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Neuropsychological evidence for case-specific reading: Multi-letter units in visual word recognition

Deborah A. Hall, Glyn W. Humphreys, and Adam C.G. Cooper

University of Birmingham, Birmingham, UK

We describe a patient (GK) who shows symptoms associated with Balint's syndrome and attentional dyslexia. GK was able to read words, but not non words. He also made many misidentification and mislocation errors when reporting letters in words, suggesting that his word-naming ability did not depend upon preserved position-coded, letter identification. We show that GK was able to read lower-case words better than upper-case words, but upper-case abbreviations better than lower-case abbreviations. Spacing the letters in abbreviations disrupted identification, as did mixing the case of letters within words. These data cannot be explained in terms of letter-based reading or preserved holistic word recognition. We propose that GK was sensitive to the visual familiarity of adjacent letter forms.

What are the units of visual information used to identify words? Current debates on the issue of the visual units mediating word recognition centre on three possibilities; preliminary letter identification, outline word shape, and multi-letter units (groupings of letters or features spanning more than one letter) (see Figure 1). This study uses data from a patient with symptoms of attentional dyslexia to assess whether word recognition can be based on direct activation of multi-letter, familiar, letter forms. In this Introduction, we discuss in turn evidence for the three types of visual unit.

Preliminary letter identification

Several pieces of evidence suggest that words are primarily identified on the basis of their individual component letters. For example, Evett and Humphreys (1981) demonstrated that the masked presentation of a lower-case word (e.g., while) facilitated recognition of the upper-case form of the same word and also close orthographic neighbours (e.g., WHITE), even when the exposure duration was so brief that subjects failed to report the existence of the prime word

Requests for reprints should be sent to Deborah A. Hall, MRC Institute of Hearing Research, University Park, Nottingham, NG7 2RD, UK. Email: debbie@ihr.mrc.ac.uk

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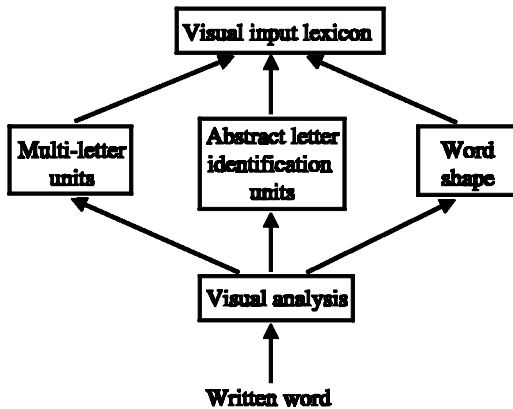


Figure 1. Model showing the three sources of information that are analysed in parallel and are possibly involved in word recognition (adapted from Howard, 1987).

(see also Forster, 1987; Humphreys, Evett, & Quinlan, 1990). Case-independent priming effects suggest that there is a level of letter identification units that gathers information about abstract letter identities (see also Besner, Coltheart, & Davelaar, 1984). Word recognition is based on the activation of these abstract letter representations. Similarly, studies of the word superiority effect (WSE) (and in particular the better identification of letters in words than in pseudowords) demonstrate that it is largely unchanged by presenting stimuli in mixed-case letters (Adams, 1979; McClelland, 1976). Mixed-case presentation disrupts both overall word shape and multi-letter units, as the familiarity of consecutive letter pairs is altered, but it leaves available individual letter information. The maintenance of the WSE under those conditions suggests that letter identities, rather than word shape or multi-letter units, are used to activate lexical information from words. The interactive activation model of word recognition incorporates the assumption that lexical information is retrieved from parallel letter identification, without the involvement of supra-letter information (i.e., word shape or multi-letter units) (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982).

Word outline

A number of studies suggest that word shape is important. In particular, the word envelope present for lower-case, but not upper-case, words can influence both beginning (e.g., Feitelson & Razel, 1984; Guttentag, 1981; Healy & Cunningham, 1992), and skilled (e.g., Haber, Haber, & Furlin, 1983; Monk & Hulme, 1983; Underwood & Bargh, 1982) readers. For example, Underwood and Bargh found that naming latencies for upper-case words were significantly affected by spelling-to-sound regularity, but, in lower-case format, latencies for regular and irregular words were equivalent. This suggests that lexical access occurs via a direct visual route, for regular and irregular words alike, when word envelope information is available (i.e., with lower- but not upper-case stimuli). When the word envelope is not present (e.g., with upper-case words) reading may operate via non-lexical conversion of orthography to phonology, hence spelling-to-sound regularity can affect performance.

For some studies, the apparent influence of word outline can be explained in other terms, for instance, due to effects at the letter-level (see Henderson, 1982; Paap, Newsome, & Noel,

1984). For instance, manipulations such as case mixing not only change word outline, but also decrease the distinctiveness of individual letters (by lateral masking and by reducing the salience of letter features, such as ascending line segments). Consequently, without appropriate controls, effects of manipulations such as case alternation can be attributed to letter-level factors. Even proof-reading studies using only lower-case stimuli (e.g., Haber & Schindler, 1981; Monk & Hulme, 1983) have failed to include adequate control over possible letter-level influences (see Paap et al., 1984). More recent evidence has also failed to support a role for word shape in normal reading. For example, Besner (1989) found that the effect of case alternation was no stronger on function words than on matched nouns, even though function words are more likely to be identified on the basis of their shape, due to their short length and high frequency.

Multi-letter units

Much of the debate on word identification has contrasted letter-based and holistic word recognition operations (see earlier), although a variety of other visual units could be involved. Some proposals have stressed the role of visual units corresponding to particular phonological or morphemic forms. Examples include vocalic centre groups (Spoehr & Smith, 1973), basic orthographic syllable structures (Taft, 1979), morphological structure within the orthographic system (Stolz & Besner, 1998) and onset and rime units (e.g., Treiman & Chafetz, 1987; Treiman, Mullennix, Bijeljacabic, & Richmondwely, 1995). Whiteley and Walker (1997) also report the operation of supra-letter visual units, which do not necessarily correspond to phonological or morphemic forms but which, when activated across a word, could be used for lexical access.

Recent demonstrations of priming effects in the context of a “yes/no” alphabetic decision task suggest that visual multi-letter units are directly activated in parallel from a word. For example, Greenberg and Vellutino (1988) found that alphabetic decisions made on high frequency, upper-case, consonant bigram targets were facilitated by their occurrence in the initial or final position of a preceding prime word. Low-frequency bigrams, however, facilitated responses only to their individual letters. This suggests that in the internal representations of orthography, high-frequency bigrams are coded as single units, at both the beginnings and the ends of words. In contrast, low-frequency bigrams are represented in terms of their individual letters. These results were extended by Whiteley and Walker (1994, 1997) who showed that bigram priming was most pronounced for lower-case letters, which are more visually familiar than upper-case or alternate-case letters. The results are difficult to reconcile with the preliminary letter identification viewpoint. Instead, Whiteley and Walker suggest the consonant bigrams are represented as multi-letter units that are directly activated by lower-case forms. Although the precise definition of such multi-letter units has remained elusive, they may include the spaces between common letter pairs (Wheeler, 1970), the configurations formed across letter features (Besner & Johnston, 1989), letter cluster density (Haber & Haber, 1981) or grouped entire letter forms (Mayall, Humphreys, & Olson, 1997).

Neuropsychological evidence

The role of multi-letter units in word identification is also supported by several neuropsychological cases. Using a patient with Balint's syndrome, Baylis, Driver, Baylis, and Rafal

(1994) showed that performance was based on the coding of familiar letter clusters. The patient, RM, was frequently able to read single letters and words, but failed to identify the letters within words. RM's superior identification of isolated letters over groups of letters reflects a core symptom of attentional dyslexia (Price & Humphreys, 1993; Shallice & Warrington, 1977), which Baylis et al. suggest is closely associated to Balint's syndrome. Interestingly, RM was able to report letters in familiar words more accurately than those in nonwords. He also showed an advantage for pronounceable nonwords over unpronounceable nonwords. Baylis et al. proposed that the familiar letter clusters contained in words (and to a lesser extent in pronounceable nonwords) were perceived as single multi-letter units. Thus, RM's preserved word naming could be supported by chunking letters into familiar clusters, which can be used to access the lexicon; on the other hand, letter-based access to the lexicon and/or to phonology was restricted due to the poor coding of letters within strings.

Howard (1987) studied the contribution of multi-letter units to reading in a patient (TM) with severe speech, comprehension, and reading impairments. TM, like RM, appeared unable to rely on letter identification in reading. Single letter naming, cross-case matching, and spoken-to-written letter matching were all very poor. Nevertheless, TM's oral reading was better than would be expected if word identification relied solely on preliminary letter identification (32%). He was also highly susceptible to visual manipulations. Performance declined significantly when words were presented with plus signs (p+l+u+s) between the letters, in alternate (aLTeRNaTe) case, and in diagonal arrays. These conditions distort both outline shape and multi-letter units, and so it is possible that TM's residual reading ability was based on one or other of these supra-letter visual codes. However, Howard ruled out the influence of outline word shape, as (1) there was no reliable difference between the naming of lower- and upper-case words, and (2) letter substitutions that either maintained or altered word shape had no effect on nonword lexical decisions. By elimination therefore, Howard concluded that the patient's reading was mediated by some form of multi-letter units.

The present paper

In this paper, we present the case of a patient (GK) with bilateral parietal damage causing Balint's syndrome (optic ataxia and simultanagnosia) and symptoms of attentional dyslexia. Simultanagnosia is a deficit in the voluntary switching of attention generally associated with the inability to see unattended objects. Attentional dyslexia may be a symptom of simultanagnosia in patients with bilateral parietal damage, as they may be able to assimilate words (perhaps using supra-letter information without shifting attention) but the identification of the letters within words may be impaired because this task requires attention shifts¹. GK's single letter and word identification is relatively good, as is his ability to translate single letters and words into phonology. However, he is severely impaired at identifying constituent letters in letter strings, and he makes letter migration errors when presented with two words:

¹ Poor assimilation of multiple visual elements can also follow lesions of the inferior occipito-temporal region of the left hemisphere, in the syndrome labelled by Farah (1990) as ventral simultanagnosia (see also Kinsbourne & Warrington, 1962). In our view, ventral simultanagnosia is likely to be distinct from simultanagnosia caused by dorsal (parietal) lesions. The latter is linked to impaired switches of attention between objects without necessary deficits in assimilating multiple parts of single objects. Due to their poor assimilation of multiple parts, ventral simultanagnosics are likely to read in a letter-by-letter manner (see Humphreys, 1998, for relevant evidence).

both symptoms of attentional dyslexia (Baylis et al., 1994; Price & Humphreys, 1993; Shallice & Warrington, 1977). GK's nonword reading is extremely poor. We suggest that this is due to his problems in identifying members of multi-letter strings. To examine the factors that can maintain word identification under these circumstances, we investigated the nature of the visual information that mediates GK's reading.

Experiment 1 compared the reading and constituent letter naming in words and nonwords. Experiment 2 measured visual recognition of letters, words, and nonwords when overt naming was not required. Experiments 3 and 4 assessed the case specificity of reading, contrasting GK's reading of upper- and lower-case words and abbreviations. Experiments 5 and 6 evaluated the effects of case alternation. These experiments reveal effects of manipulating groups of visual letter forms on GK's reading accuracy. Moreover, case manipulations effects are not attributable to lateral masking when letters do not differ in size (in Experiment 6 alternate-case letters were the same size). The results reveal that GK is highly dependent on supra-letter units that respond to familiar letter clusters. We discuss the role of such units in normal reading.

CASE REPORT

GK was born in 1939 and left school at the age of 14. He was a business man who started a successful import-export company and often travelled overseas. In 1986, he suffered two strokes, which occurred 3 months apart. This resulted in lesions of (1) the right temporo-parietal regions, (2) the right occipito-parietal region, and (3) the left temporo-parietal region (Figure 2). Following the second stroke, he was temporarily cortically blind and aphasic, but these difficulties recovered over a period of time. At the time of testing, perimetric tests revealed that GK had full visual fields, and his speech was also much improved, although some word-finding difficulties remained (with phonemic paraphasias being generated on occasions).

The difficulties that restrict GK's normal daily activities are mainly visual in nature. Previous testing had shown that object recognition was slightly impaired, but that GK was relatively good at perceiving familiar faces (Humphreys, Donnelly, & Riddoch, 1993). GK also shows a left-sided visual neglect that affects a variety of tasks such as eating a meal, reading, and line bisection. In addition, GK has symptoms characteristic of Balint's syndrome, particularly in misreaching under visual guidance (optic ataxia) and in the inability to perceive more than one object at once (simultanagnosia). The simultanagnosic deficit is reflected in his inability to search through a list of items for a target and almost certainly contributes to his text-reading impairment (see Figure 3). GK is also severely impaired at judging visual locations. When asked to indicate whether a predefined object, shown for 500 ms, appeared 3° above or below the fixation point, he scored at chance level (Humphreys, Romani, Olson, Riddoch, & Duncan, 1994).

Earlier neuropsychological testing also revealed extinction effects. GK failed to detect the left-most of two stimuli when presented simultaneously and bilaterally (Gilchrist, Humphreys, & Riddoch, 1996). However, failure to detect items was based on object, rather than spatial, properties when stimuli were presented in the upper and lower fields (Humphreys et al., 1994). Despite the lateralized nature of some of GK's deficits, the evidence we describe later shows that the lateral position of letters in words only impacts mildly on his single word recognition under long exposure conditions. The data reported in this paper were

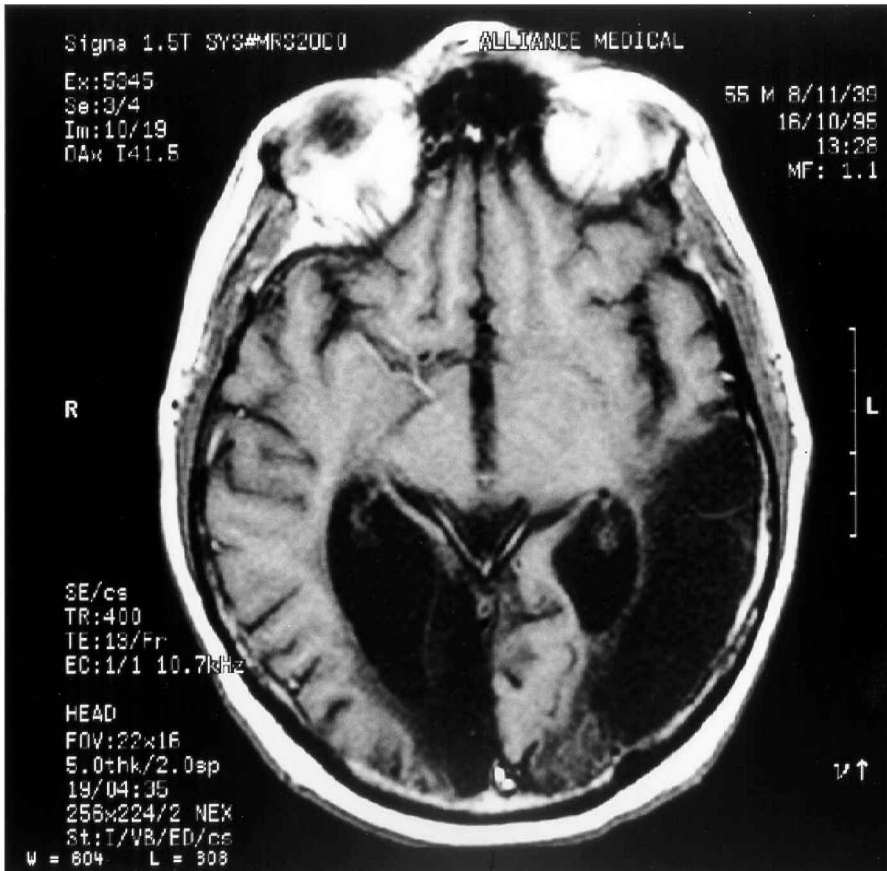


Figure 2 (above and opposite). CT scan of GK taken in 1986 showing his extensive bilateral temporo-parietal lesions.

collected between January 1992 and March 1999, during which time GK's performance remained constant.

PRELIMINARY ASSESSMENT OF WORD RECOGNITION

Reading tests were carried out using an Apple Macintosh Duo Dock computer with a 12" colour monitor. Unless otherwise stated, on each trial a central fixation point was displayed for 1 s to indicate the location of the following stimulus. Stimuli were presented for an unlimited duration until GK made a response.

GK made few errors on single letter naming. On initial testing, he named 22/26 lower-case and 24/26 upper-case letters correctly. In tests conducted at the time of the abbreviation study (Experiment 4), GK scored 26/26 on both lower- and upper-case letters. Letter-matching ability was also assessed using pairs of different-case letters presented sequentially for 1 s. GK scored 43/52 initially on this task and 52/52 subsequently. Even initially, he was significantly



Figure 2 (continued).

The Queen was in bed watching television with Harris. Harris yawned, displaying his sharp teeth and liver-coloured tongue.

“A funny word.. sharp.. it looked like.. provision.. something is.. what would that be.. television.. a name like Harris or colour? Teeth, I saw.. now that’s wrong again.. Harris.. control.. or silver.. something like that. watching is there. The Queen.. is that right?”

Figure 3. A transcription of GK's ability to read a short passage of text illustrating his severe difficulty in reading multiple visually presented words.

better than chance (binomial probability, $p < .001$). Thus, GK's performance showed that he has relatively good access to an abstract letter code for letters presented individually.

Single word reading was slow, but was relatively accurate compared with his impoverished text reading skills (see Figure 3). Word reading was abnormally affected by exposure duration. When each word was presented for 40 s, GK named 32/52 (62%) four-letter words correctly. At word presentation durations of 500 ms, reading accuracy declined to 11/52 (15%). Further assessments of single word reading, under free viewing conditions, showed that identification performance was not affected by word frequency (33/46 vs. 32/46 for high- and low-frequency words, respectively; $\chi^2 < 1.0$), nor by regularity (51/69 vs. 48/69 for frequency-matched regular and irregular words; $\chi^2 < 1.0$). Despite GK's ability to read many words, he was practically unable to read any nonwords. For example, in one test, he named 26/34 words, but only 1/34 nonwords that had been derived by changing one letter of the words, $\chi^2(1) = 35.4, p < .001$.

GK completed a lexical decision task that used high-imageability words matched for length and N value to nonwords (where N represents the number of orthographic neighbours that differ from the target word by only one letter). GK scored above chance (17/24; 8/12 on words and 9/12 on nonwords), but far from perfect. In a second lexical decision task, containing function words and nonwords, he correctly categorized 41/48 (85%) function words and 38/48 (79%) orthographically matched nonwords. Despite being unable to name nonwords, he could often categorize them as not being words.

Spelling performance was much worse than word recognition. On a test of oral spelling, he scored 7/18 (39%) on regular words and 2/18 (11%) on irregular words. The effect of regularity did not reach significance (Fisher exact test, $p = .07$), but this lack of a significant difference may reflect the small number of data.

Identification of words from their oral spelling was also poor. On three-to-five letter words, GK correctly identified 17/46 (37%), most of which were on the shortest words ($N = 9$). GK found both spelling tasks extremely difficult, and each word had to be repeated many times before he gave a response. However, he also reported that he had always been a poor speller. We note that poor spelling may prevent GK from using a "spell back" strategy of reporting letters after reading words.

Previous work on attentional dyslexia has shown that: (1) Patients are able to name a single target more accurately when it is surrounded by stimuli from a different category than when it is surrounded by items from the same category (Shallice & Warrington, 1977; Warrington, Cipolotti, & McNeil, 1993), and (2) with multiple words, reading errors include letter migrations from different stimuli. GK's reading errors reflect both these defining features of the syndrome. GK was requested to name a central letter or digit with flankers from either the same category (e.g., a central letter with letter flankers) or a different category (e.g., a central letter with digit flankers). GK performed better when flankers were from a different category to the target. This held for letter targets: 5/25 vs. 21/26 for same and different categories; $\chi^2(1) = 16.48, p < .001$; and for digit targets 16/40 vs. 26/36 for same and different categories; $\chi^2(1) = 7.94, p < .01$. We also tested the reading of word pairs presented simultaneously above and below fixation, with the time adjusted so that GK could perceive two words on about 80% of the trials (time = 11 s). Critical words pairs ($N = 26$) shared the same initial and final letters, and real words could be formed by exchanging either the second or third letters (e.g., "wove ware" can form migratory words "wave wore", see McClelland & Mozer, 1986; Mozer, 1983).

In a control condition, one of the words from the critical condition appeared with a word that shared letters but would produce nonword migration errors (e.g., “wove wife”).

GK named six word pairs correctly. GK's naming errors included migrations of the central letters (6 of the 52 word pairs), and he made other types of errors on 40 of the word pairs (e.g., “lace love” → “ace, cove”, “robe rice” → “bible, icing”). In his studies, Mozer calculated true migration responses by subtracting the number of migration errors in the critical condition from those in the control. GK made no nonword migration errors in the control condition; a result that may be affected by his failure to produce nonword responses in any naming task. However, in other studies, we have found that GK makes reliable numbers of migration errors relative to chance levels calculated from a single word baseline (Humphreys, Watson, & Oliver, 1999). Hence they appear to be real phenomena. The few migration responses that GK did make were categorized as migration exchanges (where letters were exchanged between words) and migration copies (where a letter intruded from one word to the next, overwriting the replaced letter). One of the word pair errors was a migration exchange (e.g., “bond bald” → “band bold”), and five were copies (e.g., “park peck” → “park pack”). Statistical comparisons between such small numbers is not possible. Nonetheless, the proportion of migration errors relative to the number of trials and the distribution of migration types is within the range produced by normal readers under brief masked viewing conditions (Mozer, 1983). Thus, although GK made other errors when naming pairs of words, his error corpus did include a reliable number of letter migrations.

Summary

GK made some errors when naming words, letters, or pictures in isolation, but showed no effects of frequency or regularity. He was practically unable to name any nonword. He was poor at identifying letters in abbreviations and also at identifying the central item in a string of three from the same category. He also generated letter migrations in word naming, even when given 11 s to read word pairs. These symptoms are characteristic of attentional dyslexia.

EXPERIMENT 1: Whole word naming and full letter report

The preliminary assessment confirms that GK shows symptoms of attentional dyslexia; particularly the poor report of a central letter in a string and the migration errors. In Experiment 1, we assessed word and letter naming, to test whether word naming operated over and above GK's ability to identify the constituent letters. The experiment also compared his letter identification in words and nonwords. Baylis et al. (1994) reported that patient RM's letter identification was better in words than in nonwords, even when words, as a whole, could not be named correctly. They suggested that reading ability in Balint's syndrome could be supported by using letter clusters, present in words, but not in nonwords. Here, we tested whether the same held for GK.

Method

A total of 90 words that varied in length were selected: 30 each containing 3, 5, and 7 letters (e.g., act, whole, century). Items were chosen so that they did not include any letter repetitions, since this might

bias under-reporting in letter identification (see Kanwisher & Potter, 1990; Mozer, 1989). Lack of repetitions also facilitated scoring the letter report task, as each letter name corresponded uniquely to one position. Words were matched across the three groups for word frequency (mean = 241 occurrences per million in the Kuçera & Francis, 1967, word count) and imageability (mean = 416 according to the Oxford Psycholinguistic Database imageability rating, Quinlan, 1992). A set of 90 pronounceable non-words was created from this word list by reassigning the order of letters in each item (e.g., tac, holew, nycture).

Word naming and letter identification were administered on separate occasions, and both words and nonwords were presented in mixed blocks in an ABBA design. In the naming task, GK was required to look at the stimulus as a whole and to name the word or, in the case of a nonword, to try to pronounce the item. Items were displayed until GK began his naming response. In the letter report task, GK named aloud as many letters as possible from left to right.

Results

Whole string naming

Whole string naming responses were scored as either correct or incorrect and the results are reported in Table 1. Words were named more accurately than nonwords: 69/90 vs. 2/90; $\chi^2(1) = 104.41, p < .001$. In fact, one of the two nonwords named correctly (deb) was actually also a shortened form of the experimenter's name and so may not have been treated as a nonword by GK. Most of his nonword errors ($N = 54, 61\%$) were visually similar real words (e.g., yad \rightarrow "yard"). The remainder were either attempted nonword responses ($N = 20, 23\%$; e.g., wef \rightarrow /wif/) or "don't know" responses ($N = 14, 16\%$). Naming errors on the real words included visual errors in which the target and response shared at least 50% of their letters in common, but not necessarily in the same order (e.g., country \rightarrow "county"). Errors also involved the incorrect identification of the left side of the word (e.g., low \rightarrow "below"). We term these responses "neglect errors". Note that, in the prior literature on neglect dyslexia, neglect errors can include letter additions, substitutions, and omissions (Ellis, Flude, & Young, 1987). GK made all three classes of neglect reading errors. Word naming accuracy was not affected by word length, $\chi^2(2) < 1.0$. Length effects for nonword stimuli could not be computed because of the small expected frequencies.

TABLE 1
Accuracy in naming and letter report of words and nonwords as a function of word length

		<i>Naming</i>	<i>Letter report in position</i>	<i>Letter report in any order</i>
Word	3-letter	0.73	0.78	0.86
	5-letter	0.80	0.65	0.76
	7-letter	0.77	0.43	0.65
Nonword	3-letter	0.07	0.64	0.76
	5-letter	0.00	0.56	0.65
	7-letter	0.00	0.34	0.58

Note: Letter report accuracy is calculated on the basis of the proportion of letters correctly identified within each item presented.

Letter report

Performance on the letter report task was poor (see Table 1). GK was successful at naming all the component letters within a string on only 25 of the stimuli (14%). This is much worse than his performance on naming the words and nonwords, thus suggesting that GK's whole word and nonword naming is unlikely to be based on explicit identification of the component letters. To test for differences between individual letter identification in words and nonwords, a more sensitive scoring procedure was employed, which took account of individual letter reports rather than whole string accuracy. A number of letter names given by GK (132/763, 17%) did not actually appear in the target letter string (e.g., tra → "f r c"). These were disregarded in both letter analyses. Two different letter-scoring methods were adopted, each reporting the percentage of letters correctly identified in each item as a function of length. The first method, "position correct", scored responses only according to correct letter identity and relative position. This scoring criterion was lenient, so that if fewer letters were identified than were actually present, or if erroneous letters were named, a score was allocated to letters that lay in the correct relative position (e.g., shandub → "s a n d" scored 57%). The second method, "any position", scored responses according to correct letter identity, irrespective of its position. Letter repetitions were ignored. For example, maverol → "e v o l e" scored 57% (on the position correct procedure this would be scored 43%).

When scored according to accuracy of position, constituent letter identification was significantly better for words than for nonwords: 62% for words and 52% for nonwords, Table 1; $t(178) = 2.50, p < .05$. The same pattern of results was also obtained when letter report was scored irrespective of position: 76% for words and 66% for nonwords: $t(178) = 3.20, p < .01$. Scores were generally lower for the "correct position" scoring method, as many of GK's responses reflected the correct letter identity but were reported in the incorrect relative position (e.g., chief → "c h e i f").

Scoring requiring the correct position showed a significant effect of length on the proportion of letters identified correctly, $F(2, 174) = 26.96, p < .001$. The interaction between word length and word type was not significant, $F(2, 174) = 0.17, n.s.$, thus indicating that letter identification in both words and nonwords was similarly affected by length. Table 1 shows that as length increased, letter naming accuracy decreased. A Scheffe's post hoc test showed that GK's performance on seven-letter items was significantly worse than for three- and five-letter items ($p < .001$). An increase in the number of letter omissions as a function of length can account for the decline in letter report accuracy. On average, GK gave three-letter responses for 3-letter items, four-letter responses for five-letter items, and only five-letter responses for seven-letter items.

The decline across word length in letter report accuracy, but not in word naming, might suggest that GK's residual ability to identify letters is unlikely to support a successful guessing strategy for word naming. Longer words tend to have fewer orthographic neighbours than shorter words, and so, perhaps counter-intuitively, a guessing strategy *could* be more useful for longer words even when letter report itself is not fully accurate. To measure the outcome of a guessing strategy, we presented GK's letter report responses to three controls who were required to guess the identity of each word (word length information was supplied to facilitate guessing). The controls' mean naming accuracy declined with word length (three-letter words = 60%, five-letter words = 43%, and seven-letter words = 24%), indicating that this guessing

strategy is ineffectual for longer words. Hence, we suggest that GK's naming ability is unlikely to rely on letter identification alone.

The word superiority effect in letter report. In their study of the Balint's patient, RM, Baylis et al. (1994) ruled out the possibility that the word superiority effect in letter report could be produced artifactually by a guessing bias towards the production of lexically correct sequences, regardless of the stimulus type. They classified the sequence of letters given in each response according to whether it formed an unpronounceable or a pronounceable letter string, or a true word. Adopting a similar analysis procedure on GK's responses revealed that, unlike RM, he did not show a general bias towards the production of lexical responses in the letter report task (see Figure 4); in fact, he tended to make more nonword than word responses. If GK was trying to use a "spell back" strategy, then perhaps his poor spelling ability contributed to the large proportion of nonword responses. Whatever the case, the benefit for reporting letters in words over those in nonwords cannot easily be attributed to a general bias in producing a word response.

Rather than a lexical guessing strategy, Baylis et al. (1994) favoured an explanation for the word advantage shown by RM in letter report in terms of the frequency of orthographic clusters. They argued that frequently occurring, "familiar" letter clusters contained in words (and to a lesser extent in pronounceable nonwords) might be perceived, even when their individual components could not (e.g., based on the activation of multi-letter units). If more letters could be identified when they were "chunked" into familiar multi-letter units, and if there were more of these units in the word than in the nonword set, then letter report would be better in words than in pronounceable and unpronounceable nonwords. However, this explanation was merely intuitive as no definitive measures of the frequency of orthographic units across stimulus types were made by Baylis et al.

In the case of GK, to further investigate the issue of letter-cluster "familiarity", a post hoc analysis was conducted by assessing the frequency of all possible adjacent combinations of

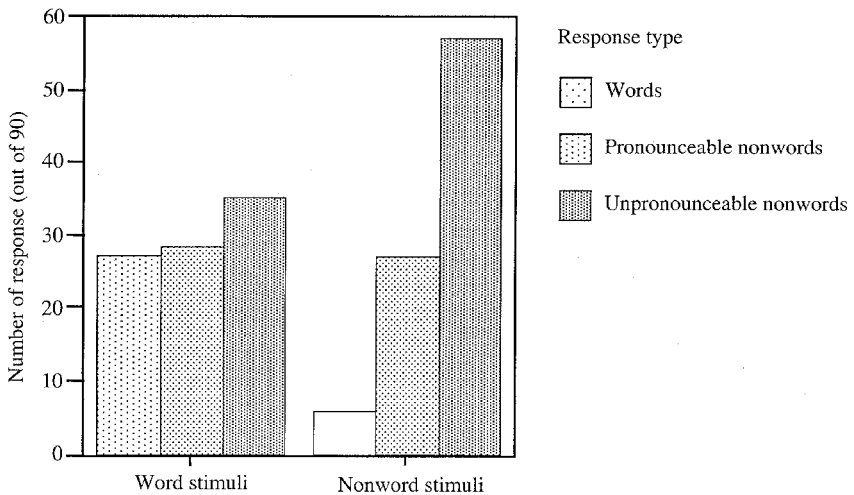


Figure 4. Graph to show the lexicality of the type of letter report responses given by GK for words and nonwords in the letter report task. Responses were categorized irrespective of their accuracy.

letter bigrams in each item. This yields an approximate measure of the frequency of the constituent letter bigram clusters for both words and nonwords (frequencies were calculated using tables based on a sample of 20,000 words; Mayzner & Tresselt, 1965). A paired *t*-test indicated no significant difference in the frequency of bigram clusters paired across words and nonwords (i.e., those sharing the same constituent letters), $t(80) < 1.0$. The mean frequencies of each bigram cluster was 439 for words ($SD = 480$) and 431 for nonwords ($SD = 620$). A second post hoc analysis was carried out that took a subset of the 30 most common bigram clusters according to Mayzner and Tresselt. We then compared the proportion of correctly reported clusters across both the word and the nonword stimuli. If the word advantage was due to an increased ability to identify high-frequency letter clusters per se, as Baylis et al. (1994) suggested, then no difference between words and nonwords would be expected. However, GK accurately named 44/98 (45%) of the letter clusters when they appeared in words and only 15/92 (16%) when they appeared in nonwords, $\chi^2(1) = 16.81, p < .001$. Therefore, in the case of GK, the word advantage in letter report was not due to an effect of the frequency (“familiarity”) of orthographic clusters per se.

Discussion

Whole string naming

We suggest that it is unlikely that GK's word-naming ability involves successful guessing based on his residual letter identification ability, because letter report accuracy declined with word length and yet word naming did not. In addition, the dissociation between word and nonword naming was striking. GK's deficit with nonwords cannot be attributed to a poor ability to link letters to sounds, as he could do this for single letters. Furthermore, in other tests, GK was able to blend individual phonemes into spoken nonwords (20/20, e.g., /t/ /e/ /k/ → /tek/). As phonological assignment and phoneme blending are good, the problem seems to arise at an earlier stage of processing, such as orthographic coding (see Coltheart, 1985; Funnell, 1983). For example, if systematic left-to-right encoding of graphemes was impaired, nonword reading would be contingent on partial activation of lexical entries (see Funnell & Davidson, 1989; Kay & Marcel, 1981). Consistent with the partial lexical access hypothesis, GK gave a high proportion of real word names in nonword reading.

Letter report

When asked to identify the letters in strings, GK often reported the correct letter identity, but in the incorrect position. The finding is consistent with an earlier study of GK (Humphreys et al., 1994) that reported a deficit in his making even simple location judgements (above or below fixation). In the case of letter report in Experiment 1, the location deficit would be exaggerated by the increased number of items in the display and the specificity of the location information required. GK's simultanagnosia may further contribute to his inability to make judgements based on the spatial relationships within a letter string; if he selects only one letter at a time (for letter report), he may have little information about the relative positions of the letters. The tendency to report letters in the incorrect spatial order was also noted by Baylis et al. (1994) in their patient with Balint's syndrome. For example, in a set of four-letter words, their patient reported on average only two letters in the correct position.

In addition, GK showed a word superiority effect in letter report, when the data were scored for both letter identities and positions. We were able to eliminate accounts in terms of a lexical production strategy, because GK tended to produce letter strings that formed nonword sequences and because the effect tended to occur even when he did not name all the letters in the string correctly. His apparently poor spelling knowledge would make the orthographic decomposition of a phonological code an extremely difficult task, making a “spell back” strategy in letter report unlikely. An explanation for the word superiority effect in terms of perceptual chunking of high-frequency letter units also seems incorrect. The word advantage was still maintained when report accuracy on a subset of the most common bigram letter clusters was compared across both stimulus sets and there was no difference in the frequency of the bigram clusters in the words and nonwords.

The fact that the word advantage occurred even for report of the high-frequency letter clusters suggests that whole-word codes may be important for GK rather than multi-letter units or units coded at the letter level. We return later to review this proposal and to re-interpret the present data. For now, however, it is the most obvious account of the results and one that is tested in the following experiments. When identification of letters in strings is impaired (as in the case of GK), word reading may draw upon cues that may only play a minor role in normal word naming, such as word shape or other supra-letter cues. Data from normal subjects suggest that supra-letter information may contribute to word recognition, but this is task dependent. For example, disrupting supra-letter codes by case alternation can influence lexical decision more than naming, because lexical decision probably involves additional computations such as a lexical familiarity check mechanism (Besner & McCann, 1987; Mayall & Humphreys, 1996). If GK is highly dependent on supra-letter information, then manipulations that alter this information may significantly affect his reading. This was examined in Experiment 2, which did not involve an explicit reading task, but instead examined the impact of lexical information on individual letter and letter string report judgements. Experiments 3–6 tested for effects of supra-letter information in explicit reading tasks.

EXPERIMENT 2:

The effects of word and letter shape on recognition

In Experiment 2, GK had to make a two-alternative forced-choice decision as to whether either a particular letter or a particular letter string was presented. The visual similarity between the two alternative items was manipulated by crossing the visual similarity of letter shape and the visual similarity of the word shape to give four experimental conditions. As an example for the target “h”, substitution “b” maintains word shape and has a confusable letter shape, “d” maintains word shape but has a distinctive letter shape, “n” alters word shape but has a confusable letter shaped and “m” alters shape and has a distinctive letter shape. Ratings of visual similarity were derived from the letter matrix reported by Paap et al. (1984). This matrix has seven letter targets (t, l, s, e, h, o, r), thus yielding 28 (i.e., 4×7) substitutions.

Paap et al. (1984) used a proof-reading task and reported that normal readers showed a significant effect of confusability between letters in the correct and incorrect spellings of words, but no effect of confusability in word shape. In the present task, GK saw a single item and was then required to select it from two alternatives that were read aloud. If GK is sensitive to letter shape, he should be more accurate at distinguishing between alternatives that have distinctive,

rather than confusable, shapes. Alternatively, if GK acquires word shape information, then he should be most accurate at distinguishing between alternatives that grossly alter word outline.

Method

Pairs of confusable letters (a “target” and a “substitution”) were selected according to the matrix of Paap et al. (1984) and were used to create three stimulus sets according to their context of presentation; letters in words, letters in nonwords, and letters in isolation.

The first set contained 80 four-letter words (mean frequencies = 72 occurrences per million, Kuçera & Francis, 1967). Target letters were distributed across each of the four letter positions (e.g., target “P”; laid, ally, pale, deal). The corresponding substituted letters also formed a real word when substituted in place of the target letter (e.g., raid, ably, pace, deaf). To eliminate forced-choice selection bias in favour of the most common word, word frequency was counterbalanced across items containing targets and substitutions. The second stimulus set contained 80 nonwords, which were created by reassigning the order of non-target letters in each word to form a pronounceable nonword. The position of the target/substituted letter remained fixed in word and nonword conditions (e.g., liad, alyl, pela, edal). The third stimulus set contained the target letters alone. Each item appeared at about the centre of the computer screen for 900 ms (exposure duration was determined by the level at which GK achieved 70% accuracy). Letter targets in isolation were displayed on the screen in the same position as they appeared in the word and nonword sets. In all stimulus sets, the target letter was displayed in red and the other letters in blue.

Two tasks were run in separate sessions, but the same stimuli were used for each. In the first task, GK was requested to attend to the red letter rather than the surround, thus providing an indication of letter discrimination when attention was focused at the letter level. After each stimulus presentation, the experimenter read out the two alternatives (e.g., nail; “was it ‘n’ or ‘h’?”), from which GK indicated his response. The word, nonword and single letter sets were run in a blocked presentation. In the second task, GK was required to focus attention at the string level. Word and nonword lists were again presented in separate blocks, but with two alternative strings rather than letter responses being presented on each trial (e.g., nail; “was it ‘nail’ or ‘hail’?”).

Results

Forced-choice letter discriminations

GK's accuracy on letter discriminations is shown in Table 2. GK's ability to recognize letters alone was relatively accurate (94%). GK made more errors on the word (66%) and nonword (68%) lists. There were no significant effects of similarity between letter shape, $\chi^2(1) = 0.11$, n.s., or word outline, $\chi^2(1) = 0.45$, n.s., on discrimination accuracy. Further tests assessed the effect of the surround context on the accuracy of letter discrimination using Cochran Q and McNemar tests. These statistics are based on the *changes* in scores on matched items across experimental conditions, rather than on the absolute difference between mean condition scores. There was a significant effect of surround context, Cochran $Q(2) = 163.7$, $p < .001$; letter discrimination was most accurate when letters were presented alone relative to when they were presented in words or nonwords (McNemar, $\chi^2 = 18.6$ and 13.5 , $p < .001$ respectively).

Forced-choice string discriminations

Again, there were no significant effects of similarity between letter shape, $\chi^2(1) = 2.04$, n.s., or word outline, $\chi^2(1) = 0.21$, n.s., on discrimination accuracy (see Table 2). However, in this

TABLE 2
Proportion of items correctly discriminated in a forced-choice discrimination task for letters and strings

<i>Discriminations</i>		<i>Word shape altered</i>		<i>Word shape maintained</i>		<i>Total</i>
		<i>Confusable letter</i>	<i>Distinctive letter</i>	<i>Confusable letter</i>	<i>Distinctive letter</i>	
Letter	Letters	0.90	0.90	0.95	1.00	0.94
	Words	0.70	0.65	0.65	0.65	0.66
	Nonwords	0.75	0.70	0.65	0.60	0.68
String	Words	0.85	0.85	0.60	0.90	0.80
	Nonwords	0.53	0.50	0.55	0.75	0.58

Note: The visual familiarity of the target and the alternative choice item was manipulated according to whether word shape was maintained or altered and also according to whether the shape of the different letter was confusable or distinctive.

task words were discriminated more accurately than nonwords, McNemar, $\chi^2 = 7.41, p < .01$. Performance on nonwords approached chance level (binomial probability = .07). It was also noted that performance on words was better when the forced-choice discriminations were between strings rather than letters (McNemar, $\chi^2 = 5.45, p < .05$).

Discussion

GK showed no effect of visual similarity of either letter shape or word outline substitutions on letter discrimination, even when response alternatives were presented in terms of whole strings in an attempt to favour a more holistic processing strategy. Thus, unlike normal readers, GK did not appear to utilize shape cues at the letter level in this discrimination task.

In the forced-choice letter discrimination task GK experienced greater difficulty in recognizing letters presented in an array than those when presented alone. This impairment may reflect the same difficulty in restricting attention to a specific spatial location that we observed in the flanking task (see preliminary reading assessment), when GK was poor at naming the central letter in an array of other letters. Identification of the cued letter might also have been further impaired here by the short exposure duration used. Nevertheless, performance remained above chance, thus providing an opportunity for effects of either letter shape or word outline to emerge. They did not.

In the letter discrimination task, performance was equivalent for word and nonwords. The use of single letter response alternatives may have favoured a recognition strategy that was based on the letter level, as for this task the context was irrelevant. In the forced-choice string discrimination task, however, a WSE clearly emerged. The WSE indicates that GK was able to switch towards a more holistic strategy under appropriate conditions. The task dependency of the WSE suggests that GK maintains an ability to control the spatial area over which he attends. Attention could be allocated at the letter or word level, but when attention was spread across the whole letter string, words improved the recognition of the component letters relative to nonwords. The emergence of a WSE in the forced-choice string discrimination task also reiterates that GK's superior reading of words over nonwords is not due to guessing.

Words can be read better than nonwords, though in this study there was no evidence for this involving word outline information as there was no effect of confusability at the string level.

EXPERIMENT 3: Naming strings in upper and lower case

In Experiment 3, we investigated further the effects of whole-word codes (word shape) on GK's reading ability. First, GK read upper- and lower-case words and second, upper- and lower-case strings. Only lower-case words have familiar envelopes (see Paap et al., 1984). If GK uses holistic pattern information that includes the word envelope, he should read lower-case words better than upper-case words. In addition, case effects should not be apparent with nonwords as nonwords should not have a familiar holistic shape. On the other hand, if a lower-case advantage for words is mediated by the higher discriminability of lower-case letters, then letters in lower-case nonwords should also be read more accurately than those in upper-case nonwords.

Method

A list of 60 five-letter words was created. Half the words were presented in upper case, and the other half were in lower case. Words were matched for frequency and imageability across these two conditions (mean frequency = 167 occurrences per million in the Kuçera & Francis, 1967, frequency count, and mean imageability = 456 according to the Oxford Psycholinguistic Database imageability rating, Quinlan, 1992). The word list was presented in a randomized order on the computer screen (in Geneva 30 font). GK sat approximately 55 cm from the monitor, and the words subtended a visual angle of 3.8°. On each trial, a central fixation point appeared for one second to indicate the position of the word. Each word was displayed centrally for an unlimited duration. The experimenter (DH) made a manual note of each response. A week after the first presentation, the stimuli were presented again for naming, but with the case of presentation reversed. In subsequent sessions, GK was presented with 30 four-letter pronounceable nonwords, half in upper and half in lower case. He was asked to read each as a whole string. The case of the nonwords was reversed in a second testing session.

Results

Word naming

GK scored 47/60 (78%) and 37/60 (62%) on lower- and upper-case words, respectively, McNemar(1), $\chi^2 = 3.36, p < .05$. Of the errors made, 15 were left neglect (SOUTH → "mouth"), 14 were visual (meant → "meat"), 7 were unclassifiable (blood → "goal"), and 2 were "don't know" responses.

Nonword naming

GK named only 1/30 lower-case nonwords correctly and 2/30 upper-case nonwords correctly. Errors were typically neglect errors (e.g., vilt → "ill") or lexicalizations (e.g., milt → "mint"). The data on the large number of error trials were then scored for the proportion of letters correctly reported in each nonword (see Experiment 1). Overall, GK's responses

included 59% of the target letters in their correct relative positions (57% lower case and 60% upper case) and 69% of the letters when position was not counted (70% lower case and 67% upper case). There was no effect of case (McNemar, $\chi^2 < 1.0$, for both methods of scoring).

Discussion

GK read lower-case words better than upper-case words; an effect of 16%. In the literature on normal word naming, few effects of letter case have been found (see Mayall & Humphreys, 1996; Monk & Hulme, 1983). This may be because redundant processes support normal word naming, including parallel letter identification, which operates for upper- and lower-case letters alike. Nevertheless, the present results are consistent with GK being sensitive to visual information present in lower-case words, such as word envelope or visually familiar letter clusters (note that visual familiarity would appear to be important here, as familiarity of abstract letter clusters would be the same for both upper- and lower-case words). Effects of word outline or the visual familiarity of letter clusters may emerge because GK is impaired at reading using abstract letter identities (though this process may not be abolished, given his level of performance with upper-case words). The lack of a lower-case advantage for non-words indicates that individual letter familiarity per se does not account for the lower-case advantage for word naming. It could be argued that it was difficult to test for a case effect with nonwords on the whole string correct measure, as performance levels were so low. However, this was not true of letter reports (on average over 60% correct), yet no effect of case was apparent. Case effects were specific to word reading.

EXPERIMENT 4: Naming and defining abbreviations

There is evidence that, for normal readers, familiar abbreviations, such as FBI, are lexically represented (Henderson, 1974). Many abbreviations are typically written in upper case and so, unlike words, are visually more familiar in their upper-case form. By examining GK's reading of abbreviations, Experiment 4 tested whether his reading was affected by outline shape or the visual familiarity of letter clusters. The experiment was run in two ways. In Experiment 4a, GK was asked to name upper- and lower-case abbreviations with letters that were normally spaced and with a letter order that was scrambled or unscrambled. The latter manipulation evaluated the effect of lexicality/string familiarity on GK's ability to identify component letters. In Experiment 4b, he was asked to name upper-case abbreviations in which the spacing between the letters was varied. We propose three possible interpretations of the data. First, if GK is sensitive to the visual familiarity of the multiple letter forms, he should read upper-case better than lower-case abbreviations, and naming performance should be disrupted by spacing. Second, if GK is sensitive to familiar outline shape then there should be no case effects, as upper-case forms do not possess outline shape and the lower-case abbreviations are not familiar. Third, if GK is sensitive to the familiarity of individual letter forms, lower-case abbreviations should be read more accurately than those in upper case, given the advantage for lower-case words in Experiment 3.

Method

Experiment 4a

In Experiment 4a, GK was given to read 40 common, three-to-five letter abbreviations in both their upper- and lower-case forms. The abbreviations were not acronyms, in order to minimize effects of phonological recoding that might be used with word-like abbreviations, such as “NATO”. The case format of the abbreviations was presented in mixed blocks over two separate occasions, separated by one week. GK saw every abbreviation once in each session. He was encouraged to try to define each abbreviation and then to report the letters that he could see. Subsequently, GK was tested again on the same set of abbreviations in two further sessions, with the two later sessions separated by 6 months from the first. In the later sessions GK was given both unscrambled and scrambled versions with upper-case letters (e.g., RSPCA, CASRP) and was asked to identify component letters from left to right. Due to an error only 39 of the 40 strings were presented. The scrambled and unscrambled versions were randomized within a session and presented in an ABBA design across sessions. In addition, each abbreviation was read aloud to GK, and he was asked to provide a definition. The definition task evaluated GK's understanding of the abbreviations used. GK's responses were scored by three experienced raters on a 3-point scale according to the degree of accuracy. The raters were not informed of the case of presentation or of the purpose of the data. GK scored two points for each correct definition (e.g., VIP → “very important person”) or for a response that was very closely semantically related to the target (e.g., GCSE → “something to do with schools, 16 year olds”), even if he did not explicitly name all the letters in the abbreviation. One point was awarded for a more ambiguous semantic association (e.g., TUC → “something to do with national unions, not of electricians”). The median rating for each item was used for subsequent analysis.

Experiment 4b

In Experiment 4b, GK was given a new set of 39 common, three-to-four letter abbreviations presented in upper case. The abbreviations had normal letter spacing, or one or two extra spaces inserted between the letters (zero, one, and two spacing conditions). The stimuli were presented over three blocks of trials, in different sessions, with each abbreviation appearing once within a session, in one of the three spacing conditions. The spacing conditions were presented in a random order within each session. GK's definition responses were scored again by independent raters using a 3-point scale.

Results

Experiment 4a

GK named the abbreviations accurately for 10/40 of the upper-case and 5/40 of the lower-case stimuli. He could also provide accurate descriptions for many abbreviations, even on trials where he was unable to name all the letters explicitly, suggesting a problem in name finding rather than in reading (e.g., RSPCA → “something to do with animals. A charity, for example, when dogs are injured or lost they are sent to this place. A I C”). These descriptive responses also scored 2 points. Only a small number of GK's responses received 1 point (spoken $N = 2$; lower case $N = 2$; upper case $N = 1$). The analysis considered only those items that received full points.

The further testing showed that letter naming within strings was generally poor, but GK identified all the letters in unscrambled (11/39) better than in scrambled (2/39) versions (McNemar, $\chi^2 = 7.36, p < .01$). Thus, as in Experiment 1, GK showed an effect of lexicality/string familiarity on letter report. When the abbreviations were presented in spoken form, GK

gave suitable definitions for 30/40 items. On the visual presentation, GK gave suitable definitions for 26/40 abbreviations in upper case, but only 14/40 in lower case. A Cochran Q test revealed that the difference between upper- and lower-case strings was significant, $Q(2) = 18.09, p < .001$. Pair-wise comparisons showed that poor performance on the lower-case items was the basis of this significant difference (McNemar, χ^2 ; lower vs. upper = 6.72, $p < .01$; lower vs. spoken = 12.5, $p < .001$).

Experiment 4b

GK named 27/39 of the abbreviations accurately in the zero spacing condition, 24/39 in the one spacing condition and 20/39 in the two spacing condition. The differences between the zero and two spacing conditions was reliable (McNemar, $\chi^2 = 7.0, p < .01$). Definition responses were also scored in the same way as those in Experiment 4a. GK scored 54, 49, and 40/78 for the zero, one and two spacing conditions, respectively. There was a reliable effect of spacing, Cochran $Q(2) = 7.05, p < .05$; with performance in the zero spacing condition significantly better than that in a two spacing condition (McNemar, $\chi^2 = 5.44, p < .02$). Overall performance was somewhat better than that in Experiment 4a, probably due to the different set of items used and the elimination of the longer abbreviations.

Discussion

In Experiment 4a, GK showed an upper-case advantage in defining abbreviations. This result contrasts with the lower-case word naming advantage shown in Experiment 3. The upper-case advantage seen with abbreviations could therefore reflect GK's sensitivity to the visual familiarity of the forms; upper-case abbreviations are more familiar than lower-case abbreviations. Note that upper-case abbreviations do not have characteristic outline shapes (word envelopes), so their advantage could be conferred by a level of description between single letters and whole-word shapes: multi-letter units. GK shows better identification of visually familiar multi-letter units (e.g., lower-case words and upper-case abbreviations) than of visually unfamiliar forms (e.g., upper-case words and lower-case abbreviations). These data also show that GK was poor at using the information from single letters within strings for reading and confirm the results from GK's reading of nonwords in Experiment 1.

This argument, for identification based on multi-letter units, is supported by other data from Experiment 4b. In this study, we demonstrated that GK's identification of abbreviations decreased when the letters were spaced more widely. Spacing the letters ought, if anything, to improve letter identification by reducing lateral masking (at least under free viewing conditions). The detrimental effect of spacing here suggests instead that GK used representations of adjacent letters for lexical access; when the letters were spaced the multi-letter units responsive to adjacent letters were activated less strongly, disrupting identification.

EXPERIMENT 5: Effects of case alternation

In Experiment 5, we transformed the visual properties of words again by presenting the stimuli in alternate (AlTeRnAtE) case. Alternate-case stimuli disrupt both holistic word shape and familiar multi-letter units; if GK depends on such units to read, then alternate-case word

naming should be particularly impaired. Alternate-case words may also reduce letter identification by lateral masking from large (upper-case) onto small (lower-case) letters. To eliminate such masking effects in the subsequent experiment, Experiment 6, we examined performance with alternate-case letters that did not differ in size.

The disruption to word-naming latencies by presenting letters in alternate case has been well documented in the literature on normal readers (e.g., Besner & Johnston, 1989; Besner & McCann, 1987; Mayall et al., 1997). Recent evidence suggests that case alternation specifically disrupts multi-letter units. For example, Mayall et al. found that alternate-case words were read faster when the letters were spaced than when they had normal spacing. This positive effect of spacing may come about because letters in closely spaced alternate-case words tend to form inappropriate groups (e.g., if letters of the same size and case are grouped, they will activate inappropriate lexical entries; consider BeAuTy → “BAT”). Alternatively, it may be because spaced letters are less subject to lateral masking. However, Mayall et al. showed that similar positive effects of spacing did not occur with letters of different size but the same case (e.g., mixed), though masking should still operate. Mayall suggested that word recognition is mediated by units corresponding to groups of letters of the same size and case. In Experiment 5, we presented words in alternate case and also in mixed case in which consecutive letters had the same case. If GK uses multi-letter units (in which letters occur in the same case), then his reading performance may be more accurate in the mixed-case than in the alternate-case condition, despite both manipulations disrupting holistic word shape.

Method

A total of 100 six- and seven-letter words were selected. Words were all of high frequency (mean frequency = 133 occurrences per million, Kuçera & Francis, 1967) and high imageability (mean imageability rating = 442, Quinlan, 1992). The three case manipulations provided three conditions: same case (e.g., bright, HEALTH), alternate case (e.g., aNsWeR), and mixed case (e.g., weIGHt, huSBanD). Same-case units in a quarter of the mixed-case items corresponded to single phonemes (e.g., cAUght), whereas the rest did not (e.g., naTurAL). The proportions of upper- to lower-case letters were matched across alternate- and mixed-case items as closely as possible.

Stimuli were randomized and presented via a computer monitor in Geneva 30 font. GK sat approximately 55 cm away, and the stimuli subtended a 5° visual angle. A central fixation spot appeared for 1 s followed by the stimulus across the central position. The word remained in view until GK responded. The experimenter (DH) manually recorded each response. The conditions were presented in random order across four sessions spread over a period of 6 months to reduce any potential learning effects. No word was repeated in a session.

Results

GK's overall reading accuracy was 60% (181/300). Reading accuracy was significantly affected by case (Cochran $Q = 41.78, p < .001$). Naming accuracy in the same-case condition (82/100) was significantly better than that in the alternate-case (37/100) and mixed-case (62/100) conditions; McNemar, $\chi^2 = 53.02, p < .001$ and $8.20, p < .01$, respectively). Naming accuracy in the mixed-case condition was also significantly better than that in the alternate-case condition (McNemar, $\chi^2 = 12.26, p < .001$). For the same-case condition, GK scored 44/50 for the words in lower case and 38/50 for those in upper case.

GK provided a name for almost every word and made only 21 (7%) “don't know” responses—17 of which occurred in the alternate-case condition. He made equal numbers of left neglect errors (31/300; e.g., hIsToRy → “Tory”) and visual errors (31/300; e.g., HEaLTh → “heather”). The remaining errors were classified as “other” responses (e.g., REaDINg → “nutmeg”; ECONOMY → “something about money”).

Discussion

GK showed marked effects of case mixing on reading accuracy. This is the first study of such an effect in a patient showing symptoms of attentional dyslexia. Deleterious effects of case mixing have also been shown on another class of dyslexic readers: letter-by-letter readers (e.g., Warrington & Shallice, 1980). Letter-by-letter readers in other respects present with the opposite pattern of symptoms to attentional dyslexics, as they have difficulties in reading the word as a whole rather its constituent letters. Case-mixing effects demonstrate a breakdown in the ability to read when the visual familiarity of printed words is disrupted and/or when lateral masking between letters is increased. For GK, the disrupting effect was most severe for alternate-case words and somewhat less when case mixing preserved consecutive letters in the same case. The results indicate that either (1) letters in the same size and case are extremely helpful for GK's reading, or (2) he is strongly affected by masking from upper- onto lower-case letters. Both of these factors could lead to some preservation of reading in the mixed-case condition as (1) consecutive letters are the same size and case, and (2) there are fewer alternating (and hence masking) letter sequences. In Experiment 6, we presented alternate-case letters with the same size, to test a masking account of the case alternation effect. Note, however, that the result in the mixed-case condition goes against one account of case alternation effects, which is that they are due to a loss in the distinctiveness of letters when they are presented in a context in which both upper- and lower-case letters are possible (e.g., so that lower case and upper case may then be confused). In Experiment 5, GK's performance was significantly better in the mixed-case than in the alternate-case condition.

EXPERIMENT 6: Alternate case with equal letter size

For normal subjects, the effects of alternate case can be decomposed into two factors: one due to the presence of different-case letters and a second due to letters differing in size (Mayall et al., 1997). Thus, when alternate-case letters are made the same size (e.g., tH), the cost to reading is reduced, but not eliminated (Coltheart & Freeman, 1974; Mayall et al., 1997). This may be both because lateral masking is reduced when letters are the same size and because size information contributes to grouping between letters (Mayall et al., 1997). Here we assessed whether the disruptive effect of case alternation remained when letter size was constant across the word. If GK's word naming is still impaired by case alternation, then the lateral masking hypothesis would be an unlikely explanation for his poor performance.

Method

A set of 80 six- and seven- letter words was selected for naming. Within each word, all letters had distinctive upper- and lower-case forms, thus excluding words containing letters such as o, c, and u which

have the same form in both upper and lower case. This criterion ensured that when alternate-case words were presented with same-sized letters, there was a visible effect of case alternation (e.g., **rEGRET**, **dEbAtE**). Words had a mean frequency of 60 occurrences per million (Kuçera & Francis, 1967) and a mean imageability rating of 478 (Quinlan, 1992).

Letters were presented via a computer monitor in Times font, with upper-case letters in Size 50 and lower-case letters in Size 62 so that overall letter size was constant for alternate-case words. For the same-case words, half were presented in lower case and half in upper case. A central fixation spot appeared for 1 s followed by the stimulus across the central position. The word remained in view until GK responded, and the experimenter (AC) manually recorded each response. Stimuli were randomized, with each of the 80 words being presented in both same and alternate case in a counter-balanced order, thus giving a total of 160 trials. Stimuli were presented across four sessions, and no word was repeated within a session.

Results

Naming performance for words presented in the alternate-case condition (23/80) was significantly worse than that for the same-case condition (51/80, 64%) (McNemar, $\chi^2 = 20.25$, $p < .001$). In fact, GK named 32 of the words correctly when they were presented in same, but not in alternate, case. For the same-case condition, GK scored 25/40 for the words in lower case and 26/40 for those in upper case. Many of GK's naming errors were visual ($N = 44$; e.g., gender \rightarrow "legend") or left neglect errors ($N = 10$; e.g., **AffAIR** \rightarrow "fair"). Other errors included "don't know" responses ($N = 14$) and miscellaneous errors ($N = 18$; e.g., **TENdEr** \rightarrow "learning").

Discussion

GK's naming of words in alternate case was impaired with respect to his naming of words in same case even when size differences between letters were eliminated. This goes against an account of case alternation effects in terms of lateral masking from upper- onto lower-case letters (Besner & Johnston, 1989; Mayall et al., 1997). If masking were important, GK's reading accuracy should have improved when alternate-case letters were the same size. There was no support for this, and case alternation again significantly disrupted GK's reading accuracy. However, the data are consistent with the maintenance of consecutive same-case letter shapes being crucial for GK's reading ability. Case alternation is effective because it disrupts these same-case units, not because GK's reading ability is strongly influenced by lateral masking.

GENERAL DISCUSSION

We have reported data on GK, an attentional dyslexic, who showed the following effects:

1. GK showed a word superiority effect since words were recognised and named better than nonwords (Experiment 1). Letter report was generally poor, but letters were also reported more accurately in words than in nonwords (Experiment 1). This word advantage was unrelated to the frequency of the constituent bigrams. Letters in words were also better discriminated from those in nonwords under forced-choice conditions when GK was encouraged to attend to the whole string (Experiment 2).

2. In a discrimination task, GK was unable to use cues for the shape of individual letters (Experiment 2).
3. Lower-case words were read better than upper-case words, but lower-case nonwords were not read any better than upper-case nonwords (Experiment 3).
4. Upper-case abbreviations were read better than lower-case abbreviations and upper-case abbreviations without spaced letters were read better than those with spacing (Experiment 4).
5. GK was poor at naming words presented in alternate case, but naming was improved when consecutive letters had the same case. The disadvantage of alternate-case over same-case word naming was unaffected by whether alternate-case letters were the same or different in size (Experiments 5 and 6).

GK could name letters presented in isolation with few errors, but had difficulty in encoding individual letter representations when letters were presented in strings. Several findings are consistent with this interpretation. GK was considerably better at naming words than nonwords and was also better at naming words than at naming their component letters. Indeed, Experiment 1 showed that GK was materially impaired at reporting letters within strings. Due to this problem, GK's reading of nonwords is also impaired as he is unable to translate letters systematically within strings into sound. Note that we found no problems in letter-sound assignment for individual letters or in phonological blending once phonemes have been assigned. Although GK could identify letters quite accurately when they were presented alone, a discrimination task showed that he was insensitive to shape cues, both for letters presented alone and for letters in strings. Thus, additional types of letter-level information that may be available to normal readers (Paap et al., 1984) may not be accessible to GK.

If GK's encoding of individual letter representations within strings is disrupted, how is he able to read words? We have presented three major pieces of evidence on this. One is that GK is better at reading lower-case than upper-case words. This lower-case word advantage does not generalize to nonwords, and so it does not seem to be due to improved letter coding. Alternatives are that GK uses the word envelope, or that he uses visually familiar multi-letter codes (groups of lower-case letters in words being more visually familiar than equivalent groups of upper-case letters). A second piece of evidence is that GK's word naming was severely disrupted by case mixing, even when alternate-case letters were the same size (contrary to a letter-masking account). This suggests that he used visual information coded above the level of individual letters. Interestingly, GK's reading did improve in the mixed-case condition when some consecutive letters had the same size and case. Familiar word shapes should still be disrupted in the mixed-case condition. The positive benefit then indicates that GK's reading used multi-letter units, preserved in the mixed-case strings. The third piece of evidence was that GK was better at reading upper-case than lower-case abbreviations, and his reading accuracy for upper-case abbreviations decreased with wider letter spacing. Upper-case abbreviations lack familiar word outlines. Individual upper-case letters are also no more familiar to GK than lower-case letters (indeed GK was unable to read the letters in the abbreviations when their positions were randomized). Thus, the advantage for upper-case letters in this context must be because abbreviations are usually presented in this form and GK uses the multiple letters present to access the lexicon. It follows that the lexicon is addressed by representations of

multiple letters that are case specific. For the lexical representations of abbreviations, multiple upper-case letters form a visually familiar code.

Although we argue for a role of visual multi-letter codes (units) in lexical access, GK's ability to read words by other means is not completely abolished. He was able to read some mixed-case words and some abbreviations presented in lower case. This suggests that GK remains able to access some single-letter identities in words and to use this information to activate the lexicon for word report. However, our evidence shows that any letter-based activation is added to by visually familiar multi-letter representations. GK is also unable to use any letter-level information to guide a serial, non-lexical reading process. The substantial number of mislocation and letter migration errors made in reading indicates that serial reading processes are limited by poor location coding and/or by impaired switching of attention.

We may account for the pattern of reading performance in GK in terms of the model outlined in Figure 1 (discounting any role for word shape information). Let us suppose that, for GK, early visual analysis provides relatively intact form information, but impoverished location coding for the form features. This is consistent with GK's parietal lesions and with the parietal lobe being important for spatial location coding (cf., Ungerleider & Mishkin, 1982). Multi-letter units will be activated on the basis of the presence of appropriate features, which may be ordered with respect to each other, but not necessarily accurately specified with respect to the rest of the word. Such units, once activated, can frequently access lexical knowledge based on co-occurrence constraints even without any information about the relative positions of the units. For instance, the lexical representation for the word *DEAL* may be accessed by co-activation of the multi-letter units *DEA* and *EAL*, even without position information, as no other word can be generated from other spatial combinations of the units. Indeed, just such constraints are incorporated into several current connectionist models of reading (e.g., Mozer, 1991; Plaut, McClelland, Seidenberg, & Patterson, 1996). In contrast, individual letter representations that are activated need to have at least relative position information coded, as these representations can often be combined to form different words (e.g., the units *D*, *E*, *A*, and *L* may be combined to form the words *DEAL*, *LEAD*, *DALE*, etc.). Loss of position information will limit the ability of letter-based representations to access lexical knowledge, even if such representations are coded in parallel across a word. The multi-letter codes derived by GK do seem to be coded across the complete letter strings, as word-naming accuracy was unaffected by word length (see Experiment 1). GK appears able to select across two words (when two or more words are present), although poor location coding may begin to impinge on recognition-based multi-letter-based codes. Constraints on lexical access of multiple words, from multi-letter codes, are much less than those on lexical access for single words. As a consequence, errors due to the migration of letters across words may sometimes occur, though these may be limited by the extent to which patients can select information across relatively broad spatial areas. GK did make migration errors at an above-chance level with multi-word displays, but they were not a striking aspect of his performance (see the preliminary assessment).

One result that seems to fit less easily with our account of multi-letter units in reading is that the WSE for letter report in Experiment 1 remained even when bigram frequency was identical for words and nonwords. This does not mean, however, that other units necessarily mediated lexical access for GK; rather it simply shows that the frequency of occurrence of the clusters may be unimportant. This may be because access depends on which particular multi-

letter units are co-active rather than on their frequency of occurrence in general. Even infrequent clusters may be useful if they constrain lexical retrieval in combination with other clusters.

Models of normal reading

We have discussed the evidence from GK in terms of a multi-level model of normal reading, in which lexical access is based on visual units coded at a multi-letter, as well as at an individual letter, level. However, it can be argued that a single patient with acquired neural damage may be reading using either residual processes that play little role in normal reading or processes that have only been adopted following the damage. As a consequence, such a case may tell us little about normal reading. We would argue against this on several grounds. First, in repeated testing of GK over an extended period since the time of his lesion (13 years) we have found no change in his reading pattern. There has been no indication of his developing a new (perhaps even novel) reading strategy. Second, if there were development of a novel strategy, we would not expect some of the present results to be mirrored in the normal literature. Yet there is evidence for case-specific, multi-letter units mediating normal reading as well as GK's reading. As we have noted, Mayall et al. (1997) found positive effects of letter spacing on the reading of mixed-case words, but not when letters were of mixed size within the words. This last result argues against the spacing effect as being due to a reduction in lateral masking. Instead, Mayall et al. proposed that spacing reduced inappropriate grouping between letters of the same size and case, which is disruptive to reading of the whole word. Henderson and Chard (1976) also reported a type of "word superiority effect" on same/different matching of abbreviations (comparing known abbreviation with random arrangements of the same letters), but only when the stimuli were in familiar upper-case format. Both of these results suggest that case-specific, multi-letter units are not unique to GK. However, the involvement of such units in word recognition is highlighted in GK's case because of his deficit in reading using letter-level information. We propose that normal reading involves independent coding of multiple visual units, some of which are differentially sensitive to impairments in location coding.

The relevance of other deficits to GK

GK has a set of clinical deficits in addition to attentional dyslexia including simultanagnosia, neglect and left visual extinction. To some extent, these deficits may be related. The parietal lobes encode spatial information, and this spatial representation may facilitate the perception of a coherent visual world and may also help to direct attention to the objects at the represented locations. Unilateral parietal damage can then lead to biases in the allocation of spatial attention to the contra-lesional side (see Cohen, Romero, Servan-Schreiber, & Farah, 1994). GK has bilateral damage, which is more severe in the right than in the left hemisphere (see Figure 2). This will generate problems in attending to stimuli on both sides of space (simultanagnosia), with left-side stimuli faring less well than right-side stimuli when they are placed in competition (left-side neglect and extinction). In other patients showing attentional dyslexia without these other symptoms, there may be less damage (so the full clinical symptoms of simultanagnosia do not emerge), and/or damage may be symmetrical (so that lateralized deficits such as neglect and extinction are not found).

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