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Perceptual Cues in Pure Alexia

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This study provides evidence that pure alexia, or letter-by-letter reading, may be attributed to a general perceptual deficit that extends beyond an orthographic disorder. The perceptual problem may be unmasked when appropriate perceptual cues are not available to aid in the derivation of an integrated structural description. Four pure alexic patients and eight non-brain-damaged controls participated in this study. In the first two experiments, subjects' reading abilities were assessed on a naming latency and a lexical decision task. Experiment 3 replicated Farah and Wallace's (1991) results that the pure alexia deficit was not specific to orthography. Experiments 4 and 5 further explored the nature of the perceptual disorder using nonorthographic stimuli. In Experiment 4, patient performance on a target detection task was unaffected by the number of parts comprising the object but was impaired when the perceptual cue of good continuation was absent. Patient performance also declined when the perceptual cue of symmetry was not available to aid in the integration of occluded object parts in Experiment 5. Overall, the results imply that pure alexia is most likely to arise from a more general, nonorthographic deficit, and that the nature of the disorder is revealed when the perceptual context lacks strong perceptual cues.

Keywords: alexia, perception, perceptual deficit.

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INTRODUCTION

Pure alexia, or letter-by-letter reading, is a disorder that results from brain damage in premorbidly literate adults. The main feature of this disorder is the loss of the ability to read quickly and efficiently. Occasionally, these patients will name the individual letters out loud before piecing a word together but, even in those cases where the letters are not overtly named, the letter-by-letter method of reading can be inferred from patients' personal accounts and reaction time measures. This reading disorder manifests itself as a linear increase in reaction time with an increase in the number of letters in the string, a phenomenon referred to as "the word length effect." Pure alexia typically results from damage to the left anterior inferior occipital cortex and involves the posterior cerebral artery (Black & Behrmann, 1994), although this need not always be the case (Henderson, Friedman, Teng, & Weiner, 1985). Some patients also suffer from a right homonymous hemianopsia or quadrantanopsia (usually superior) or a loss of colour vision but these impairments do not always co-occur (Benson, 1985; Damasio & Damasio, 1983; Greenblatt, 1973; Patterson & Kay, 1982).

The long-standing and widely accepted view of pure alexia was that the reading deficit was the only major neurobehavioural impairment suffered by these patients. If any additional accompanying deficits existed (for example, anomia, colour deficits), they were mild. According to this view, the failure to recognise words is specific to orthographic items (*the orthographic view*) and, thus, patients are only impaired in the processing of alphanumeric materials (e.g. Déjèrine, 1892: in Bub, Arguin, & Lecours, 1993; Geschwind, 1965; Patterson & Kay, 1982; Shallice & Saffran, 1986; Warrington & Shallice, 1980). The *perceptual view*, on the other hand, claims that a more basic and inclusive visual processing deficit underlies pure alexia (e.g. Farah, 1991, 1992; Farah & Wallace, 1991; Friedman & Alexander, 1984; Kinsbourne & Warrington, 1962). Whereas the orthographic view implies that there is a separate area of the brain dedicated to processing visually-presented language-related items, and that this system can be selectively impaired, the latter perceptual view does not require the invocation of this type of structure. According to the perceptual view, the more widespread perceptual deficit underlying pure alexia is most obvious when patients attempt to process multiple letters comprising words (i.e. in reading); however, this impairment can also be observed under stringent testing of general visual perceptual abilities. In contrast with a view of a reading-dedicated structural or functional area, the perceptual view suggests that reading, which is a relatively newly acquired phylogenetic ability, is "piggybacking" on a pre-existing visuoperceptual ability (see Farah & Wallace, 1991).

Evidence consistent with the perceptual view was first presented by Kinsbourne and Warrington (1962), who showed that patients with pure alexia were unable to recognise multiple shapes, both orthographic and nonorthographic, presented simultaneously and in rapid sequence. Similarly, Friedman and Alexander (1984) demonstrated that their pure alexic patient was not only impaired at identification of letters but also at recognition of visual objects. Evidence for a perceptual deficit has also been inferred from the reading behaviour of these patients; they make a high proportion of visual errors during reading, often confusing letters, especially those that are visually similar (Bub & Arguin, 1995; Hanley & Kay, 1992; Karanth, 1985). Although support for a perceptual basis for pure alexia is gaining in popularity, almost all versions of this hypothesis suffer from the weakness that they derive from the observed association between pure alexia and a perceptual deficit, i.e. they reflect a correlational relationship between the co-occurrence of a perceptual deficit and pure alexia. One of the recent results from Farah and Wallace (1991), however, reveals a more direct causal relationship between the two. The authors presented the case of patient TU, who showed the hallmark word length effect associated with pure alexia and was also impaired on various nonorthographic tasks. For example, TU had below-normal performance on timed letter detection, object matching, and number string comparisons. Farah and Wallace reasoned that if TU's reading problem was attributable to a difficulty in visual encoding, then a manipulation known to affect the visual encoding process should exacerbate the word length effect. They tested this by manipulating the quality of the letters in word strings using a pattern mask and examining the effect of the degradation on the word length effect in oral reading. Whereas control subjects did not show an interaction between word length and visual quality in their reading reaction time, TU was disproportionately affected by the visual quality of words. These results led Farah and Wallace to conclude that the locus of TU's impairment was at a stage of *perceptual* encoding and that this had direct consequences for his reading of the letter strings.

Based on these and other results, Farah (1991, 1992, 1994) proposed a theory that has renewed interest in the perceptual view. Farah attributes pure alexia to a selective failure in the perceptual representation of multiple object parts prior to recognition of the whole object. She further suggests that pure alexic patients may have preserved recognition of objects that do not require individual part recognition. Farah hypothesises the existence of two types of structural descriptions within the visual recognition system: one for representing multiple part objects and the other for representing more holistic, "complex" objects. The former involves extensive part decomposition, yielding multiple simple parts, and the latter involves less decomposition and yields fewer but more complex parts. Because word recognition involves extensive part decomposition and requires the representation of numerous parts, mild damage to the structural description system subserving multiple-part processing gives rise to pure alexia. The obvious claim made by this account is that the deficit in patients with pure alexia extends beyond alphanumeric processing, with the consequence that these patients will also be impaired in processing all objects that require decomposition.

Although some instantiation of the perceptual view has gained in popularity, not all studies on pure alexia have taken an explicit stand on the orthographic–perceptual distinction. Many of these more neutral studies have suggested, for example, that a deficit in letter identification is the primary mechanism giving rise to the word length effect in pure alexia (Behrmann & Shallice, 1995; Bub & Arguin, 1995; Kay & Hanley, 1991; Reuter-Lorenz & Brunn, 1990), or that letter-by-letter reading is a consequence of a decreasing left-to-right gradient of accuracy in feature representations. Note that the evidence from all these studies is entirely compatible with the perceptual view. Thus, a fundamental visual perceptual disturbance may give rise to the letter identification deficit or may impair the even and equal deployment of resources across the spatial array. Like most research on pure alexia, these papers focus predominantly on the reading deficit and do not consider more primary perceptual impairments. Importantly, however, they are entirely consistent with the perceptual view.

The goal of the present study is to explore further the extent to which a general perceptual deficit underlies pure alexia and to characterise, as far as possible, the precise form of the perceptual disorder. If a general perceptual problem does underlie pure alexia, then the deficits found in these patients should not be limited to orthographic materials. Although most studies utilise orthographic stimuli in testing pure alexic patients' abilities, there have only been occasional attempts to investigate this issue using nonorthographic stimuli (e.g. Farah & Wallace, 1991; Friedman & Alexander, 1984; Kinsbourne & Warrington, 1962). Most of these attempts, however, have been studies of single cases and, therefore, the generalisability of the perceptual account remains unclear. Furthermore, in many of these documented cases, the brain lesions are not circumscribed, and in some, they extend beyond the area necessary to produce pure alexia. It is conceivable, therefore, that these cases exhibit more widespread functional deficits than would be found in distinct cases of pure alexia and that this would account for the co-occurrence of pure alexia and a perceptual deficit. In this paper, we avoid this problem by investigating the behaviour of four patients with pure alexia, some (although not all) of whom have fairly restricted lesions, in order to assess how generalisable the perceptual deficit might be. In addition to establishing that a perceptual disorder exists in these patients, we also test whether these patients have a particular difficulty in representing multiple parts of objects. If, by Farah's account, the deficit in pure alexia results from a general inability to decompose stimuli and to represent their numerous parts, then patients with pure alexia should have difficulties on nonorthographic tasks requiring part decomposition and representation.

METHOD

Subjects

Four experimental and eight control subjects participated in all the following experiments. Any deviations from this are described under the particular experiment. All agreed to participate in this research.

Experimental Subjects

All four experimental subjects were right-handed and were fluent English speakers. MA, a 37-year-old female, sustained a closed-head injury from a car accident in 1991 that resulted in a right homonymous hemianopia and difficulty reading. At the time of the accident, MA was employed as an accountant in a large bank. No focal lesion was evident on neuro-imaging although EEG recordings showed a bilateral slowing over the frontal lobes and an HMPAO SPECT showed mildly decreased cerebral perfusion bilaterally. The absence of a focal lesion is not surprising given the aetiology of the deficit, but the right homonymous hemianopia is consistent with a posterior left-hemisphere lesion. MA scored 57/60 on the Boston Naming Test, reflecting normal performance. There is no overt evidence of aphasia and, aside from some hesitations and word-finding difficulties in spontaneous speech, her language is fluent. On writing single words to dictation (using a subset of the levels of regularity lists from Shallice, Warrington, & McCarthy, 1983), MA made several regularisations, including writing CAULIFLOWER → collyflower, AISLE → ille and SEIZE (disambiguated through context) → seas. These errors to exception words reflect surface dysgraphia, a pattern that is sometimes seen in association with pure alexia (Friedman & Hadley, 1992; Patterson & Kay, 1982). When black-and-white line drawings of single objects (Snodgrass & Vanderwart, 1980) were shown on a computer screen and the time to name the objects was measured, MA made few errors in object identification, but was slower than matched normal control subjects, particularly for items of high, relative to low, visual complexity (Behrmann, personal observations). MA was able to identify all single letters of the alphabet without error at 33msec duration when they were presented to the left of fixation.

TU, a 56-year-old male, has been studied previously by Farah and Wallace (1991). In November of 1989, he sustained a left occipital haemorrhage secondary to a ruptured arterial venous malformation, which was resected. TU showed an impairment in reading, a right homonymous hemianopia, and a right hemiparesis. Damage in the left temporal lobe was revealed by post-surgery CT scan. TU was able to identify 80% of all single letters presented to his intact left hemifield at 33msec duration. TU named correctly 22 out of the last 30 items on the Boston Naming Test (Goodglass, Kaplan, & Weintraub, 1983) and 3 additional items with cueing (Farah & Wallace, 1992). He did, however, exhibit marked anomia for fruits and vegetables even when name frequency and familiarity were taken into account. Despite this, there was no overt evidence of aphasia and TU conversed fluently and effortlessly. TU has a high-school education and worked as a railroad inspector prior to his injury. Following his surgery, he worked occasionally at a small factory.

DS is a 37-year-old female who suffered a posterior cerebral artery occlusion in late 1986. A CT scan done at the time revealed an infarction of the left occipital lobe, which was probably migrainous in origin. DS suffered from right homonymous hemianopia and a right hemiparesis. The latter resolved soon after the incident, and the former gradually progressed into a quadrantanopsia in her upper right visual field. Her reading skills were impaired following the CVA, but other language skills remained intact and there was no evidence of aphasia. DS identified correctly 58/60 single upper-case letters presented for 17msec each to the left of fixation. Aside from a small number of errors on the Boston Naming Test, she labelled all items correctly. Neuropsychological investigations eight months after her stroke revealed mild impairments in attention, concentration, and verbal learning. DS's writing is unimpaired when evaluated on tasks requiring her to write single words to dictation (even those that have irregular spelling–sound correspondences on the Shallice et al., 1983 list) and on the writing tasks of the Western Aphasia Battery. This patient is described in greater detail in Behrmann, Black, and Bub (1990) and Behrmann and Shallice (1995). DS originally worked as a nurse. Following her stroke, she continued her work as a home-maker raising her children. More recently, she has attempted to learn to type but has found this laborious and painstaking. As in the case of MA, SD is accurate but slower than control subjects in her naming of black-and-white drawings, particularly for objects of high visual complexity.

MW is a 67-year-old male minister who sustained a left occipital CVA in April of 1992 that resulted in slowed reading ability. Reading and writing had always played a central role in his life and, at the time of the stroke, he was engaged in writing his memoirs. MW was receiving treatment for ensuing depression during testing for this study. MW was also slower than normal subjects in naming line drawings but did not show an obvious difference for those of high vs. low complexity. He was not obviously aphasic and was fluent and expressive in his spontaneous speech. MW was able to identify all single letters presented to left of fixation at 50msec duration.

Control Subjects

Control subjects were 3 males and 5 females aged 34–67 with a mean age of 50.5 (standard error [SE] = 1.77). Subjects were recruited from the volunteer pool at the Rotman Research Institute at Baycrest Geriatric Centre, Toronto and were matched to the pure alexic patients on age and education levels as far as possible. Mean education level was 13.4 years (SE = 0.63). All subjects were right-handed and had normal or corrected-to-normal vision. None had a history of reading difficulty nor of a neurological deficit.

Two initial experiments were carried out to establish that the four patients were indeed letter-by-letter readers. In these experiments, performance was assessed on a naming latency and a lexical decision task for words of varying length. To obtain information on normal performance on these tasks, control subjects also completed the experiments. It was expected that the pure alexic patients would show an increase in response latency with increasing word length, whereas the effect of word length on normal subjects' reaction times was expected to be minimal.

EXPERIMENT 1: READING LATENCIES

Subjects

All subjects, with the exception of control subject KA, participated in this experiment.

Materials

Apparatus

A Macintosh SE with standard built-in 9″ screen was used in the reading assessments. The experiments were created using PsychLab software (Bub & Gum, 1989, version 0.85). Verbal response times were recorded via a microphone and verbal response relay system.

Stimuli

Two lists of 60 words each were constructed, and each list contained equal numbers of 3-, 5-, and 7-letter words. All words were presented in upper-case Geneva 24-point bold font in black on a white background. The visual angles subtended for 3-, 5-, and 7-letter words were approximately 0.5° vertically and approximately 1.5°, 2.4°, and 3.6° horizontally, respectively. Word frequency was controlled across the 3 letter string lengths with an equal number of high- and low-frequency words per length. High-frequency words were those that occurred more than 20 times per million; low-frequency words appeared less than 20 times per million (Kuçera & Francis, 1967). The entire set of 120 words had a mean word frequency of 52 (SD = 70). Half the words were abstract with the remaining half concrete. These same word lists have been used in several studies with pure alexic patients (Behrmann et al., 1990; Behrmann & McLeod, 1995; Behrmann & Shallice, 1995).

Procedure

Subjects were instructed to read aloud as quickly and as accurately as possible single words that appeared on the computer screen. Individual words varying randomly in string length were presented in the following sequence: on each trial, a fixation point appeared in the centre of the screen for 1000msec. Then, 500msec following the offset of the fixation point, the target word appeared on the screen and remained there until the subject activated the vocal-response key by reading the stimulus word aloud. An interval of two seconds occurred between trials. For all subjects, words were presented to the left of fixation, corresponding to the patients' intact left visual field, and the final letter of each word appeared in the character space immediately to the left of fixation. The computer recorded reaction times in msec, and the experimenter noted any errors. Prior to the experiment, the subjects practised on a short list of six words, none of which appeared on the subsequent experimental lists.

Results and Discussion

Control Subjects

Figure 1 shows the mean reaction times across the control group and for each of the individual experimental subjects. An ANOVA with one between-subject factor (group) and one repeated measures within-subject factor (word length) revealed the critical interaction between group and length [$F(2, 20) = 7.3$, $P < .01$], with no effect of length for the control group but a significant word length effect for the patients. The difference between the groups [$F(1, 10) = 13.4$, $P < .01$] and the difference across the different lengths, collapsed across the two groups [$F(2, 20) = 7.6$, $P < .01$], were also significant. The mean reading latencies for the control group were 682, 693, and 703msec for 3-, 5-, and 7-letter words

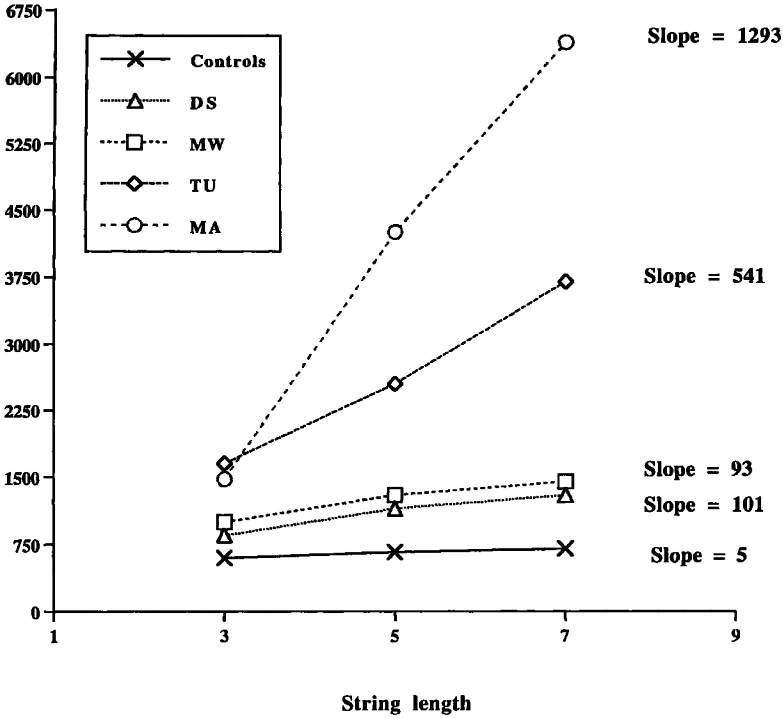

FIG. 1. Mean reading latencies for control group and individual patients in msec as a function of string length. Slope is measured in msec/letter.

respectively. The slope of the reaction time function for reading latencies across the control group was five msec/letter, suggesting minimal change in reading performance with each additional letter. Control performance on this task was near perfect. As with the patient data, any errors were excluded prior to analysis. Additionally, any trials on which the microphone was mistriggered (fewer than 1% of the trials) were excluded.

Because analyses of the RTs for each individual patient will be conducted, we also wanted to assess the variability in performance across the control subjects, and therefore performed ANOVAs on the data collected from each individual control subject with trial acting as a random factor. Only one control subject, JL, had significantly different naming latencies for any of the word lengths [$F(2, 116) = 6.02$, $P < .003$] and his reading latencies showed a slope of 10msec/letter. However, JL does not show the same pattern found in pure alexic patients, that of increasing RT as the length of the word increases. Rather, he shows a large difference in RT only in the seven-letter word condition relative to the three- and five-letter conditions. None of the control subjects displayed results indicative of letter-by-letter reading and the outer limit of the RT regression slope, calculated from RT as a function of word length, is 10msec per additional letter. These findings are consistent with previous data showing minimal effects of word length on response latency in normal readers (Bub & Lewine, 1988).

Pure Alexic Patients

As can be seen in Fig. 1, all patients show a significant monotonic increase in reading times as word length increases. The patients vary in severity, as indicated by the different slopes of 1293, 541, 101, and 93msec/letter. Even the milder impairments (101msec/letter for DS and 93msec/letter for MW) are significantly abnormal when compared with results from the control subjects in this study and in previous studies (Bub & Lewine, 1988). The presence of the word length effect, characteristic of pure alexia, in each of the four patients demonstrates that these patients may all be classified as letter-by-letter readers.

EXPERIMENT 2: LEXICAL DECISION

To confirm further that these patients are truly letter-by-letter readers, they participated in the lexical decision experiment, a task typically used to reveal the word length effect in pure alexia.

Subjects

All subjects, with the exception of patient TU and control subject MS, participated in this experiment.

Materials

Apparatus

The same apparatus was used as in the previous experiment. Responses were recorded using two keys on the computer keyboard. Subjects responded using two fingers of their dominant (right) hand.

Stimuli

Sixty of the words used in Experiment 1 were combined randomly with 60 nonwords, all of which were created by changing 1 or 2 letters of the real words. All nonword strings were pronounceable and orthographically legal; for half the nonwords, the difference from a real word occurred at the beginning of the word whereas the converse was true for the remaining half.

Procedure

Subjects viewed individual letter strings on a computer screen, and the subjects decided whether or not the string was a real English word. A trial consisted of a fixation point that remained on the screen for one second followed by a blank screen for one second. Then the letter string appeared to the left of the screen's centre, with the final letter occupying the position to the immediate left of fixation, and the string remained visible until a key-press response was made. The inter-trial interval was one second. Subjects responded by pressing either the "," or "." key on the computer keyboard for a "yes" or "no" response. Keys were counterbalanced across subjects, and subjects performed practice trials to familiarise themselves with the appropriate responses. Subjects were told to complete the task as quickly as possible without sacrificing accuracy.

Results and Discussion

Figure 2 shows reaction times for the three patients and for the control subjects. An ANOVA with one between-subject factor (group) and two repeated measures within-subject factors (judgement—yes/no; word length) with RTs for correct responses only as the dependent measure showed that the patients were significantly slower than the control subjects overall [$F(1, 8) = 15.5$, $P < .01$] and, collapsed across both groups, the time to make "no" judgements was slower than the corresponding "yes" judgements [$F(1, 8) = 9.5$, $P = .01$]. This judgement difference was also exaggerated as a function of word length across both groups [$F(2, 16) = 7.2$, $P < .01$]. Again, independent of group there was a significant effect of length [$F(2, 16) = 8.5$, $P < .01$], with all subjects showing the tendency for slower RTs as length increased but, predictably and most importantly, this effect was disproportionately larger in the patient than the control group [$F(2, 16) = 8.5$, $P < .01$]. Control subjects obtained group mean lexical decision scores for real words of 714, 714, and 836msec for 3-, 5-, and 7-letter words, respectively. The increase in word length manifested itself only between 5 and 7 letters and the regression slope was 31msec. Although this increase in RT is not always seen in normal subjects, many studies do suggest a slight linear increase across longer strings (e.g. Frederiksen & Kroll, 1976; Seidenberg, Waters, Sanders, & Langer, 1984). The increases in RT latency for the 3 patients are all dramatically and significantly larger than those observed in the normal subjects (see Fig. 2), with slopes on the order of 1019, 304, and 119 for

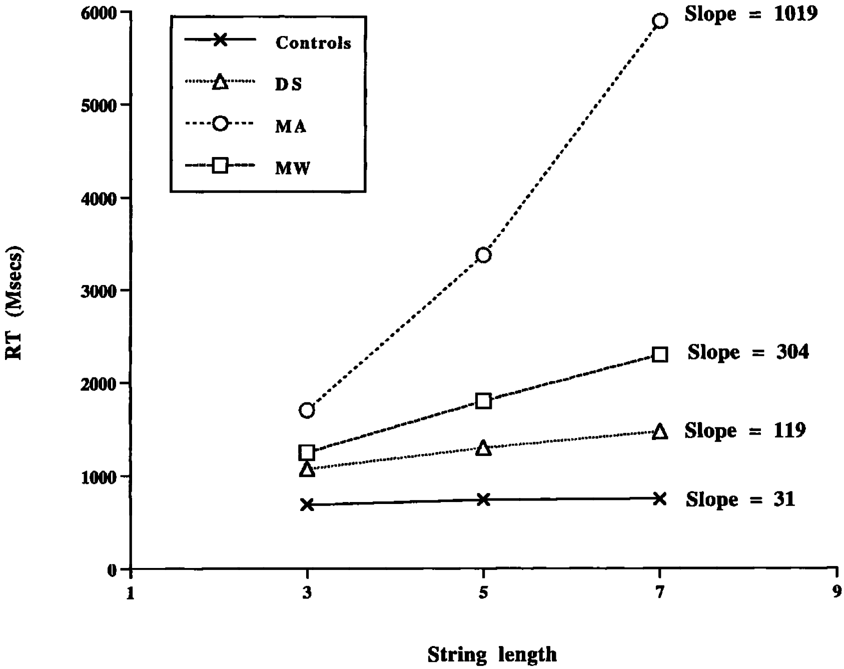

FIG. 2. Lexical decision test: Mean reaction times for correct responses to real word stimuli as a function of string length for three individual subjects and control group.

subjects MA, MW, and DS, respectively. This word length effect in lexical decision confirms the findings from the previous experiment.

Taken together, the results of the naming latency and lexical decision experiments establish that the four patients are letter-by-letter readers; all patients show the hallmark increase in reaction time with an increase in word length. Although some of the normal subjects also show a slight effect of string length, the slope of the increase is considerably smaller than that observed in any of the patients. Having established that the patients qualify as pure alexic subjects, Experiments 3–5 investigate whether these patients have a general perceptual problem that may underlie their pure alexia. These experiments use mostly nonorthographic stimuli for which reading is not required. Whereas Experiment 3 simply examines the performance of the subjects on tests of perceptual speed and fluency, Experiments 4 and 5 are designed more specifically to examine the issue of part representation and decomposition of nonorthographic stimuli.

EXPERIMENT 3: PERCEPTUAL FLUENCY

The main purpose of this experiment was to determine whether a perceptual level deficit in pure alexia limits patients' abilities to process multiple objects. Subjects completed three time-limited tests in which they were required to process multiple nonorthographic and orthographic stimuli. The three perceptual speed tests include the Finding As, Number Comparison, and Identical Pictures tests from the *Kit of Factor-Referenced Cognitive Tests* developed by Ekstrom, French, and Harman (1976). Success on these tasks requires rapid processing of multiple objects. If a perceptual deficit is involved in pure alexia, thene patients would be expected to perform significantly worse than the control subjects on all three tests.

Farah and Wallace's (1991) single case study showed that their pure alexic patient was impaired at both orthographic and nonorthographic portions of this test; TU performed poorly on all three sections of this test, which implies that his processing difficulties were not restricted to orthographic stimuli. However, TU has additional memory deficits (see Farah & Wallace, 1992), so his performance may not be typical of other pure alexics. Therefore, these tests were administered to all the patients, and their scores compared with those of the normal control subjects. Because the dependent measures for the tests differ, the data from each test was analysed separately.

Subjects

All four patients and matched control subjects took part in this experiment. All subjects were tested individually.

Materials

All parts of this experiment were performed as paper-and-pencil tests. The experimenter kept time with a hand-held stopwatch. All tests were administered and scored according to the standardised instructions provided by the authors of the tests.

Finding As

Stimuli and Procedure. Subjects received lists of lower-case real word letter strings and were instructed to mark any word containing the letter "a." Subjects were correctly informed that each column contained five target words containing the letter "a." In each of 2 experimental blocks, subjects were given 4 pages, each of which contained 5 columns of words with 21 words in each column. Although the position of the "a" in the words is not perfectly controlled for its locus at the beginning or end of the word, informal observation shows that it does vary across the string reasonably systematically. Subjects heard a standard set of instructions describing the test (Ekstrom et al., 1976). Test scores were determined by the number of words correctly marked, and no penalty was given for incorrect responses. The experimenters informed subjects of this and told them to use the most efficient strategy available. After a practice set of 16 trials, subjects had 2 minutes to complete each test block. Breaks were not given between blocks and no feedback was provided. In accordance with the standardised scoring, the final score for this section was the mean number of words correctly marked, averaged across the two blocks.

Number Comparison

Stimuli and Procedure. Pairs of digit strings, ranging from 2 to 13 digits in length, were presented in this test. Each of the 2 blocks consisted of 48 pairs in 2 columns on a single page. Sixteen practice trials were given before the two experimental blocks. All subjects heard a standard set of instructions before completing the practice trials. The experimenter told subjects to make a mark between the pairs of digit strings that were different and to ignore those pairs that were the same. Again, the locus of the difference for the different pairs was not controlled, but differences occurred more often at the middle and end than at the beginning. Subjects were given one-and-a-half minutes to complete each of the two blocks. Breaks were not given between blocks and no feedback was provided. One point was given for each correct answer, and one point deducted for each incorrect answer. The experimenter informed subjects of the scoring procedure before the test began. The dependent measure was the number correct minus the number incorrect, and a mean was calculated across the two blocks.

Identical Pictures

Stimuli and Procedure. Each trial consisted of five shapes in a row, with a cue in the leftmost position, and one target and three distracter shapes on the right. Subjects marked the target object, which was the shape that most closely resembled the cue. Subjects completed four practice trials before beginning the two experimental blocks. Forty-eight experimental trials appeared in each block, for a total of 96 trials. Each block contained 2 columns of 12 trials on each of 2 pages. The position of the target was varied across the distracter positions.

Instructions and scoring followed procedures outlined in the test manual, and subjects knew the scoring procedure ahead of time. Subjects indicated their response by making a mark underneath the item most like the cue. One and a half minutes were allowed for the completion of each of the blocks. Following the established scoring protocol, the dependent measure was obtained by subtracting one-quarter of a point for each incorrect trial from the total number of correct trials.

Results and Discussion

A comparison of the group findings revealed that patients performed significantly more poorly than normal controls; this is evident from the differences in the means, as displayed in Fig. 3. A one-way ANOVA revealed significant main effects of group for each of the three tests: Finding As: [$F(1, 14) = 26.73$, $P < .0001$]; Number Comparison: [$F(1, 14) = 24.41$, $P < .0002$]; and Picture Identification: [$F(1, 14) = 19.63$, $P < .0006$]. All of the patients' individual scores were lower than controls on these tests. As Farah and Wallace originally found, TU's scores on these tests were impaired relative to controls. TU's original scores were 15, 7, and 27 for Finding "A"s, Number Comparison, and Picture Identification, respectively, whereas this time they were 10, 8, and 15. Although his performance differs slightly across the two occasions, his performance was at least as impaired at the time of our testing as it was when originally tested by Farah and Wallace (1991). There were very few false positive errors made by the subjects and their pattern is characterised more in terms of slow than inaccurate performance.

Taken together, this series of three tests, two of which include nonorthographic stimuli, shows that all patients perform significantly more poorly than the control subjects. These results indicate that pure alexia is not specific to reading-related items and pure alexics have slowed or impaired processing on speeded perceptual tasks with nonorthographic as well as orthographic materials. It may be the case that the pure alexic patients were impaired specifically because of the tests' time constraints, and that they would perform perfectly given unlimited time. In fact, some researchers have suggested that pure alexia is a deficit in the rapid processing of visual material (Friedman & Alexander, 1984), and this account can adequately explain poor patient performance in the perceptual speed tasks. This issue is addressed by Experiments 4 and 5, which do not rely on speeded tasks but on patterns of performance within each subject group.

The group study results of Experiment 3 extend those originally reported by Farah and Wallace (1991) and show that the effect can be generalised to other pure alexic patients, and is not due solely to TU's memory deficits. Results from Experiment 3 indicate that a perceptual component may contribute to the deficit underlying pure alexia. Further experiments were conducted to isolate the characteristics of such a perceptual deficit.

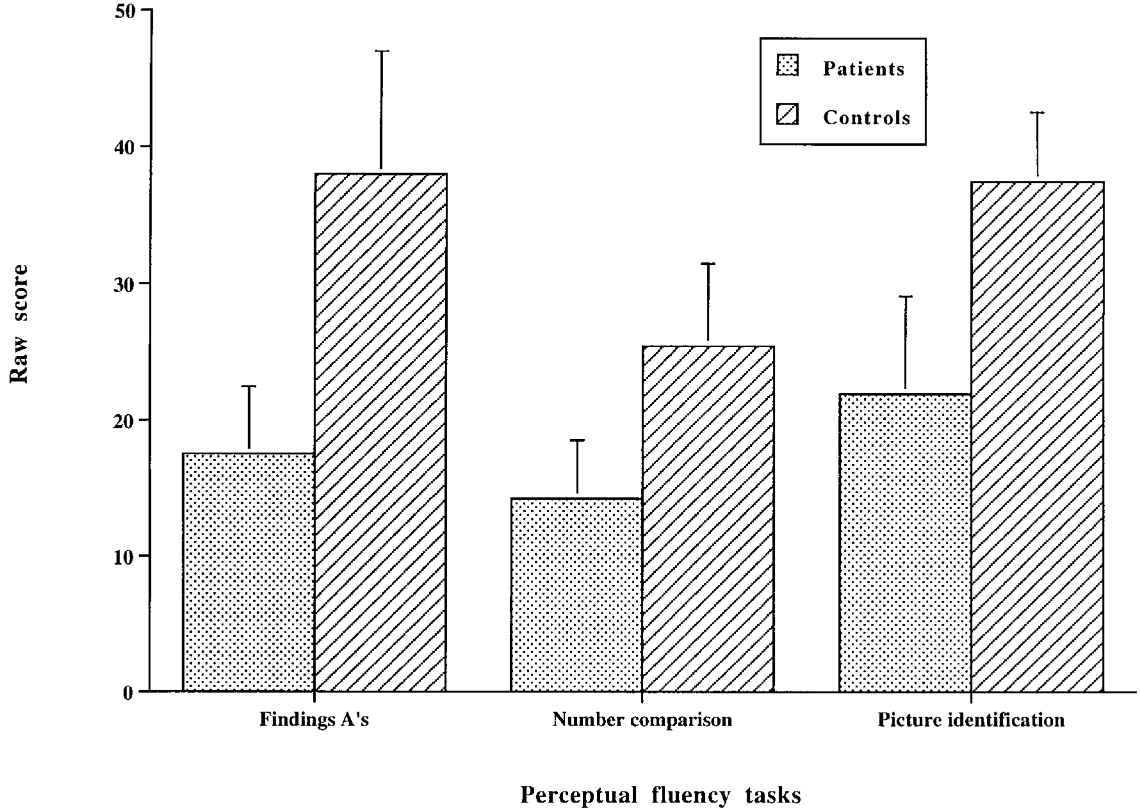

FIG. 3. Raw scores for patients and control subjects on the three perceptual speed tasks in Experiment 3.

EXPERIMENT 4: PART PROCESSING

The previous experiment demonstrated that a perceptual impairment occurs in pure alexia. Next, we explore the characteristics of that perceptual impairment. Farah (1991, 1992, 1994) recently suggested that the main problem in pure alexia centres around the patients' inability to decompose an object and to represent the multiple parts of such objects. The current experiment explores pure alexics' perception of objects containing multiple parts by having subjects detect a misoriented target in displays with increasing number of parts. It is argued that patients have difficulty integrating several letters into a whole word while reading. How does the configuration of an *nonorthographic* object affect pure alexics' abilities to integrate the parts?

The method used to examine multiple-part processing is adapted from recent work by Donnelly, Humphreys, and Riddoch (1991), in which they explored the ability of normal subjects to detect a target as the number of parts present in the display increased and as the configuration of the object was disrupted by eliminating good continuation of the parts (their Experiments 1 and 3). Examples of their stimuli, used in the present study, are shown in Fig. 4. The stimuli from these experiments provide a good opportunity to investigate simultaneously how patient performance is

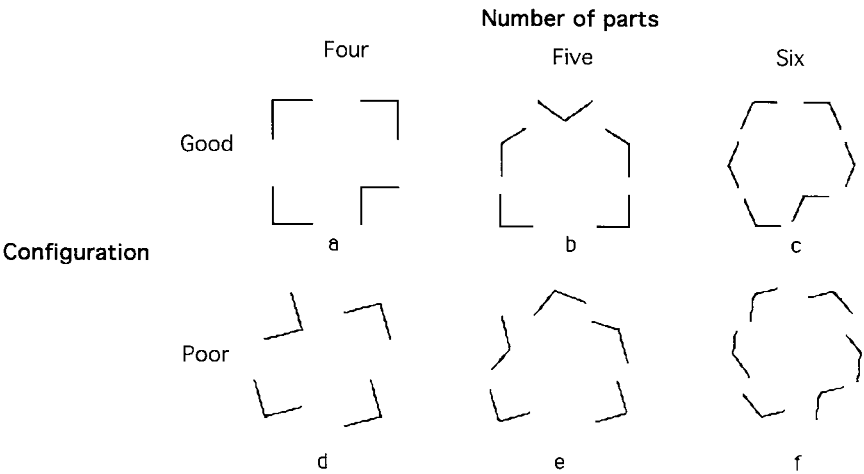

FIG. 4. Examples of stimuli from Experiment 4: (a) four parts, good configuration; (b) five parts, good configuration; (c) six parts, good configuration; (d) four parts, poor configuration; (e) five parts, poor configuration; (f) six parts, poor configuration. All stimuli shown are "target present" trials.

affected by the number of parts in an object and by the perceptual characteristics of the stimuli. Interestingly, their patient HJA, who exhibits visual object agnosia, prosopagnosia, and alexia, performed poorly on such displays, leading them to suggest that he has a deficit in grouping visual features in parallel across visual forms (Humphreys et al., 1994). Because the experiment described here is a conflation of Experiments 1 and 3 of the original Donnelly et al. (1991) experiments, it is not possible to compare the data obtained here with that presented in their study, but we compare performance to the matched control subjects.

The prediction for the pure alexic patients' performance on this task is that their target detection times will be significantly affected by the number of parts present in the display. This may manifest as a main effect of parts or they may show an interaction between number of parts and stimulus "goodness." If this occurs, the interaction will be more exaggerated than that observed in the normal subjects; because part processing is assumed to be more problematic for the patients, one might expect that in a situation in which there is no figural goodness or in which perceptual cues are weaker, the detection of a misoriented target will be disproportionately difficult for the patients. Experiment 4, therefore, extends the results of Experiment 3 by specifically examining how certain gestalt properties and the number of object parts affect patients' abilities to perform successful integration.

Subjects

All four patients and eight control subjects participated in this experiment.

Materials

Apparatus

This experiment utilised the same computer and software as in Experiment 2.

Stimuli

Examples of the stimuli are shown in Fig. 4. Stimuli varied on the following two dimensions: the number of parts and the object's configural goodness. Four, five, or six parts comprised each object (see Fig. 4a–c). In relation to words, the number of parts of an object may be analogous to the number of letters in a word, albeit at a somewhat different level of complexity. The parts had regular inter-item spacing—that is, they were the "regular" displays—and all had closure. On the second dimension, objects were either well- or poorly-configured. Well-configured stimuli had the additional gestalt property of good continuation, whereas the poorly-configured stimuli did not have good continuation. In stimuli with good configuration, imaginary straight lines could be drawn from adjacent corners to form complete objects such as a square, a "house," or a hexagon. To create stimuli with poor configuration, the corners of the good configuration stimuli were each rotated 15° counter-clockwise. This manipulation disrupted the integrity of the larger figure (See Fig. 4d–f). The good continuation displays correspond to the regular displays from Donnelly et al. (1991) Experiment 1, and both present and absent trials are included, whereas the poor continuation displays correspond to the regular displays of Experiment 3 and include both target present and absent trials.

The subject's task was to detect the presence of a target in the stimulus. Targets were created by flipping one part of an object along its horizontal and vertical axes (see Fig. 4). This resulted in the vertex of the target pointing inwards towards the centre of the object. On target absent trials all of the vertices faced outwards. If the patient's ability to integrate objects is affected by the types of perceptual cues available, then their response times to poorly- vs. well-configured items should be disproportionately longer than controls' responses. Subjects were given 24 practice trials before the experiment began. Stimuli were presented in 3 blocks of 144 randomised trials, composed of 12 repetitions of each combination of number of parts × target presence × configuration type, for a total of 432 trials.

Procedure

The procedure for this experiment was adapted from that originally used by Donnelly et al. Subjects determined whether a target was present on each trial. To aid in this task, they were told to ask themselves, "is one corner pointing in?" They responded by pressing the "," and "." keys on the Macintosh keyboard using the index and middle fingers of their right hand. If the subjects performed Experiments 2 and 4 in the same session, both of which required keyboard responses, then the allocation of the key-response mappings was kept consistent to avoid confusion and to maximise correct responses. Otherwise the mapping was randomly determined for the patients, and the control subjects used the same mappings as their corresponding matched patients. On each trial, a stimulus appeared at the centre of the screen immediately following the offset of a 500msec fixation point. The stimulus remained on the screen until the subject responded. The computer recorded RT and accuracy. The delay between trials was 1000msec. Subjects did not receive feedback during the experiment, and they took breaks in between blocks if they so desired.

Results

The four-way interaction between target (absent vs. present), configuration (good vs. poor), parts (four vs. five vs. six) and subject group (patients vs. controls) did not reach significance [$F(2, 20) = 2.8$, $P > .05$], suggesting that there was no differential effect of these variables on the patients vs. control subjects. Performance did not differ for target present vs. absent trials [$F(1, 10) = 1.28$, $P > .05$], nor did this differ across the two groups [$F(1, 10) = 0.2$, $P > .05$], and so the data, shown in Fig. 5, are collapsed across this variable for ease of viewing.

As a group, patients were slower than control subjects by 203msec [$F(1, 10) = 7.6$, $P < .05$]. Also, mean RTs to poor configuration displays were 168msec slower than to good configuration [$F(1, 10) = 32.9$,

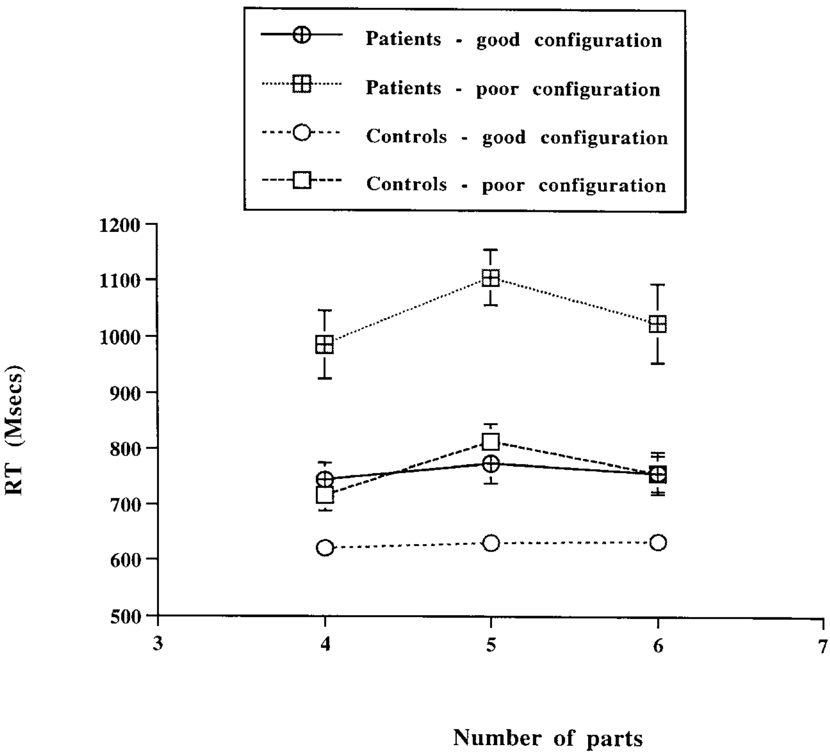

FIG. 5. Results from Experiment 4. Mean reaction time for patient and control group results on target present trials. Good configuration stimuli had good continuation, and poor configuration stimuli lacked good continuation.

$P < .001$], and this difference held, especially for absent trials [$F(1, 10) = 6.0$, $P < .05$]. The major result is that, as is evident from Fig. 5, performance on trials with five parts was slower than that with either four or six parts [$F(2, 20) = 5.9$, $P < .01$], but this held equally across the two groups, [$F(1, 10) = 0.2$, $P < .05$]. This unexpected increase is presumably attributable to the nonstandard configuration of the five-part trials and the added difficulty of discriminating between the elements on the absent trials. This difference for five-part trials is even more obvious for poor than good configuration trials [$F(1, 10) = 3.8$, $P < .05$]. Importantly, performance for patients and controls is similar and there is no linear increase in RT as the number of parts increases. An interesting finding is that patients were disproportionately slower than controls in responding to objects with poor vs. good configuration [$F(1, 10) = 4.1$, $P > .05$]; whereas control subjects were only 131msec slower, patients were 276msec slower. The difference between patient and control subject responses was disproportionate and not accounted for by the fact that the patients had higher *y*-intercepts than the control subjects.

Discussion

This experiment compares the performance of the pure alexic patients and control subjects on a perceptual task in which performance is enhanced when multiple parts of an object are integrated into a coherent whole. Patients were disproportionately slowed in responding to poor compared with high configuration stimuli. Most important, however, was that patients' performance was unaffected by the number of parts to be integrated. These results are consistent with the theory that the patients have a general perceptual deficit that is unmasked when internal perceptual cues are diminished. In addition, the results do not provide obvious support for Farah's multiple part representation theory. This theory predicts a positively increasing relationship between RT and number of parts or an interaction between parts and goodness of the stimulus disproportionate to that seen in normal subjects. This experiment's results show that subjects responded equally well to stimuli with four and six parts regardless of the configuration type. The lack of a systematic increase in RT as the number of parts increased suggests that the patients were able to integrate parts into wholes. Results from this experiment indicate that patients are able to construct whole figures from parts when stimuli are nonorthographic, but that this ability may be fragile and may be disrupted by changes in object structure or in the absence of perceptual cues like good continuation.

EXPERIMENT 5: OBJECT ADVANTAGE

Results from the previous experiments indicate that the pure alexic patients suffer from some general underlying perceptual deficit that becomes more obvious under conditions in which there is less support for perceptual processing, such as when good continuation is absent from the object. Patients were disproportionately impaired when performing tasks on items without good continuation, but they were not differentially affected by the increase in the number of parts of the object. The absence of a part effect suggests that the patients were not conducting part-based serial searches to perform the task. However, this does not necessarily indicate that patients were *fully* integrating the objects' parts to solve the task.

One way to explore further pure alexic patients' object part synthesis abilities is to examine whether patients' feature comparison performance benefits normally from integrating multiple elements into a single object. A well-documented finding is that normal subjects are better able to compare or report two features (or elements) of a display when the features come from the same object than when they come from two distinct objects (Duncan, 1984). If pure alexic patients are able to integrate object features, they should show the same single-object superiority as do normal subjects. However, if patients have difficulty representing the individual elements, as suggested by Farah, then they may not normally benefit in comparing two features from the same object vs. two features from two different objects. Experiment 5 uses this logic to determine whether the patients were able to integrate object elements into whole objects. This experiment also further explored the issue of how perceptual cues affect patients' abilities to integrate objects.

The stimuli in the present study were adapted from Behrmann, Zemel, and Mozer (submitted). In this experiment, subjects made same/different judgements of the number of bumps that appeared at two of four possible ends of a stimulus. The bump groups are considered to be elements of the objects. Examples of "same" and "different" trials are shown for each of the three test conditions in Fig. 6, with the "same" and "different" in the first and second columns, respectively. Stimuli a1 and a2 are examples of the single object (nonoccluded) condition, in which bumps are located on a single, continuous bar. Stimuli b1 and b2 are examples from the two-object condition. In this condition, the bumps were located on the ends of two different bars. Stimuli c1 and c2 represent a more complicated single object (occluded) condition in which the two disparate bars, albeit from the same object, are spatially discontinuous.

Behrmann et al.'s results indicate that normal subjects are faster at making judgements in the single-object condition (a) than in the two-object condition (b), replicating the advantage for single over two objects

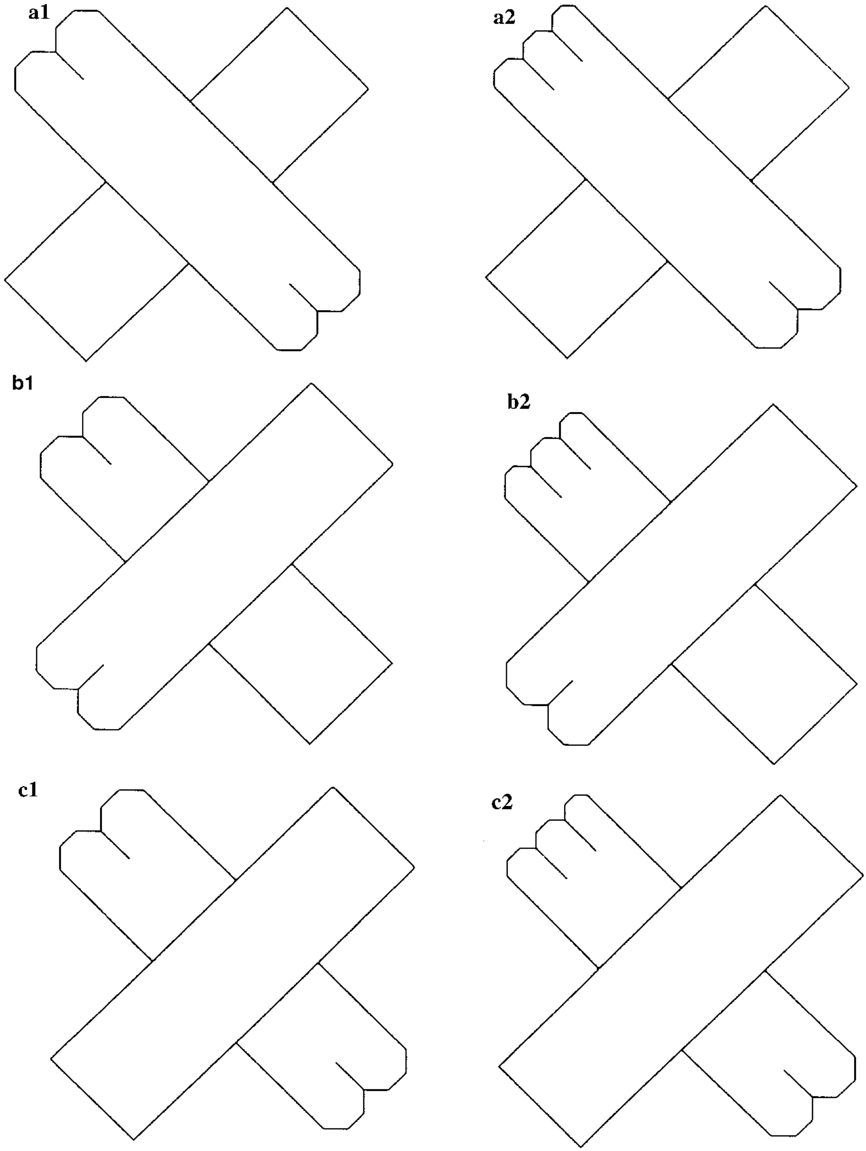

FIG. 6. Examples of stimuli from Experiment 5: (a1)–(c1) "same" trials; (a2)–(c2) "different" trials; (a1)–(a2) single nonoccluded condition; (b1)–(b2) two-object condition; (c1)–(c2) single occluded condition.

originally demonstrated by Duncan (1984). Interestingly, normal subjects show no difference in decision time for bumps on the ends of single objects when they are occluded (c) compared to when they are on the ends of a single continuous object (a). Subjects' similar RTs for judgements in the single occluded and single nonoccluded conditions led Behrmann et al. to conclude that normal subjects perceived both the single occluded and single nonoccluded objects as unified whole figures (see also Sekuler & Palmer, 1992). The prediction is that if patients perform like control subjects, RT to make same/different judgements will be faster for stimuli a1 and a2 compared with b1 and b2. Moreover, this experiment investigated whether pure alexic patients would also integrate the occluded object features into unified wholes (what is called the "single object advantage") and show the advantage in reaction time for stimuli c1 and c2 (as in a1 and a2) over stimuli b1 and b2.

These stimuli also provided an opportunity to investigate the effects of diminished perceptual cues on patient performance in integrating object parts or features. Previous research has found that perceptual cues such as symmetry can aid in completion of occluded objects (Sekuler, 1994; Sekuler, Palmer, & Flynn, 1994). In this experiment, perceptual cues were manipulated by varying the presence or absence of symmetry in same vs. different trials, respectively. The presence of occluded stimuli provides a situation in which symmetry can be utilised to integrate spatially discontinuous object parts. Therefore, Experiment 5 directly addresses the issue of whether pure alexic patients are able to integrate object elements while also investigating the effect of perceptual cues on the patients' abilities to perform the integration.

Subjects

All four patients and eight control subjects participated in this experiment.

Materials

Apparatus

This experiment used the same apparatus as in Experiments 1, 2, and 4.

Stimuli

Subjects made same–different judgements on the number of bumps located at the end of two overlapping bars with one bar partially occluding the other (see Fig. 6). The stimuli were configured so that the bumps appeared either at the two ends of one single object, or on the ends of two different objects. The bumps appeared at two of the bar ends, and each group of bumps contained either two or three bumps. Subjects decided whether the bars contained the same number of bumps on the two ends (e.g. two and two in Column 1) or a different number of bumps (e.g. two and three in Column 2 in Fig. 6). There were three experimental conditions in this experiment: a single nonoccluded object, two objects, and a single occluded object (see Fig. 6). In the single nonoccluded condition (a), bump pairs were located on the opposite ends of the top overlapping bar; this bar was not occluded and therefore clearly continuous. In the two-object condition (b), bump groups appeared on two separate bars. In the single occluded condition (c), bump groups appeared at the opposite ends of a bar that was partially occluded by the overlying bar. This condition required integration of the two ends of the bar into a single representation. It provides a perceptual middle ground between the two other stimulus groups, which clearly delineates processing within one or between two items.

The stimuli subtended five degrees of visual angle. The distance between the bumps in the single occluded and nonoccluded conditions was six degrees of visual angle. In the two-object condition, the bumps were three degrees of visual angle apart at the closest point and six degrees of visual angle apart at the farthest point between the two bump groups. Subjects were given a set of 24 practice trials. In half of the trials, the "top" (single) bar was oriented in one direction, and in the other half, it was oriented in the opposite direction (for more details, see Behrmann et al., submitted). Experimental trials were mixed and randomly presented in 3 blocks of 96 trials for a total of 288 experimental trials. There were 96 trials of each of the 3 conditions (occluded, nonoccluded, and two items). Half of each condition were "same" trials and half "different" trials. Within each block there was a full distribution of condition, judgement type, and orientation of the "top" bar.

Procedure

At the beginning of each trial, a fixation point appeared centrally and remained on the screen for one second. After a 500msec interval, the stimulus appeared on the screen left of fixation and remained on until the subject made a key press response. A response was made by pressing either the "," or "." key, which represented either "same" or "different." Response mappings were counterbalanced across subjects. All subjects used the index and middle fingers of the right hand to respond. The inter-trial interval was one second, measured from the time a response was made. Subjects were encouraged to take breaks in between blocks, although most declined. RT and accuracy were measured, but only RT was analysed as the dependent measure because accuracy was near ceiling for both the patient and control subject groups.

Results

Group data were subjected to a repeated measures ANOVA, with subject group as the between-subjects factor and judgement ("same" vs. "different") and condition (single nonoccluded vs. single occluded vs. two objects) as the within-subject variables. Group means are displayed in Fig. 7 as a function of condition and judgement. Because there were only a few patients and the power of the analysis was weak, we also ran a separate ANOVA within the patient group to examine the findings. Tukey post hoc tests ($P < .05$) were performed to aid in the interpretation of the results.

A significant but small effect of condition was found when subject group was collapsed [$F(2, 20) = 10.2$, $P < .001$], and this held equally across the two groups [$F(2, 20) = 1.3$, $P > .10$]. There was no significant difference in RTs for single occluded and nonoccluded trials but both of these were faster than the two-object condition. These results replicate those found in Behrmann et al.'s study with young normal subjects, which found a difference of approximately 40msec between single (occluded and non-occluded) and two-object trials when collapsed across judgement type. The pattern of responses to the three conditions in "same" and "different" trials differed equally for patients and controls; "different" trials are slower than "same" trials by 82msec [$F(1, 10) = 25.7$, $P < .001$]. The major result is that, relative to controls, patients were much slower, specifically on different occluded trials. Although this did not quite reach statistical significance in the group analysis [$F(2, 20) = 2.6$, $P > .05$], which is not surprising given the small number of subjects, the patient group, when considered alone, reveals no difference between occluded and nonoccluded on "same" trials but a separation between them on "different" trials. Finally, overall, patients were slower than control subjects by 392msec [$F(1, 10) = 40.9$, $P < .0001$], but were disproportionately slower than controls for the "same" vs. "different" judgements; relative to controls, they were 322msec and 464msec slower at "same" vs. "different" trials, respectively, as revealed by the judgement $\times$ group interaction [$F(1, 10) = 11.5$, $P < .01$].

Discussion

On "same" trials (i.e. with symmetrical ends), both patients and controls showed a significant single object advantage in both the occluded and nonoccluded conditions, relative to the two-object condition. On "different" trials (i.e. with asymmetrical ends), control subjects also showed this same pattern; responses to the two-object condition were significantly longer than to either of the two single-object conditions. However, the patients' "different" response deviates from this pattern. A significant advantage is still found in the single nonoccluded object condition relative to the two-object condition, implying that they are able

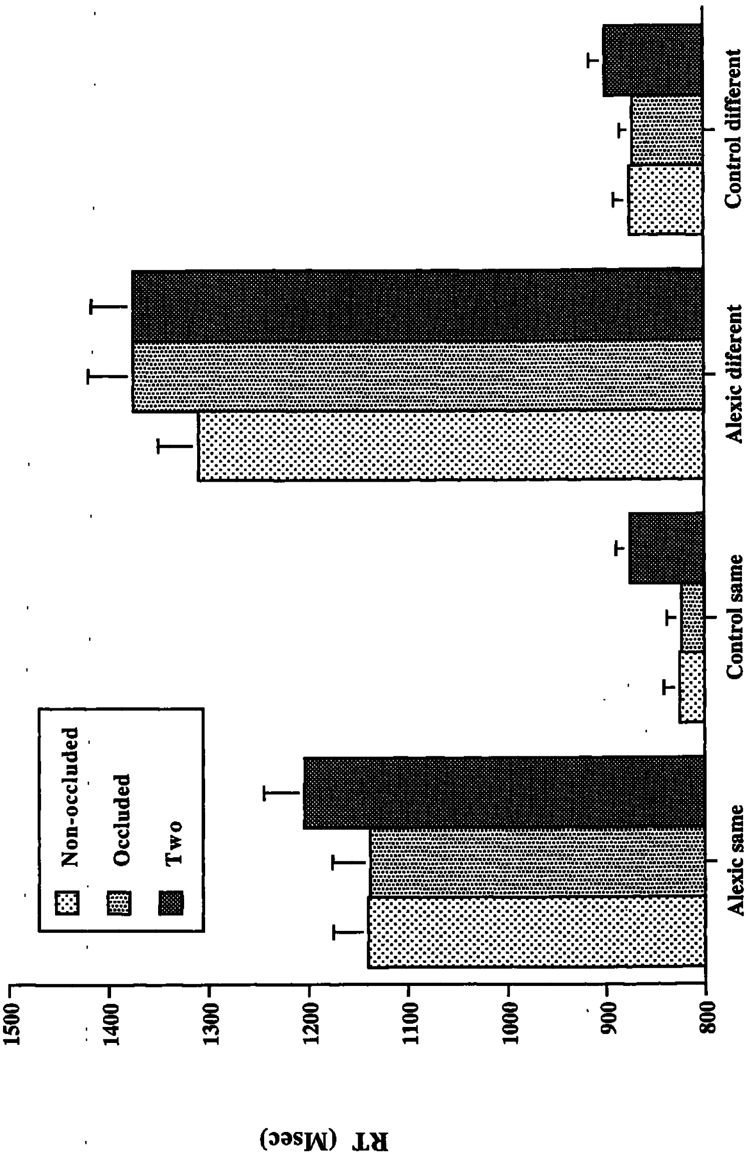

FIG. 7. Group mean reaction time for Experiment 5 plotted by subject group and judgement as a function of condition.

to form a unified percept of this continuous object but response times to "different" single occluded objects now take as long as judgements on two different objects. One interpretation of the set of findings is that patients are able to form a unified percept but only when the figure is continuous or symmetrical. When the occluded object is asymmetrical, however, patients are impaired at integrating the elements, such that the occluded objects are treated no different from the two-object displays. Normal subjects, on the other hand, do not rely on cues like symmetry and show the object advantage even on the asymmetric, different trials.

Although they do relatively well, pure alexic patients do not perform completely normally on this nonorthographic test. The problem, however, is not obviously one of integrating component parts (as they are able to do so in the "same" trials); rather, patients had a specific difficulty in integrating an occluded object when the number of available perceptual cues was reduced. The pure alexics could form unified wholes from parts or features of some nonorthographic objects, but they were more reliant on perceptual cues, such as symmetry, to integrate the objects successfully. This additional dependence on perceptual cues to aid in processing the stimulus is consistent with the view that a general perceptual problem underlies pure alexia. The problem does not seem to be one of integrating parts per se, as the patients also show the normal advantage for single occluded over two objects for the "same" and "different" trials, reflecting their ability to integrate the elements into a coherent percept. Rather, the difficulty manifests itself under impoverished perceptual conditions in which there is less support from organisational cues for representing the display.

GENERAL DISCUSSION

The goal of this study was to determine whether patients with pure alexia, or letter-by-letter reading, have general perceptual difficulties extending beyond their difficulties with word recognition and, if so, what the nature of these difficulties might be. Four patients with pure alexia and eight matched, normal control subjects participated in several experiments conducted to investigate these issues. None of the four pure alexic subjects was aphasic, their language comprehension and expression was well preserved, and so were their single letter identification abilities. Experiments 1 and 2 utilised reading latencies and lexical decision scores to determine whether the patients were letter-by-letter readers. The findings from these two studies were consistent in revealing that all four subjects showed the hallmark word length effect, reflecting the linear increase in RT with an increase in the length of the letter string. Experiment 3 assessed whether the pure alexics' deficits extended beyond orthography by examining their perceptual fluency on both orthographic and nonorthographic material.

This study served as a replication of Farah and Wallace (1991) with a larger patient sample. The final two experiments utilised nonorthographic stimuli to clarify the nature of the perceptual deficit found in Experiment 3, and evaluated whether the deficit is in the representation of parts of an object, as has been suggested by Farah (1991, 1992, 1994) or whether some alternative perceptual impairment might explain the data.

Three main findings emerged from the present study, indicating that pure alexic patients may have a more widespread perceptual basis, extending beyond a specific orthographic disorder. First, in Experiment 3, patient performance was impaired relative to the control subjects on the nonorthographic, as well as on the orthographic, tests. Second, in Experiment 4, patients responded disproportionately slower to poor vs. good configuration trials. In that experiment, patients' responses were slowed by the absence of good continuation in nonorthographic stimuli. Third, Experiment 5 showed that patients had difficulty in integrating two halves of a single object when symmetry was absent and two disparate elements had to be integrated in the presence of an occluder. This last finding is difficult to explain through damage to an orthographic-specific mechanism. All of these findings argue for a general perceptual disorder underlying pure alexia, and they also reveal characteristics of that perceptual disorder.

Recently, Farah has put forth a theoretical account of pure alexia based on general perceptual disturbances. She proposes that pure alexia is due to a disruption in a subsystem responsible for representing multiple parts (Farah, 1991, 1992, 1994). Her theory predicts that the patients would be impaired at tasks requiring several parts to be represented simultaneously. The results of Experiment 4 are inconsistent with this prediction. Patients do not show the predicted linear increase in RT as the number of parts of the object increases. Results from Experiment 5 also contradict Farah's theory. They show that patients *are* able to represent multiple parts. In "same" trials, pure alexics responded faster to single occluded than multiple (two) parts judgements, as did the normal subjects. The patients need to be able to represent simultaneously the multiple parts of the single occluded stimuli in order to gain this single item advantage. Both results disconfirm the plausibility of Farah's multiple parts theory[1].

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[1]One recent study has cast additional doubt on Farah's hypothesis. Rumiati, Humphreys, Riddoch, and Bateman (1994) have presented a case of a patient with object agnosia but no signs of prosopagnosia or pure alexia. This patient is therefore able to read and recognise faces, but is impaired at recognition of both pictures and real objects. The existence of this patient violates the foundation of Farah's hypothesis, that two separate recognition mechanisms exist. Farah claims that one recognition subsystem deals with multiple parts and one with complex parts, but in this scheme it is impossible to have any combinations of damage that would produce a patient with a deficit in object recognition alone. The presentation of this patient causes serious reconsideration of Farah's theory.

Other perceptual theories of pure alexia also fail to predict our findings completely. For example, Kinsbourne and Warrington (1962) claimed that pure alexia was a mild form of simultanagnosia, which limits perception to a single object at a time. Theoretically, the simultanagnosic visual system requires a refractory period after each object or letter is processed, and this encourages letter-by-letter reading. The simultanagnosia theory is only able to account for some of our results. For example, Kinsbourne and Warrington's theory does not accurately predict the results of Experiment 4. A patient unable to perceive more than one object at a time would show increasing latencies as the number of elements of the object increased. Results from this experiment show that set size did not have a monotonic effect on RT latencies for the patient group, nor did set size interact with whether or not the object had good or poor configuration.

Friedman and Alexander (1984) proposed yet another perceptual theory but that too cannot fully account for the present results. They claim that pure alexia results from an inability to *identify* visual input rapidly and automatically. Friedman and Alexander's theory predicts that, in Experiment 4, patients would respond no differently to good and poor configuration items in comparison to controls. The patients would also be expected to perform normally on Experiment 5 because identification of the items is not required to perform that task. Finally, in neither of these latter experiments were subjects under any time pressure for rapid or speedy perceptual processing.

None of these perceptual-level theories are able to account for all of the current findings. Our results do clearly indicate, however, that these four patients are letter-by-letter readers, all of whom also have perceptual deficits. These findings lead to two major conclusions. First, the results indicate that the deficit underlying pure alexia is not specific to orthography. Our results, therefore, do not support the existence of a functionally and/or structurally distinct visual system specific to processing language-related items. This conclusion may be unsurprising as reading is a relatively recently phylogenetically acquired skill and is likely to exploit existing visual processing systems rather than relying on dedicated, newly acquired visual abilities. Second, the perceptual deficit appears when cues are unavailable to aid the perceptual processing of the stimuli. For example, in Experiment 4, patients are differentially impaired in target detection only on poor configuration displays. When good continuation, a salient perceptual cue, is present, performance is not qualitatively different from the normal subjects. A similar finding arises in Experiment 5. Patients show the expected single-object advantage with single occluded stimuli, indicating that patients are able to integrate the occluded bar into a single object when symmetry is present (i.e. in the same condition). However, when the perceptual cue of symmetry is absent, in the different condition, the patients no longer show the advantage for the single occluded item relative to the two-object condition.

Taken together, these findings suggest that patients with pure alexia do have a general perceptual deficit that manifests itself under conditions in which the perceptual demands are greater and in which there is less support for organising or parsing the stimulus. In most everyday situations, there are a number of perceptual cues present that the patients can use to support perceptual processing. This may explain why pure alexic patients do not exhibit an obvious debilitating perceptual deficit. It is only under more controlled and rigorous testing conditions that the deficit may be uncovered. The notion of perceptual support in a display may then explain why it is that the major deficit demonstrated by these patients emerges during reading. When processing a letter string, there are no obvious aids or cues for the formulation of a coherent percept. Cues such as symmetry and figural goodness are of no direct benefit in word processing. Furthermore, in English, there are few intrinsic perceptual cues to direct the combination of letter groups into specific phonemes, syllables, or words. The absence of explicit cues makes word processing a particularly difficult situation for pure alexic patients, highlighting their deficit and bringing it to the fore. Indeed, the absence of salient cues may also explain the observed impairment in letter processing, as perceptual support is also largely absent under these conditions. Existing theories of letter-by-letter reading, such as those that focus on the deficits in letter identification and processing (Behrmann & Shallice, 1995; see also Bub & Arguin, 1995; Kay & Hanley, 1991; Reuter-Lorenz & Brunn, 1990), are therefore consistent with the claims made here. It is important to recognise that the deficit underlying pure alexia may indeed be an impairment in letter processing but that this may, in turn, be attributed to a more fundamental perceptual problem. We do acknowledge, however, that the pattern we have documented across the four patients may not apply to all patients with pure alexia, although the fact that it exists across all four suggests some generalisability. Nevertheless, the heterogeneity amongst these patients is well known (Howard, 1991; Price & Humphreys, 1992). In keeping with our findings, we propose that stringent testing of the perceptual problems in other pure alexic patients is likely to uncover a general, more widespread, perceptual deficit.

Before concluding, there is one alternative possibility that should be raised and that concerns the problem of causation. We have provided evidence that the pure alexic patients also have a perceptual problem but we have not demonstrated that it is the perceptual problem per se that gives rise to the reading deficit; i.e. correlation is not causation. This issue was noted by Farah and Wallace (1991) and they addressed it by showing that there was a significant interaction between word length and the visual quality of the stimulus in TU's reading. The finding that increasing the perceptual burden slows reading times suggests that the perceptual deficit is causally related to the reading problem. If the perceptual deficit is manifest particularly under taxing conditions (and we have argued that reading is one such condition), then we might also expect to see these patients perform poorly on object identification under difficult conditions. As discussed in our description of the patients, we have observed that these patients are accurate but significantly slowed in their object identification, especially when the objects are of high visual complexity. Documenting this systematically is an ongoing focus of research in our laboratory.

In conclusion, the results of this study are compatible with the view that a general perceptual deficit underlies pure alexia. However, previous perceptual theories, including Farah's recent multiple part representation theory, do not accurately predict our findings. For example, contrary to Farah's theory, our patients were able to represent multiple parts of an object. Although we concur with her view that pure alexic patients have a deficit extending beyond orthography, we suggest that the perceptual impairment is unmasked in situations where few intrinsic perceptual cues exist to aid in the integration of multiple parts of an object, such as in reading. Therefore the functional deficit underlying pure alexia may be related to the mechanism responsible for stimulus processing in the absence of strong perceptual cues. If this is the case, then adding additional perceptual grouping cues may ameliorate or at least reduce patients' reading difficulties. This may be accomplished by grouping letters through use of similar colour, case, or spacing. Further research will be required to investigate this possibility.

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