter n is reported less well than letter 1, even though position n is closer to the fovea than position 1. That report of letter n is more inaccurate when it comes from a nonword than a word is consistent with the findings of a word superiority effect in some patients with letter-by-letter reading (Bub et al., 1989; Kay & Hanley, 1991; Reuter-Lorenz & Brunn, 1990) and has been explained as the result of context effects from higher-order orthographic representations (as in the interactive activation model, McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). These data suggest, then, that SI is not using an "ends-in" strategy or processing the beginning and ends of words in parallel. Rather, the results are consistent with a sequential left-to-right strategy in which there is some additional benefit obtained for words over nonwords. The benefit may come about either because of feedback from the word level or because of the presence of more familiar combinations of letters in the words than in the random letter strings. The present experiment cannot adjudicate between these two alternative views.

Pre-therapy Baseline on Word Length Effects

In order to establish that SI's reading performance was not improving spontaneously prior to intervention, her reading RTs for words of increasing letter length were measured at two separate points in time, two weeks apart. These two testing sessions are compared with each other and with the naming latencies collected from SI two months prior to this (as reported earlier).

Material and Procedure. Two lists of 120 items, each including 40 three-, five-, and seven-letter words, were drawn up such that there were an equal number of high and low frequency items (above or below 20 per million, Francis & Kuçera, 1982) and an equal number of abstract and concrete items across each word length. Each of the two lists was used once to measure SI's naming latency as a function of word length. The two testing sessions took place two weeks apart. The lists were randomised across length and a single word was presented on the screen, to the left of fixation, using the same procedure as above. Again, accuracy and RT were measured.

Results and Discussion. The RT of the correct trials (120 for each of the two separate sessions and 120 from the earlier session, N = 334) was subjected to a three-way ANOVA with length (3, 5, and 7), frequency (high, low) and time (testing session 1, 2, or 3) as between-subject factors and trials as the random factor. Prior to the ANOVA, items for which the RT was more than two standard deviations from the mean of its own cell, were eliminated from the analysis. The most important result was that there was no significant effect of testing time [$F(2, 322) = 0.774, P > 0.5$]. RTs increased significantly as a function of length, as documented previously [$F(2, 322) = 17.3, P < 0.001$], particularly for low-frequency words [$F(1, 322) = 7.3, P < 0.05$]. The absence of a significant effect of testing session and no interaction of testing time with length demonstrates that SI's reading performance was stable and that the characteristic word length effect was present at all testing sessions.

Summary of Pre-therapy Baseline

The findings from these experiments confirm that SI is a letter-by-letter reader and that her performance is stable over a period of approximately three months, almost a year post-stroke. Furthermore, the results of the serial order experiments are consistent with the diagnosis of pure alexia in showing that SI processes letters in a serial left-to-right manner. When the strings are real words, there is some added benefit and SI is able to report the end letter somewhat more accurately than when the strings are the counterpart nonwords.

Therapy Procedure

The goal of therapy is to encourage SI to process letters ends-in and thereby to reduce the sequential left–right processing of letters. In this section, we describe the intervention procedure and results and thereafter, we report the outcome measures from the post-therapy testing.

Material. Lists of 20 words were drawn up, blocked by length for words of three, five, and seven letters. There were five blocks of three-letter words, and ten each of five- and seven-letter words. In each block, half the words were low in frequency, occurring less than 20 times per million, and half were high in frequency, occurring more than 80 times per million (Francis & Kuçera, 1982).

Procedure. Therapy was conducted once a week for an hour and a half over a nine week period. The major goal of therapy was to encourage SI to process the beginning and end letters of words in parallel, i.e. '"ends-in", by getting her to attend simultaneously to the two ends of a string. The general procedure consisted of presenting a list of words (all of the same length) individually on the computer screen for a set exposure duration and instructing SI to report the first and last letters (as in condition 1/n of the sequential processing experiment). Accuracy of report was measured. When a criterion level of 18/20 correct report of *both* the first and last letter for two consecutive lists was reached at a particular exposure duration, a list of longer words (to a maximum of seven letters in length) was given at that same exposure duration. When criterion was reached for seven-letter words at an exposure duration, the exposure was decreased by 100 msec. and the procedure repeated. If criterion was not reached at one exposure after five successive administrations of a particular list length, lists of shorter word length were re-introduced until criterion was established on the shorter word length lists. Thereafter, the longer length words were presented once again. If criterion was not reached on a longer list after this, exposure was increased by 50 msec. for the words of longer length. When all ten lists of seven-letter words had been used, the lists were repeated with the individual trials randomised. The ultimate goal was to continue gradually decreasing exposure duration and to use words of increasing length until performance reached normal limits. Each session was started at the exposure duration and the list length used at the end of the previous session. The starting exposure duration at the beginning of the therapy was 500 msec.

Results and Discussion. Table 2 summarises the exposure durations and list lengths for which the criterion level was achieved across the nine therapy sessions. A checkmark indicates that criterion was reached whereas a "–" indicates that it was not. SI reached criteria for three- and five-letter words with little difficulty at all exposure durations on all testing sessions. The same was not true for seven-letter words. Although SI reached criterion for seven-letter words at 500 msec. without much difficulty in the first session, she required extensive practice at all other exposure durations. She failed to reach stable performance (18/20 on two consecutive blocks) at 200 msec. after two consecutive therapy sessions, sessions four and five. The exposure duration was increased to 250 msec.,

TABLE 2
Summary of Exposure Durations and Criterion Reached for Different Word Lengths in the Therapy Session

Session	*Exposure*	*Three*	*Five*	*Seven*
1	500	√	√	√
	400	√	√	—
2	400	√	√	√
	300	√	√	—
3	300	√	√	√
4	300	√	√	√
	200	√	√	—
5	200	√	√	—
6	250	√	√	√
7	200	√	√	—
8	200	√	√	√
9	100	√	√	—

and SI achieved criterion level at this duration. When the exposure duration was decreased again to 200 msec., she initially scored 17/20 on two consecutive trials and then reached criterion in the following session. Finally, at 100 msec. exposure, she also scored 17/20 on two consecutive trials and did not reach criterion. At this stage, because of time limitations, therapy was terminated and the post-therapy evaluation was conducted. In sum, the intensive drill work on initial and final letter identification was relatively easy for words of three and five letters in length but not for those of seven letters. Nevertheless, SI persisted and after a total of 55 blocks, each containing 20 seven-letter words, across all sessions, some progress was made. Whether SI would have been able to succeed at 100 msec. for seven-letter words if therapy had continued is dubious. A week after the final therapy session, the retesting was conducted over two sessions, a week apart.

Post-therapy Results

The post-therapy assessment involved evaluating SI's ability to process letters in parallel using the same procedures as those used pre-therapy to assess the efficacy of the therapy procedure. In addition, her single word reading performance was re-examined to see whether any transfer from therapy had occurred.

Sequential Letter Processing

The identical procedure used pre-therapy was adopted here: A single target appeared prior to a string of letters and SI made a present/absent judgement on the target letter.

Results and Discussion. Figure 4 shows SI's post-therapy RT to make these decisions. Her pre-therapy data are included for ease of comparison. As can be seen from the figure, SI's post-therapy performance looks rather different from her pre-therapy behaviour. An ANOVA with time (pre-, post-therapy) and position (1–5) revealed an interaction in the data [$F(2, 269) = 9.1$, $P < 0.001$]. Post-hoc Tukey tests at $P < 0.05$ significance shows that the major differences between pre- and post-therapy RTs arise at positions three, four, and five of the strings. A main effect of time was also noted with significantly faster detection times after therapy than before. While SI does not yet show a normal M-shaped curve post-therapy, the slope is considerably flatter than it was pre-therapy. Therefore, therapy appears to have been effective in altering the nature of the letter processing strategy and for getting SI to detect the final letter relatively well.

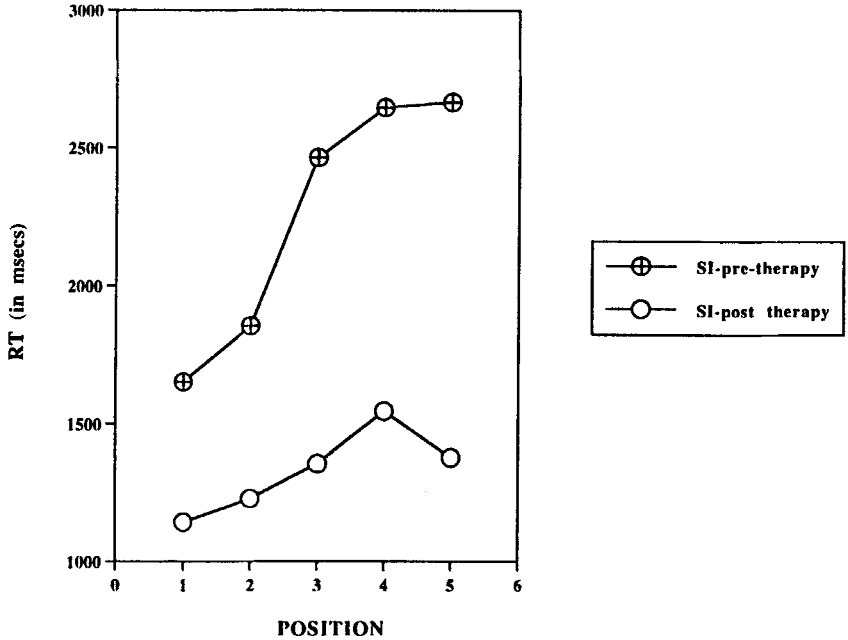

FIG. 4. Reaction time for SI pre- and post-therapy to detect the presence of a target letter as a function of serial position in a nonword string.

Ends-in Processing for Words and Nonwords

The identical procedure adopted to investigate SI's pre-therapy processing of letters in word and nonword strings was repeated post-therapy.

Results and Discussion. Table 3 shows the number of letters correctly reported for letters 1 and n for words and for nonwords. The post-therapy data are described along with a comparison of the results to the pre-therapy scores. As was the case pre-therapy, SI reported letter 1 significantly better than letter n ($\chi^2_1 = 29.1$, $P < 0.0001$) and showed no difference in the accuracy of identifying letter 1 in words and nonwords ($\chi^2_1 = 0.17$, $P > 0.5$). In contrast to the pre-therapy scores, however, post-therapy, SI identified letters in words and nonwords equally well, collapsed across position ($\chi^2_1 = 0.4$, $P > 0.1$), and reported letter n equally well from words and nonwords ($\chi^2_1 = 0.13$, $P > 0.5$). Thus, although there was no overall difference in the total number of letters correctly identified between pre- and post-therapy testing (pre: 242, post: 253; $\chi^2_1 = 1.15$, $P > 0.1$), one important significant difference is that SI's report of letter n in non-

TABLE 3
Number Correct Letter Report for Letters 1 and n as a Function of String Type Post-therapy

Words		*Nonwords*		
Letter 1	*Letter n*	*Letter 1*	*Letter n*	*Total*
73	56	71	53	253

words improved from 39 pre-therapy to 53 post-therapy ($\chi^2_1 = 4.75$, $P < 0.05$). The main effect of therapy, therefore, seems to have been in altering SI's performance on reporting the last letter of nonword strings. It is interesting to note that the benefit of therapy was restricted to nonwords, where there was the most room for improvement pre-therapy, and did not affect the report of letter n in words. These results, however, are consistent with the findings from the previous experiment, showing how the training in therapy increased the accuracy and speed of report of the final letter.

Word Reading

The results from the two tests of letter processing both show an improvement in SI's ability to identify and report the final letter. The crucial question is whether this improvement translates into a positive benefit for her word reading and particularly, whether this change alters the slope of the word length effect. This was done by having SI read the same two lists of 120 words, equally divided into those of three, five, and seven letters in length, that were used for pre-therapy evaluation. Each of the two lists was read in a different session, separated by a week. The individual words remained on the screen for an unlimited time until SI made a response. RT and accuracy were monitored.

Results and Discussion. SI made only 3/240 errors post-therapy. Figure 5 shows the mean RT from the two post-therapy sessions as a function of word length and includes the mean pre-therapy baseline data for comparison (collapsed over the three pre-therapy sessions). These data were all subject to an ANOVA with time (pre- versus post-therapy) and word length (3, 5, or 7) as between-subjects factors. Again, trials that deviated from the cell mean by more than two standard deviations were taken out of the post-therapy data prior to the ANOVA. The analysis revealed that SI improved significantly from pre- to post-therapy [$F(1, 555) = 27$, $P < 0.0001$] as is evident from the faster RTs seen in Fig. 5. However,

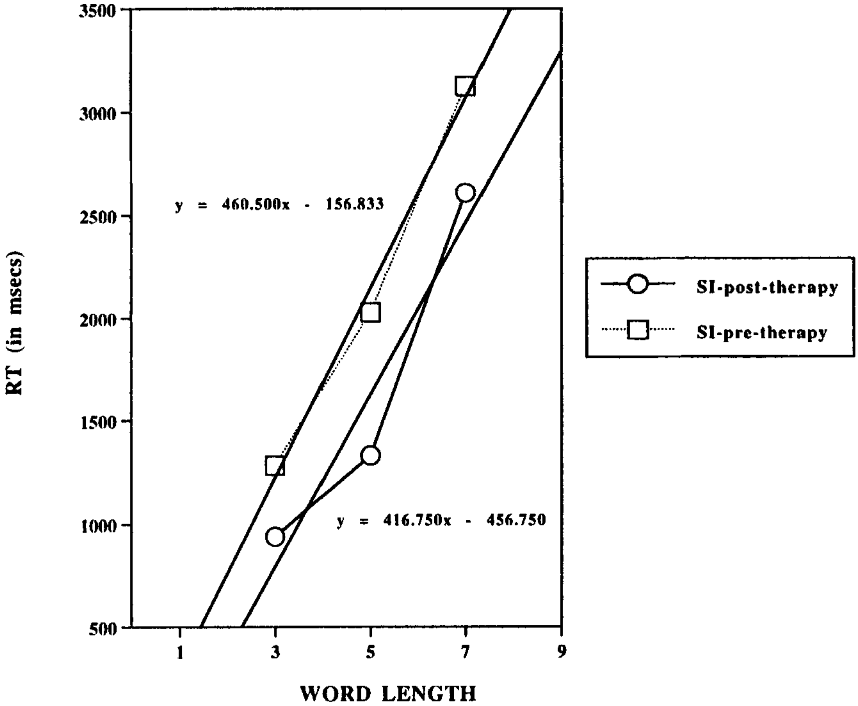

FIG. 5. The mean RT for SI for pre- and post-therapy naming latency as a function of word length.

there was a main effect of word length [$F(2, 555) = 37.3$, $P < 0.0001$] which did not interact with time [$F(2, 555) = 1.08$, $P > 0.5$]. These results suggest that, although SI did improve in that her RTs were faster overall, the absence of the interaction between length and pre/post-therapy indicates that the extent of the word length effect had not changed from pre- to post-therapy.

Word Length Effects and Parallel Processing

The results of the post-therapy word naming experiment demonstrate that SI continues to show a word length effect of approximately the same magnitude as was the case in the pre-therapy baseline data. The similarity in slope suggests that her mode of word processing was not altered despite the intervention programme. There is, however, one caveat. Although the presence of a word length effect fits naturally with accounts in which the increase in naming RT with additional letters arises from the serial processing of the individual letters, Howard (1991) has pointed out that this need not be the case. Instead, Howard suggested that the word length effect in RT might be explained by a process in which letters are processed in parallel but in which this process is subject to a significant rate of error because of the deficit in letter identification (see also Townsend, 1990, for discussion of limited capacity parallel processes as mimicking the straight line prediction of serial models). When this parallel process fails, the subject would then resort to a serial letter-by-letter approach. Howard (1991) bases his argument on the findings that some patients are able to recognise words much faster than would be predicted by a purely serial strategy: For example, patient PM took on average 15 secs to read a nine-letter word, but some words of this length were read in less than 2.5 secs. These "fast" responses cannot be accounted for by a view of sequential letter processing, leading Howard (1991) to propose that words may be read in parallel but with an increasing probability of error as word length increases. On this impaired parallel account, when the log probability of correct response is plotted against word length, there should be a linear relationship passing through the origin whose gradient, P, is the probability that a letter is misidentified. To establish whether SI's performance fits this impaired parallel account, particularly post-therapy, her correct "fast" responses are plotted against word length, and the line of best fit is plotted to see whether it is indeed linear (and therefore a parallel process) and passes through the origin.

Material and Procedure. The RT data obtained from the naming latency studies and analysed for the pre- and post-therapy comparisons reported above were used for the "fast" response analysis. Using Howard's criteria, a "fast" response is defined as that which has an RT that is faster than twice the fastest RT in the dataset. SI's fastest RTs pre- and post-therapy were 653 and 619 msec., yielding a criteria cut-off of 1306 and 1238 msec. respectively. Figure 6 shows the relation between the log probability of a fast response and word length pre- and post-therapy for SI. The plots of both pre- and post-therapy "fast" responses with log probability over the 3–7 letter range are not obviously linear. Furthermore, in neither case does the best fitting straight line intercept the y-axis at the origin as predicted by Howard (1991). The results of this analysis, therefore, do not support the impaired parallel processing account and instead are consistent with the view that SI did not process words in parallel either pre- or post-therapy. The change in the number of "fast" responses for some word lengths, such as five ($\chi^2_1 = 5.3$, $P < 0.05$) and seven ($\chi^2_1 = 6$, $P < 0.05$), but not for three ($\chi^2_1 = 0.11$, $P > 0.5$), however, is consistent with the observed improvement in overall reading time (shift in intercept in base naming latency but not in slope). The central finding from this analysis, then, is that SI's mode of word processing did not shift post-intervention to a parallel approach. Instead, it is likely that she continued

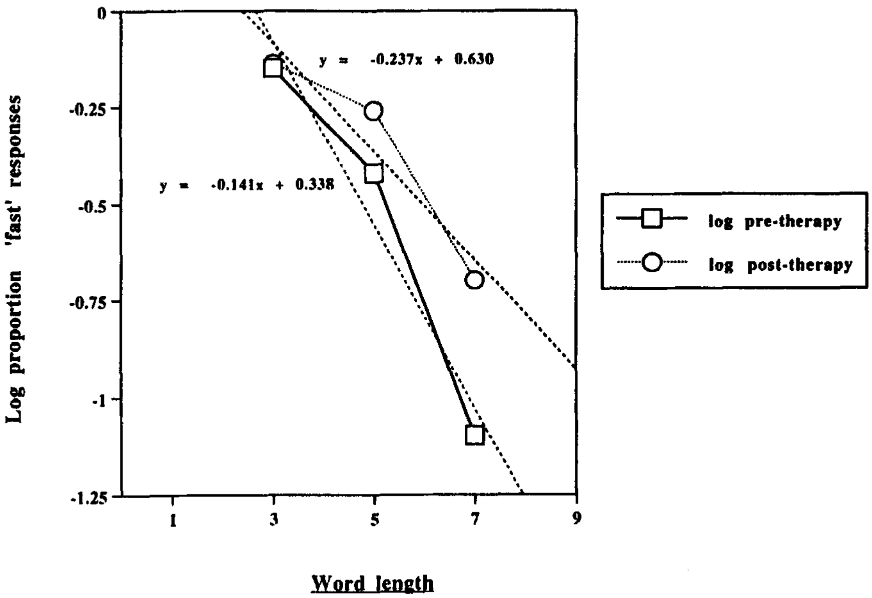

FIG. 6. The relation between log probability of SI's fast reading responses as a function of word length calculated from pre- and post-therapy naming latency RTs. Also shown is the best fitting straight line which does not pass through the origin for either function.

to process words in the same fashion, i.e. sequentially, post-therapy as she had done pre-therapy.

Summary of Post-therapy Results

The data from the post-therapy evaluation showed an improvement in SI's ability to identify the final letter in a string. She no longer showed the obvious linear increase in letter report as a function of serial order, and her report of the final letter, particularly of nonwords, improved when she had to report the letters in position 1 and position n of strings of varying lengths. Despite these changes, however, the effect of word length on her reading times did not change significantly between pre- and post-therapy testing: The slopes calculated from the lines of best fit remained essentially unchanged. In addition, the finding of the "fast" response analysis is consistent with the fact that her mode of word processing did not change following therapy even though the intercept or base RT had improved. Thus, although the intervention technique brought about positive benefits for SI, it had no obvious impact on her word recognition performance.

GENERAL DISCUSSION

This paper describes an intervention programme designed to enhance the parallel processing of letters in a patient, SI, who has an acquired dyslexia following an infarction to the left occipital lobe and surrounding areas. Initially, SI showed the hallmark feature of pure alexia or letter-by-letter reading, namely, the word length effect or increase in RT to read aloud a word with an increase in the number of letters in a string. This word length effect persisted, and there was no evidence of spontaneous improvement or fluctuation over time. In addition to the word length effect, pre-therapy, SI's accuracy in detecting the presence of a letter in a random string was linearly related to the serial order of the letter in the string. This linear function is quite different from the M-shaped curve obtained from normal subjects in which performance is better for end than for intermediate letters (Mason, 1975, 1982).

The goal of therapy was to facilitate SI's processing of the ends of the string, by getting her to report the identity of the first and last letter in words presented for a limited exposure duration. Over nine sessions, the length of the string was gradually increased, while the exposure duration was gradually decreased. In the final therapy session, SI was able, on 17/20 trials, to report correctly both the first and last letters of seven-letter strings at 100 msec. exposure. Whether further improvement might have been possible is unknown but given the difficulty in getting SI to this level of performance, it seems unlikely that she would have continued to improve without concentrated and intensive drill. Post-therapy evaluation attested to the beneficial effects of therapy and revealed significantly better identification of the final letter in the string on two different tasks. The most critical finding, however, was that, despite this improvement, SI's word length effect was of the same magnitude as it was prior to therapy, and her mode of word processing did not shift to a more parallel approach after intervention.

There are several possible explanations for the lack of transfer from improved final letter identification to word reading. One possibility is that, even though the function of the letter detection curve was flatter following therapy than prior to therapy, it still did not approximate the normal function sufficiently to produce normal reading behaviour. Thus, although the final letter was identified faster and more accurately by SI, the shape of the curve was still not quite M-shaped. The prediction that follows from this is that, if therapy could somehow further alter the shape of this curve and bring about a more normal, M-shaped curve, the benefits for word reading would then be observed. This outcome seems rather dubious given the effort required to alter SI's performance even to its current level.

A more plausible explanation of the discrepancy between the advantage for end letters in letter detection and the spatially parallel mode of word processing is that the computational properties required for ends-in activation differ from those needed for parallel word processing. Whereas therapy might have served to increase the strength of input activation on the end letter, this still does not guarantee that the temporal dimension, i.e. parallel or serial processing, is affected. Thus, increasing the parameter of input strength and spatially parallel processing need not go together; and in spite of this increased activation, the word length effect could still persist. This pattern is seen in the well known Interactive Activation Model where manipulating the strength of the input activation, as in the simulations of the serial order effects, has no bearing on whether or not processing is spatially parallel or sequential (Rumelhart & McClelland, 1982). There is also empirical evidence from neuropsychology to support the independence between input activation and parallel processing. For example, Reuter-Lorenz and Brunn (1990) showed that their pure alexic patient, WL, was most accurate in reporting the letters from the first and last position of a string in a free report task of briefly presented stimuli. This "ends-in" advantage or stronger activation of the extreme letters resembled the normal pattern of accuracy of report for subjects under lateralised viewing conditions (Bouma, 1987). Despite this seemingly normal letter perception curve, WL showed a robust length effect, with an increase in RT from 700 msec. for a two-letter word to approximately 3.4 sec. for a six-letter word (Reuter-Lorenz & Brunn, 1990, Fig. 1, p. 4; see also Bub et al., 1989 for a similar result). The presence of an "ends-in" processing curve concurrently with a sequential letter-by-letter reading suggests that these two processes might indeed be separable and independent. As such, the ability to detect end letters with more accuracy or speed than other letters is insufficient for remediating letter-by-letter reading.

In spite of the rather compelling evidence for a separation between the processes involved in performing ends-in letter detection and parallel word reading, it might still be the case that the same processes are used to accomplish these tasks. Any discrepancies between performance on letter detection and word reading may then arise not from some fundamental difference between the two tasks but from the fact that subjects have available to them multiple strategies which they invoke selectively and differentially to maximise performance on each of the tasks. Howard (1991), for example, reported that his pure alexic patient, KW, could read aloud 75% of the five-letter words presented for 250 msec. and then masked. When the task was shifted to letter report, however, KW was only able to report correctly all the letters on a single trial of a four-letter word even when it was not masked. Based on the discrepancy between KW's performance on letter report and word reading, Howard (1991) argued that KW was able to shift from a slow serial letter identification strategy, used in letter report, to a faster, more parallel process for word identification. Along similar lines, Bub and Arguin (in press) showed that their patient, DM, was also able to adopt different modes of processing for different tasks. Whereas DM seemed to rely on an inefficient analysis of letters for some tasks, such as naming and semantic decision, he did not rely on this mechanism for lexical decision. Lexical decisions were made accurately even at brief exposure durations, and performance was not affected by word length or by case alternation to the same extent as was seen in DM's performance on tasks such as naming or semantic judgement. The differences in performance in naming and semantic judgement, compared with that on lexical decision, led Bub and Arguin (in press) to conclude that more than one method of processing may be available to their patient, DM.

Although the word length effect on SI's naming latency was not significantly altered, her base reaction time rate was faster following the intervention. A possible explanation for this is that, following therapy, SI was better able to identify single letters or combinations of the letters but that she had not substantially altered her basic reading procedure. Following the completion of our study, another intervention study with a letter-by-letter reader came to our attention. The results of this study are remarkably consistent with our findings. After considerable preliminary testing, Arguin and Bub (1994b) determined that their patient, DM, was unable to convert letter tokens to letter types. Thus, DM did not benefit from cross-case priming (e.g. A a) even though he was able to identify the individual letters when they were presented in isolation. Based on these results, they argued that the failure to identify letters based on abstract orthographic representations may explain the hallmark word length effect seen in DM's performance. To encourage DM to use an abstract letter-type process, they trained him to perform cross-case nominal matching (e.g. G g). In addition, to promote the use of letter type encoding and holistic identification of letter strings, they trained DM to read pronounceable letter strings under time pressure. Although the approach taken by Arguin and Bub in therapy was different from the one adopted with SI, the findings are almost identical. Whereas improvement in the trained tasks was evident and base RT was faster, there was no significant change in the slope of RTs as a function of stimulus length following therapy, Arguin and Bub (1994b) argued that DM showed an increased rate in letter identity encoding (and this applied to both letters that were trained and letters that were not trained) and that DM had also improved in his ability to assemble individual letters into subword combinations (i.e. bigrams or trigrams). Nevertheless, these changes did not translate into direct improvement in word reading.

The absence of direct transfer from the improvement in letter identification or matching to word recognition suggests that the relationship between letter processing and word reading is not as transparent as one might think.

If this is so, and the results of the existing therapy studies suggest that this is the case, then rehabilitation for pure alexia would seem to require some alternative approach to therapy. As discussed previously, compensatory procedures which circumvent the basic deficit might be appropriate. Therapy techniques such as tactile-kinesthetic feedback through copying or repetitive practice of text, which do not address the specific deficit giving rise to letter-by-letter but which have proven effective, might provide one solution. An alternative, potentially fruitful approach that does address the defective functional process, might be to use the same method as described in this study with SI. To ensure transfer to word reading, however, instead of requiring simply first and last letter report, all letters should be reported or better yet, the whole word should be read on each trial.

The pattern of association and dissociation shown in SI longitudinally suggests some constraints on the mechanisms underlying word recognition and sheds some light on the separability of two seemingly related processes, letter identification and word reading. Showing change over time in the patterns of behaviour in a study such as this, then, may provide important evidence for the theoretical mechanisms underlying normal cognitive behaviour. The study of performance over time, however, is particularly difficult and is subject to numerous methodological limitations. Rehabilitation studies in which identical pre- and post-therapy evaluations are conducted may be one valuable approach to the study of change.

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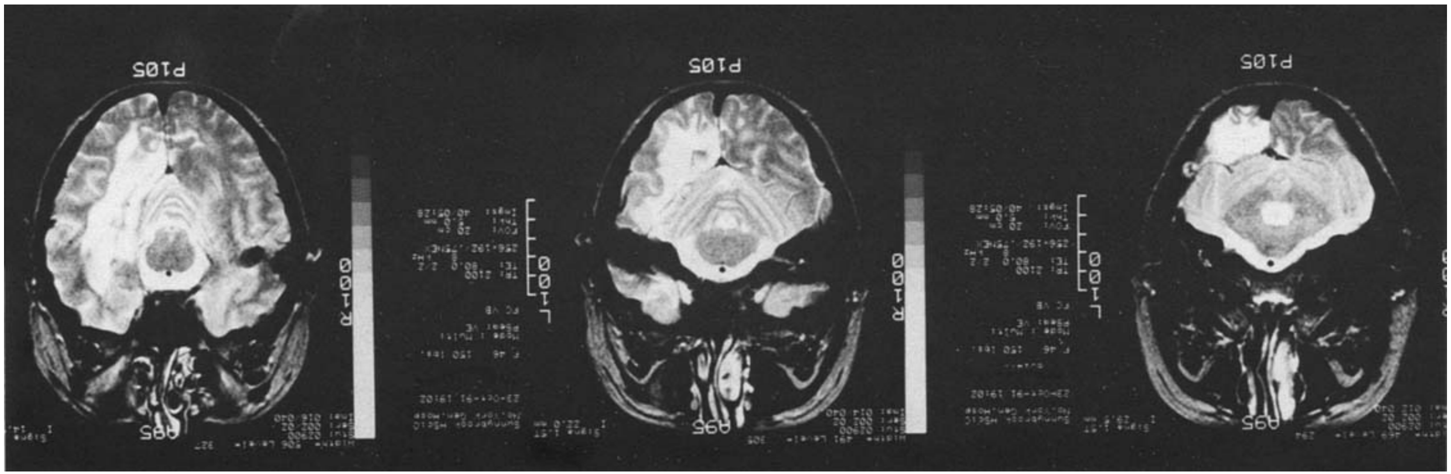

PLATE 1a. MRI scan done in October 1991 for SI: Horizontal sections showing posterior lesions. Note the sparing of the corpus callosum but the involvement of the inferior optic radiations.

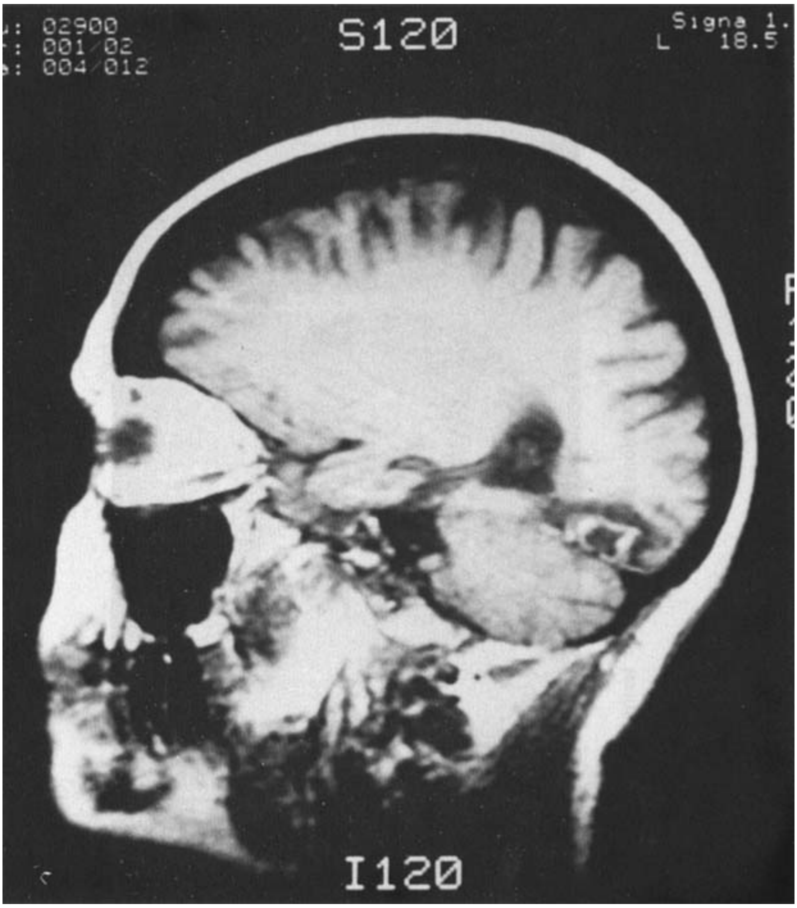

PLATE 1b. MRI scan done in October 1991 for SI: Sagittal section showing occipital lesion.