LEXICAL RETRIEVAL IN SPELLING

by

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SYNOPSIS

This thesis is an investigation of how written words are processed and represented for output. A single case study of an acquired dysgraphic patient is presented who produced a serial position effect in spelling tasks characterised by an increase in error rate from word beginning to word end. This pattern is assumed to reflect a deficit in the retrieval of stored orthographic representations. It is suggested that the order of output of letters may be encoded by an ordering of activation values. The nature of the deficit in terms of distinctions between input and output and access and storage are considered. The findings are discussed in relation to an existing connectionist model of spelling which was implemented and lesioned in an attempt to reproduce certain aspects of the patients data. Furthermore, a detailed analysis of the patients spelling errors suggests that orthographic representations consist of representational units other than the single letter and whole word. Finally, the role of the semantic system in lexical retrieval was investigated with regards to the distinction between proper names and common nouns. The ability of two patients to write/read proper names semantically was studied. Differences in the representational properties of proper names may result in them being selectively spared or impaired.

To Mum and Dad,

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How could I have remained sane without the support of my friends and the evenings spent in Staff House? Special thanks to Adam, Martin, Sarah & Rich, Nina & Deepak, Laura, Sarah B, Dani, Raj and the Foreign Office to name a few.

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1. WRITTEN WORD PRODUCTION: A REVIEW

1.1 A Functional Architecture for Spelling

Most models of written word production (e.g. Ellis & Young, 1988; Patterson, 1988; Shallice, 1988) assume that a spelling may be produced via several distinct routes (but see Campbell, 1983). A sub-lexical route converts speech sounds into their corresponding orthographic units (phoneme-grapheme conversion). Whereas, a lexical-semantic route retrieves a stored spelling from an orthographic (output) lexicon via a specification of its meaning. The existence of these 'dual-routes' enables both nonwords (e.g. *blim*) and words with irregular spellings (e.g. *island*, *yacht*) to be produced. Evidence for separate routes comes from acquired surface dysgraphic patients who can spell nonwords better than irregular words (Baxter & Warrington, 1987; Beauvois & Dérouesné, 1981; Hatfield & Patterson, 1983; Goodman & Caramazza, 1986a), and acquired phonological/deep dysgraphic patients who can spell real words better than nonwords (Baxter & Warrington, 1985; Bub & Kertesz, 1982; Shallice, 1981); suggesting selective damage to lexical-semantic and sublexical routes respectively.

A third spelling route from the phonological (input or output) lexicon to the orthographic lexicon which bypasses semantic knowledge may also exist (Hall & Riddoch, submitted; Kremin, 1987; Morton, 1980; Patterson, 1986). Although, many of the phenomena attributed to this 'third route' may also be explained by a compensatory interaction between partially damaged sublexical and lexical-semantic routes (Hillis & Caramazza, 1991; 1995; Miceli, Capasso & Caramazza, 1994).

These routes may be illustrated using black-box and arrow diagrams, which describe the relationship between the various components of the spelling system (see Figure 1). Such diagrams may best be viewed as a short-hand way of representing the various mechanisms needed to produce a spelling rather than an endorsement of a strict 'modular' architecture in Fodor's (1983) sense of the word. Architectures such as these may, at least in principle, operate in a cascaded fashion (e.g. McClelland & Rumelhart, 1981, for reading).

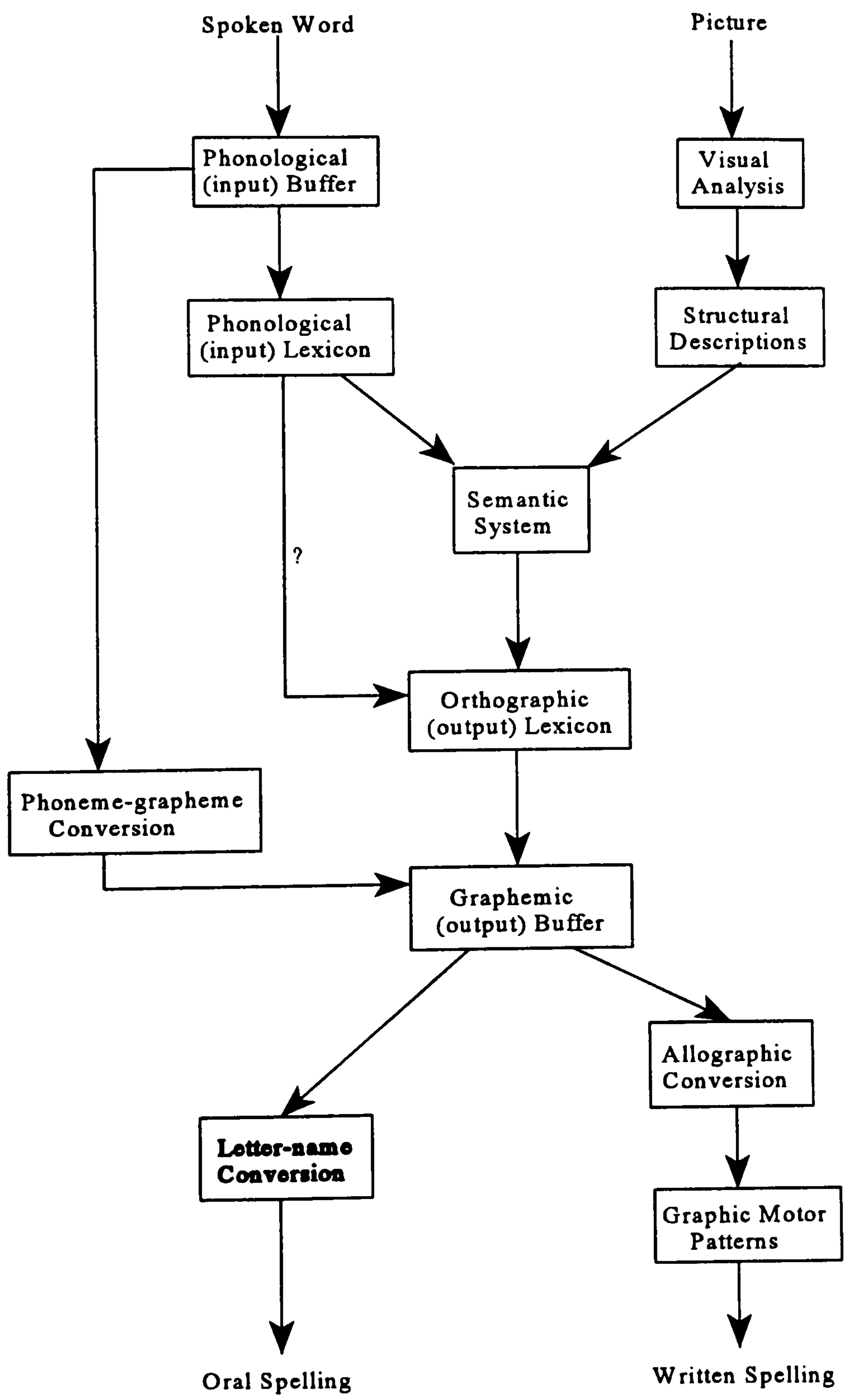

Figure 1: Black-box and arrow diagram indicating how a spelling (oral or written) may be generated from a picture or spoken word prompt.

The sublexical and lexical-semantic routes are assumed to converge at the graphemic (output) buffer, which temporarily stores orthographic representations (Ellis, 1982; Margolin, 1984). The representation in the graphemic buffer is assumed to be used in all output tasks (typing, writing and oral spelling), (but see Lesser, 1990). There are several motivations for postulating a working memory system at this point in the functional architecture. Wing and Baddeley (1980) suggest that a buffer may be needed due to the temporal characteristics of spelling; namely that lexical retrieval is assumed to be rapid but that the mechanical constraints of output makes serial letter processing slow. Caramazza, Miceli, Villa and Romani (1987) suggest that a buffer may be needed in order to mediate between the lexical/sublexical routes which will generate multi-letter or word-size units and output procedures which are assumed to operate on single letters.

The abstract letter code in the graphemic buffer may then be converted into letter names for oral spelling (e.g. *k*→"kay"). Alternatively, they may then be processed for written output: first as letter allographs (e.g. B/b/𝒷/ℬ), then as stored graphic motor patterns and finally as a series of pen strokes (Ellis, 1982; Margolin, 1984).

The general aim of this thesis is to build upon this framework by considering in more detail the structure of lexical-orthographic representations in spelling and how they are retrieved for output.

1.2 Serial Position Effects in Spelling Errors

One phenomenon which has received much interest is the observation that spelling errors are not uniformly distributed throughout all positions in the word but tend to be concentrated at certain positions. These so-called 'serial position effects' have been observed in the spelling errors of normal adults (e.g. Wing & Baddeley, 1980), brain-damaged patients (e.g. Caramazza et al., 1987), deaf spellers (Olson, 1995) and even in children learning to spell (e.g. Mendenhall, 1930).

Serial position effects in spelling are of theoretical interest for a number of reasons. Firstly, the question of how the brain encodes serial order in general has been a central problem in psychology since the work of Ebbinghaus (1913) and Lashley (1951). It has been suggested that serial position effects in spelling may shed light upon this issue, because the task of spelling is essentially the serial recall of a stored and ordered letter string (Houghton, Glasspool & Shallice, 1994; Jensen, 1962; MacNeilage, 1964).

Secondly, without specifying the nature of the representations or components, black-box and arrow architectures cannot readily account for serial position effects. Serial position effects in spelling may, therefore, provide a source of constraint or motivation in developing computationally/representationally explicit models of the spelling process itself.

1.2.1 Skilled Spelling

Several studies have investigated the serial position effects found in the spelling errors of skilled adult spellers (Hotopf, 1980; Jensen, 1962; Kooi, Schutz & Baker, 1965; Wing & Baddeley, 1980). Wing and Baddeley (1980) analysed the spelling errors produced by university entrance examinees. The 'slips of the pen' produced by these subjects could generally be classified as single letter substitutions (e.g. gentle→*gestle*), omissions (e.g. gentle→*getle*), additions (e.g. gentle→*geantle*) and transpositions (e.g. gentle→*genlte*). These errors were most likely to occur in the middle of a word and least likely at the beginning and end of a word, forming a bow-shaped or inverted-U function.

Wing and Baddeley (1980) assumed that the 'slips of the pen' must have arisen from a peripheral component (i.e. not the lexicon or semantic system) because subjects were at other times able to spell the word correctly which, they argued, implies a fully and correctly specified lexical-orthographic representation. They attributed the locus of this effect to the graphemic buffer, with the serial position effect arising from interference between neighbouring items in the buffer. Medial letters are flanked on both sides and are therefore the most susceptible to information degradation, giving rise to a bow-shaped function.

This pattern has also been found in a study of skilled typing. Sternberg, Monsell, Knoll and Wright (1978) found that the interval between successive keystrokes is a function of serial position with the longest latencies occurring in medial positions and the fastest latencies occurring towards the beginning and end of the word. A similar pattern to that reported by Wing and Baddeley (1980) has also been reported in the spelling errors of brain-damaged patients.

1.2.2 Damage to the Graphemic Buffer

A number of patients have been reported in the literature with damage ascribed to the graphemic buffer (Caramazza et al., 1987; De Partz, 1995; Jonsdottir, Shallice & Wise, 1996; Katz, 1991; Kay & Hanley, 1994; McCloskey et al., 1994; Posteraro, Zinelli & Mazzucchi, 1988; Tainturier & Caramazza, 1996; Trojano & Chiacchio, 1994). For example, patient LB (Caramazza et al., 1987; Caramazza & Miceli, 1990) made many single letter errors in spelling both words and nonwords. The same pattern was found in different output modalities (oral and written spelling) and disregarding of input modality (written picture naming, writing to dictation, delayed copying). This suggests that the locus of damage is indeed the graphemic buffer since this component is common to all these tasks.

Damage to the graphemic buffer was originally assumed to be insensitive to lexical and semantic factors such as word frequency, imageability and lexicality (Caramazza et al., 1987). Although these factors may well exert an influence if the spelling system is assumed to be interactive (e.g. Pate & Margolin, 1990); that is, if it is assumed that higher levels of processing can exert an influence at lower ones and vice versa. Another characteristic which has been associated with damage to the graphemic buffer is a strong effect of word length since the buffer is assumed to have a limited capacity.

Three of the studies cited above do not discuss whether a serial position effect was found (Kay & Hanley, 1994; McCloskey, et al., 1994; Tainturier & Caramazza, 1996). Five out of six of the remaining patients produced bow-shaped serial position curves in which errors were predominantly found in medial positions; again, in a variety of different spelling tasks (Caramazza et al., 1987; De Partz, 1995; Jonsdottir et al., 1996; Posteraro et al., 1988; Trojano & Chiacchio, 1994). In some cases, the bow-shape appeared to be symmetrical (Caramazza et al., 1987; Posteraro et al., 1988; Trojano & Chiacchio, 1994) whereas in others it was skewed more towards the end of the word (De Partz, 1995; Jonsdottir et al., 1996). The remaining patient (HR; Katz, 1991) showed a linear serial position effect with errors increasing from left to right. This was interpreted as temporal decay from the graphemic buffer.

1.2.3 Temporal Decay from the Graphemic Buffer

The serial position effect produced by HR (Katz, 1991) was characterised by a linear increase in the number of errors from word beginning to word end. This may be explained by assuming that the longer a letter is held in the buffer the more likely it is to err. In support of this, Katz found an improvement in writing the final letters when words were written backwards (e.g. *happy* should be spelled as Y,P,P,A,H). Although this explanation is plausible, alternative explanations not involving the graphemic buffer may also be possible. For example, there may be an accumulation of inhibition over time (or 'refractoriness') at an allographic level. HR did apparently have some difficulties at this level since his responses were often in miXeD cAsE.

Indeed, a similar serial position effect to HR has also been reported by Bub, Black, Howell and Kertesz (1987). However, this patient was significantly better at oral compared to written spelling. This was attributed to temporal decay from an allographic buffer which is used in written but not oral spelling.

1.2.4 Neglect Dysgraphia

Several patients have been documented in which spelling errors are produced almost exclusively on the left or right hand side of words. Patients have been documented in the literature who show left-sided neglect dysgraphia (JL - Barbut & Gazzaniga, 1987; ORF - Baxter & Warrington, 1983; RB - Hillis & Caramazza, 1990; ML - Hillis & Caramazza, 1995) and right-sided neglect dysgraphia (NG - Caramazza & Hillis, 1990a, 1990b; HH - Hillis & Caramazza, 1990; HB - Hillis & Caramazza, 1995). This pattern may be interpreted as an interaction of a more general visuo-spatial deficit with the spelling system because of the presence of neglect in other tasks (Caramazza & Hillis, 1990a) and may imply that orthographic representations used in spelling are spatial in nature (Hillis & Caramazza, 1989). Baxter and Warrington (1990), however, suggest that this pattern may reflect damage to attentional mechanisms dedicated specifically to spelling.

As an illustrative example of a neglect dysgraphic patient, NG (Caramazza & Hillis, 1990a; 1990b) made spelling errors almost exclusively on the right side of words, regardless of the length of the word. The same pattern of errors was found in written spelling, oral spelling, backwards writing and delayed copying for both words and nonwords. This suggests that attentional mechanisms interact with the spelling system at the level of the graphemic buffer since this component is common to all these tasks whereas other components (e.g. the orthographic lexicon) are not (Hillis & Caramazza, 1989). The probability of making an error was related to distance from the centre of the word and not on the ordinal/serial position that the letter occupies. Thus, NG produced more errors on the third letter of a four letter word (right of centre) than on the third letter of a seven letter word (left of centre).

Other patients in the literature have been interpreted as having separate but interacting neglect and graphemic buffer deficits. In such cases the resultant serial position effect may be construed as a combination of the two separate serial position curves. Patient DH (Badecker, Hillis & Caramazza, 1990; Hillis & Caramazza, 1989) produced a right-skewed bow-shape function in spelling tasks, whereas patient ML (Hillis & Caramazza, 1989; 1995) produced a left-skewed bow-shape function. Hillis and Caramazza (1989) interpreted these patterns as arising from an interaction between a graphemic buffer deficit and a separate neglect deficit (right-neglect for DH and left-neglect for ML)[1]. Both patients showed signs of clinical neglect in non-spelling

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[1]In a later paper, Hillis and Caramazza (1995) offer a somewhat different explanation for patient ML. They suggest that her serial position effect is due to a neglect deficit alone and that the patient shows an advantage for initial letters because she is able to utilise phoneme-grapheme conversion information for the more salient initial letter. However, Hillis and Caramazza (1995)

tasks (e.g. drawing).

The preceding sections have suggested that different serial position effects might be characteristic of damage to different components of the spelling system or that different types of damage to the same component may result in different serial position effects. Chapter 2 of this thesis will document a different type of serial position effect in a patient with damage attributed to a failure to fully activate lexical-orthographic representations. It will be suggested that this serial position effect may be useful for elucidating the underlying mechanisms of lexical retrieval.

A detailed investigation of the nature of spelling errors produced in patients such as those described above may also be useful for constraining theories of the structure of orthographic representations.

1.3 The Structure of Orthographic Representations in Spelling

Analyses of patterns of spelling errors have also led many researchers to conclude that orthographic representations consist of more than just a string of letter identities. This evidence is reviewed below.

1.3.1 Consonant-Vowel Status

There is some evidence to suggest that the consonant-vowel (CV) status of letters is

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note that this explanation does not rule out their earlier one.

represented within the orthographic representation. Cubelli (1991) described a patient with a transient dysgraphia who exclusively omitted vowels in writing (e.g. Bologna → *B L GN*), leaving gaps in their place. Although the locus of this effect was not determined, it suggests that vowels may be selectively impaired by brain damage. Cubelli (1991) also reported another patient who made significantly more errors in writing vowels (82.9%) than consonants (17.1%) in all tasks tested. Kay and Hanley (1994) reported the opposite pattern of more errors in writing consonants (79.4%) than vowels (20.6%). Both patients had damage attributed to the graphemic buffer. Thus, performance on vowels and consonants forms a double dissociation. Furthermore, patients with postulated damage to the graphemic buffer tend to transpose letters in consonant-consonant pairs and vowel-vowel pairs but not mixed-CV pairs (e.g. table→*talbe* but not table→*tabel*; Caramazza & Miceli, 1990; Jonsdottir et al., 1996). Moreover, these patients also typically substitute consonants for consonants and vowels for vowels (Caramazza & Miceli, 1990; Kay & Hanley, 1994; McCloskey et al., 1994; Jonsdottir et al., 1996; Schonauer & Denes, 1994). For example, this pattern was observed in 99.3% of single letter substitutions in patient LB (Caramazza & Miceli, 1990). Substitutions between consonants differing by one phonological feature were infrequent (e.g. b/d, l/r, f/v), suggesting that the effects are orthographic and not phonological in nature. Substitutions, instead, tended to consist of (in 75% of cases) anticipation or perseveration of another letter in the word (e.g. onesto [honest] → *onento*). Cubelli (1991) concludes that "consonant/vowel opposition is not just a formal distinction but reflects a psychological reality" (p.260).

1.3.2 Ortho-syllables

The existence of consonant-vowel marking may serve to restrict the number of possible ways of ‘repairing’ a representation following damage/decay (McCloskey et al., 1994). Alternatively (or in addition), a consonant-vowel tier may serve as a substrate on which higher-order sublexical units could be attached, such as ortho-syllables (Caramazza & Miceli, 1990). This is illustrated below for the word *beetle* (where 'D' denotes that the letter should be doubled; see Section 1.3.3).

```
syllable tier            σ       σ
                       / | \    / \
CV tier              C   V   C   V   C
                     |   |   |   |   |
identity tier        b   e   t   l   e
                         |
quantity tier            D
```

Phonological syllables may be ordered in terms of complexity, with the consonant+vowel syllable (e.g. “pagoda” [CV.CV.CV]) regarded as the most simple (e.g. Cairns & Feinstein, 1982). Phonemic errors may have a tendency to produce a more optimal, i.e. less complex, syllabic configuration (Calabrese & Romani, 1991). This has been termed the ‘Minimum Complexity Principle’. Caramazza and Miceli (1990) have attempted to adapt this principle to ortho-syllables. They found that their patient, LB, was significantly better at spelling words consisting only of consonant+vowel syllables (termed ‘simple-CV’) than words containing more complex syllables (termed ‘complex-CV’). Furthermore, different error types were observed for the two types of words. Errors on simple-CV words were mainly substitutions. In contrast, no single letter deletions were observed on simple-CV words but many deletions occurred in complex-CV words (e.g. giunta → *gunta*). This is consistent with a notion of ortho-syllables in which spelling errors tend to minimise ortho-syllabic complexity (hence deletions in complex-CV words) but maintain the overall number of ortho-syllables (hence substitutions and not deletions in simple-CV words)[2]. They argue that phonological factors are unlikely to play a significant role since digraphs representing single phonemes, e.g. *ch*, do not behave as single units and the processing of the *sc* digraph is the same when it corresponds to one phoneme (/s/) as when it corresponds to two phonemes (/sk/). However as Jonsdottir et al. (1996) note, this only demonstrates that LB does not use phonological information at the phoneme level and does not demonstrate that he is unable to use phonological information at the syllable (or onset-rime) level.

Two studies of English speaking graphemic buffer patients have failed to replicate any effect of ortho-syllabic complexity (Jonsdottir et al., 1996; Kay & Hanley, 1994). Kay and Hanley (1994) found no difference between simple-CV and complex-CV words, in terms of either error rate or error type. Jonsdottir et al. (1996) found no difference in error types between simple-CV and complex-CV words, but found that simple-CV words were actually more error prone than complex-CV words (the opposite pattern to that predicted by Caramazza & Miceli, 1990). This apparent difficulty with simple-CV words was explained by the fact that words with this structure are relatively infrequent in English orthography. Both Kay and Hanley (1994) and Jonsdottir et al. (1996), concluded that there is no compelling evidence for ortho-syllables. Both studies attributed the apparent effect of 'ortho-syllables' in LB to a use of phonological information owing to the sound-spelling regularity of Italian orthography compared to English orthography.

There is, however, some evidence for the existence of ortho-syllables in English spelling. Marcel (1980) noted that when subjects were asked to orally spell bisyllabic words, pauses were

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[2] This could also be due to the fact that deletions on complex syllables tend to preserve orthotactic constraints whilst deletions on simple syllables do not, rather than on solely due to complexity.

found between the internal consonant clusters marking syllable boundaries (e.g. c, r, I, m....s, o, n). There is also evidence to suggest that ortho-syllabic effects are not an artefact of phonology. Olson (1995) studied the spelling errors of deaf students who had profound hearing difficulties from a very young age. The spelling errors of these subjects did not consist of regularisations (e.g. yacht → *yot*) and overall error rate was not influenced by phoneme-grapheme regularity (unlike a matched group of hearing subjects). Nevertheless, the spelling errors were remarkably 'word-like'. Olson (1995) argued that this did not arise out of statistical regularities in the orthography due to frequency-sensitive bigram/trigram units since the misspellings were not statistically more favourable than the correct spellings. Moreover, if one were to hypothesise bigram/trigram type units one would also need to make them sensitive to position since the misspellings not only preserved legal letter sequences but also preserved legality with regards to ortho-syllabic position (e.g. *nt* is a legal coda but not onset).

1.3.3 Geminate/Double Letters

There is an increasing body of evidence which suggests that geminate (double) letter information (e.g. book, apple) appears to function as a representational unit in its own right and does not consist merely of two consecutive occurrences of the same letter unit (Caramazza & Miceli, 1990; McCloskey et al., 1994; Miceli, Benvegnu, Capasso & Caramazza, 1995; Tainturier & Caramazza, 1996; Venneri, Cubelli & Caffara, 1994; but see Romani & Calabrese, 1996, for counter-arguments). Evidence for this comes from the relatively common occurrence of spelling errors in which letter doubling information shifts independently of letter identity (e.g. rabbit→*rabitt*) but the rare occurrence of errors (relative to non-geminate letter pairs) in which doubling information is lost (e.g. rabbit→*rabsit*, or rabbit→ *rabibt*). This is observed both in normal spellers/typists (e.g. Rumelhart & Norman, 1982) and in the acquired dysgraphic population (e.g. Caramazza & Miceli, 1990). For example, the graphemic buffer patient, LB (Caramazza & Miceli, 1990) made many errors in which the geminate was displaced but the letter identities remained in their same positions (e.g. sorella [sister]→*sorrela*). Whereas geminate creation (e.g. tavolo [table]→*tavvolo*) was very rare and geminate splitting (e.g. sorella→*solerla*) never occurred. Caramazza and Miceli (1990) proposed a symbolic representational system in which information about letter quantity is represented separately to letter identity. For example, the orthographic representation of the word *rabbit* may be symbolised as below, where D carries the doubling information.

```
letter identity tier        r a b i t
                                /
letter quantity tier            D
```

McCloskey et al. (1994) propose a slightly different model, in that they regard the geminate as being represented by a single token connected to two abstract or position-encoding tokens (as below). They argue that this is supported by a relatively high proportion of geminate 'pseudo-substitutions' in their patient (e.g. rabbit→*rabnit*), which suggests that these errors do not arise by a simple letter addition (which would be the Caramazza & Miceli, 1990, prediction)..

```
letter position tier        X  X  X  X  X  X
                            |  |  \  /  |  |
letter identity tier        r  a    b   i  t
```

Tainturier and Caramazza (1996) have extended this work in their patient by showing that geminate letters behave differently from repeated but non-consecutive letters (e.g. *prop*), and letter pairs which represent a single phoneme (e.g. *sock*). Other evidence that geminates are represented/processed differently comes from patients who produce perseverative errors only when writing geminates (e.g. intelletto [intellect]→*intellletttttto*; Venneri et al., 1994) and patients who produce deletion errors almost exclusively on double letter pairs (Miceli et al., 1995).

Whilst the studies described above provide good empirical evidence for a separate representational mechanism for geminates, they do not provide a strong theoretical motivation as to why they should be represented differently. It will be shown in Section 1.4.2 that computational models of spelling may help to bridge this gap.

Chapter 3 will investigate whether there is any evidence for consonant-vowel marking and ortho-syllables in a patient with an hypothesised lesion to the orthographic lexicon (or connections to it). The patient is unable to utilise sublexical spelling so, unlike in previous patients, artefactual effects of phonology can be minimised. The patient's performance on geminate letters and repeated but non-consecutive letters (e.g. prop) will provide a source of constraint on a connectionist model of spelling which is lesioned in Chapter 4.

1.4 Connectionist Models of Spelling

1.4.1 Background

Since the early 1980's there has been a rapid increase in the use of connectionist (or neural network or parallel distributed processing) models of the cognitive system (see Bechtel &

Abrahamsen, 1991, for a summary). Connectionist models do not make a clear distinction between representations and the algorithms which operate on them. Rather, the medium of representation/processing consists of a collection of simple firing units (nodes) which activate one another via connections between them (weights). Real-world concepts may be represented by a single node (localist representation) or by many nodes in combination (distributed representation). The advantages of this approach are typically cited as: the ability to form categories and make generalisations, the ability to learn, a tendency to show 'graceful degradation' (i.e. damage does not completely abolish performance), and their neural-like behaviour and simplicity.

In some respects connectionist models may be envisaged as an implementation of, rather than a competitor to, existing information-processing or symbolic models (e.g. Fodor & Pylyshyn, 1988; but see Schneider, 1987). It is hoped that a consideration of connectionist models in this thesis will provide more insight into the basic problems faced by any model of spelling (whether at an implemented or abstract level) and offer at least some tenable solutions to these problems.

There are a number of basic questions which a fully implemented model of spelling should address. Firstly, how does the semantic system select an appropriate lexical-orthographic representation for output? Is a single lexical representation activated or a whole cohort of semantically similar candidates (e.g. Caramazza & Hillis, 1990c)? Secondly, how do lexical-semantic and sublexical routes converge? Is one route completely 'switched-off' or can one route facilitate another (e.g. Barry & Seymour, 1988)? If so, what prevents the two routes from blending (e.g. yacht→*yoct*, as a result of blending *yacht* and *yot*)? Thirdly, what is the underlying structure of orthographic representations? Fourthly, how does a parallel architecture produce a serial output of letters?

The first question will be addressed in terms of the distinction between proper name and common noun processing (Chapter 5). The question of how spellings are generated by phoneme-grapheme conversion will not be investigated in this thesis (see Brown & Loosemore, 1994, and Olson & Caramazza, 1994, for two connectionist models), but will be returned to in the General Discussion (Chapter 6). The latter two questions form the basis of two experimental chapters (Chapters 2 and 3), and will be considered in the context of an implemented and lesioned connectionist model (Chapter 4). There are already some existing connectionist models which have addressed these two questions.

1.4.2 Rumelhart and Norman (1982) and the Concept of Activation Gradients

Rumelhart and Norman (1982) developed a model of skilled typing which aimed to explain the existence of certain error types (e.g. geminate shifts) as well as timing and kinematic data associated with the production of a motor response (a keypress). The model consists of three broad domains: (1) a perceptual encoder and parser which reads words into a buffer (2) a mechanism whereby a word (or a similar sized unit) activates a series of letter nodes, and (3) a response system which initiates a series of motor commands resulting in a keypress. The second mechanism is of particular relevance to this thesis since this is assumed to be common to all spelling tasks (oral spelling, typing and handwriting) whereas the other mechanisms are essentially restricted to the skill of typing.

The word node activates the set of letter identities needed to spell the word, which are part of a larger pool of 26 nodes representing the letters of the alphabet. For example, the word node *very* would activate (equally) the nodes *v*, *e*, *r* and *y*. Learned inhibitory weights between these letters would then be applied such that each letter inhibits all the other letters which are to be produced after it. This is illustrated in Figure 2.

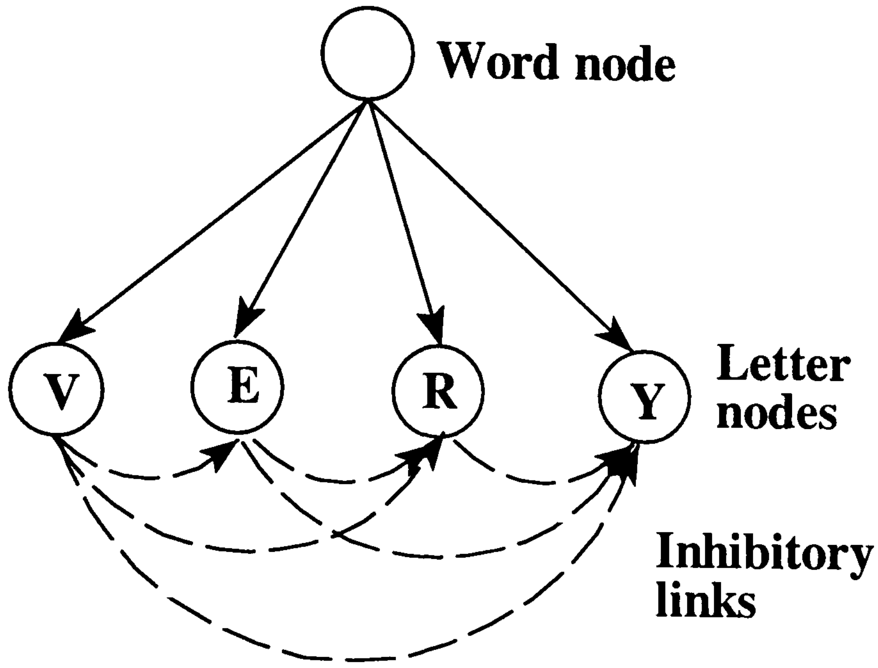


Figure 2: The typing/spelling model of Rumelhart and Norman (1982).

This lateral inhibition between the letter nodes establishes an activation gradient such that the serial order of letters is determined by the ordering of their activation values (an idea originally proposed by Estes, 1972, and Grossberg, 1978). In this example the ordering of activations is: $v > e > r > y$. The most active letter is then selected for output (*v*) and then immediately inhibited so that the second letter in the word (*e*) becomes the most strongly activated and is therefore selected, and so on. Evidence for the fact that more than one letter is active at a given time (albeit by different amounts) comes from 'coarticulatory' effects in typing whereby the hand moves towards a position appropriate for upcoming letters and from the fast interstroke interval between keypresses which is often shorter than the neural transmission time between the spinal cord and fingers (suggesting that upcoming keypresses have been released before output of the current letter).

This form of orthographic representation (a single set of letter types activated by a single lexical node) generates a number of problems, only some of which can easily be accommodated by this particular model.

The model, as described above, would not be able to produce geminate letters (e.g. *book*) because after the first *o* had been selected it would be inhibited to below the activation of the *k* node and could not be immediately reselected for output. In order to enable reselection, Rumelhart and Norman (1982) created a geminate node (or 'doubling schema') which is activated like any other letter node and acts to prevent the to-be-doubled letter from being inhibited. Typing of the word *book* would, therefore, involve the consecutive selection of 4 letter nodes *b*, *D*, *o* and *k* (D=geminate node). This provides a computational motivation to back-up the empirical finding that letter quantity appears to be represented separately from letter identity (Section 1.3.1).

The 'repeated letter' problem

A related computational problem to that described above for geminates occurs for non-consecutive repeated letters (e.g. these, paper). Rumelhart and Norman (1982) tackled this problem by assuming that the letter string is 'chunked' at repeated letter boundaries. For example the word *perception* would be produced in two chunks *perc* and *eption* (and similarly for words with more than one geminate, e.g. *committee* → *coDmi*, *Dt* and *De*). However, empirical evidence is more consistent with chunking occurring at morphological boundaries (Badecker et al., 1990).

An alternative way of solving the repeated letter problem would be to have a separate mechanism (akin to the geminate node) for encoding such sequences. Rumelhart and Norman (1982) claim that the existence of 'alternation reversal errors' (e.g. these→*thses*) in their error corpus provides evidence for this mechanism. However, no such errors were found in the 847 'slips of the pen' in the Wing and Baddeley (1980) corpus and these errors have apparently not been documented in the acquired dysgraphic literature. It would appear that such errors are either extremely rare or are restricted to the task of typing, and hence arising at a different level to that of lexical retrieval.

Thus, the Rumelhart and Norman (1982) model is not able to offer a satisfactory solution to this problem, nor is it able to offer a solution to the 'anagram problem'.

The 'anagram problem'

The activation gradient is established by learned sequence specific weights between letter nodes. For example in the word *very*, *v* inhibits *e*, *r*, and *y*; *e* inhibits *r* and *y*; and *r* inhibits *y*. However, such weights cannot exist for words which contain exactly the same letters but in a different order (e.g. *rat*, *art*, *tar*). Thus, the Rumelhart and Norman (1982) model is not able to represent words which are the anagrams of other words.

In short, the model of Rumelhart and Norman (1982) contains a number of interesting features (notably the concept of an activation gradient) and provides an explanation for at least some empirical phenomena (e.g. geminate errors). However, a number of problems remain including a difficulty in representing words with repeated letters and words which are the anagrams of other words. Other models of spelling may be able to overcome some of these difficulties.

1.4.3 The Model of Houghton, Glasspool and Shallice (1994)

The model of Houghton, Glasspool and Shallice (1994; see also Shallice, Glasspool & Houghton, 1995) was designed to (a) overcome some of the difficulties associated with the model of Rumelhart and Norman (1982) and (b) to reproduce some of the effects associated with damage to the graphemic buffer (see Section 1.2.2).

The model of Houghton et al. (1994) consists of three layers: a word layer, a letter layer and a 'competitive filter'. The model is summarised in Figure 3 (only one lexical item is shown). Each word consists of two sequencing nodes (I and E) which send a time-varying pattern of activation to the letter layer which consists of 26 letter nodes and a special node for producing geminate letters. The order of letters in the word is encoded by a series of learned weights between the sequencing nodes and the letter layer rather than inhibitory links between the letter units themselves. The I-node connects more strongly with initial letters in the word and the E-node connects more strongly with letters at the end of the word. These differential weights enable words which are the anagrams of other words (e.g. *slit*, *list*, *silt*) to be represented. The presence of two sequencing nodes for each word also enables words with repeated letters (e.g. *fence*, *widow*) to be represented. Like the Rumelhart and Norman (1982) model, the sequencing nodes establish an activation gradient (termed 'competitive queue') over the letter nodes to be produced. The most active node at the letter layer is selected by the competitive filter which functions as a peak-picking device. The selected node in the filter then inhibits the corresponding letter node to prevent spurious reactivation.

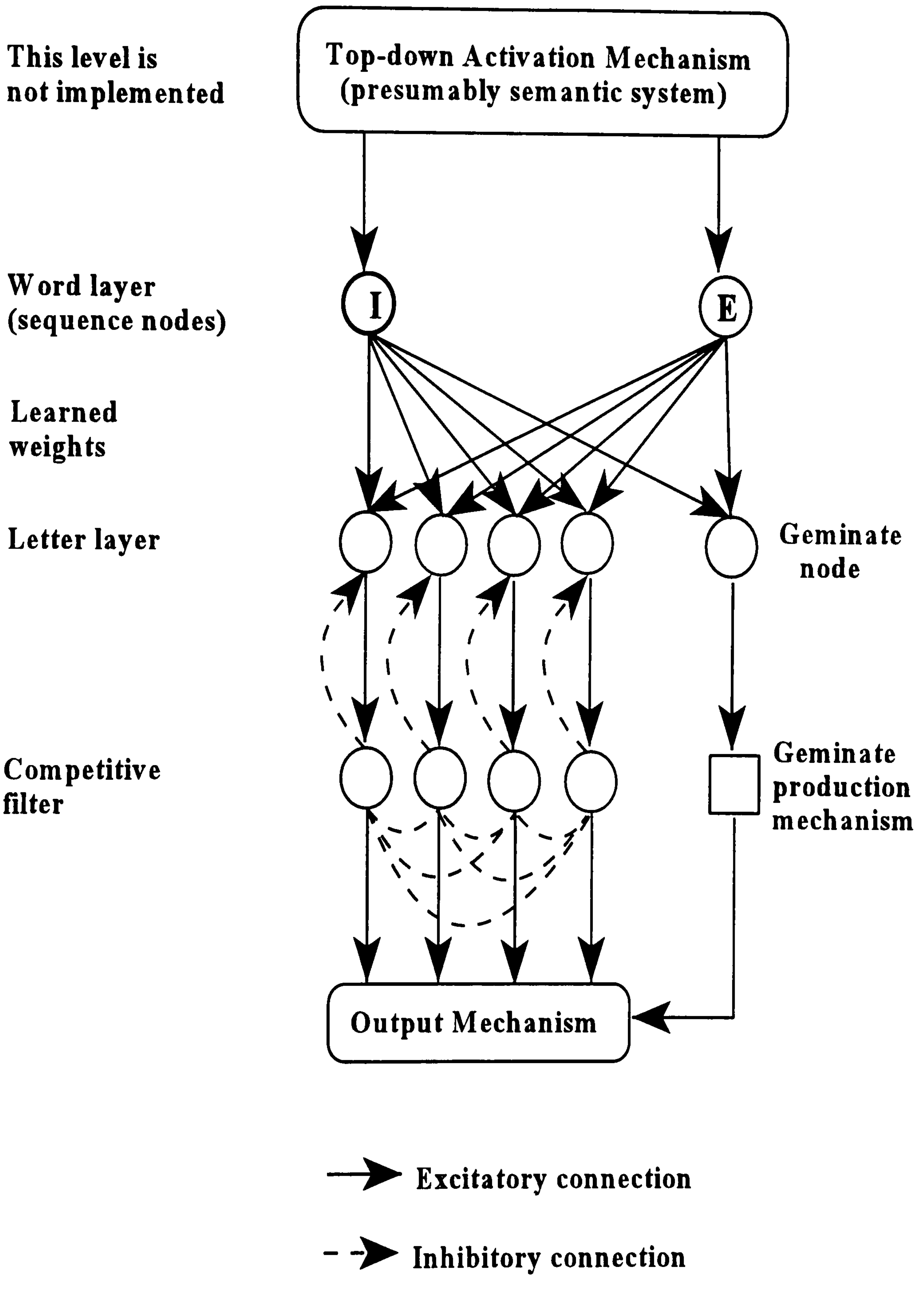


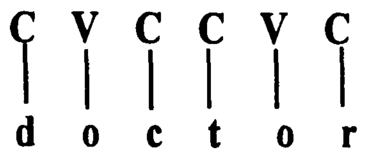
Figure 3: The competitive queuing model of Houghton et al. (1994).

Houghton et al. (1994) found that adding noise to the letter level reproduced many phenomena associated with damage to the graphemic buffer, including single letter errors, geminate shifts, a strong length effect and a bow-shaped serial position effect. Initial letters are spelled well because of strong activation from the I-node. Medial letters are spelled worse because of a reduction in the activation supplied by the I-node together with decay of letter activation over time. This results in different letters in the queue having similar activations and hence being more vulnerable to noise. Letters at the end are spelled well because there are fewer competitors in the queue and because of strong activation by the E-node.

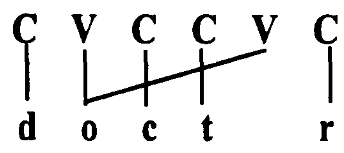
In summary, the model of Houghton et al. (1994) was able to overcome the repeated letter and anagram problem faced by Rumelhart and Norman (1982) by employing more than one sequencing node. An alternative solution to the repeated letter and anagram problems is provided by models which contain multiple copies (tokens) of each letter.

1.4.4 Other Approaches towards Modelling Orthographic Representation

Two broad approaches may be identified in modelling of orthographic representations: I shall refer to them as 'type only' and 'repeated token'. Type-only models contain only one representational unit for each letter, whereas repeated-token models contain several representational units for each letter. The models of Rumelhart and Norman (1982) and Houghton et al. (1994) would be considered as type-only. The symbolic models, outlined in Section 1.3, would be classified as a repeated-token model since different tokens at the identity tier are used to represent the same letter (following Clements & Keyser, 1983, for phonology), as illustrated below. Both Caramazza and Miceli (1990) and McCloskey et al. (1994) reject the second interpretation due to the fact that letter substitutions do not co-occur in both repeats (e.g. doctor → *dactar*). However, without an implementation of this abstract description such a conclusion may be premature.



and not



Two other repeated-token models of orthographic representation involve positional slots in which the same letter tokens are redundantly represented at each position (e.g. for reading, McClelland & Rumelhart, 1981; for spelling, Margolin & Goodman-Schulman, 1992) and trigram models in which the same letter is redundantly represented in many letter contexts (e.g. for reading, Seidenberg & McClelland, 1989; for spelling, Brown & Loosemore, 1994). For example, *bad* would be represented by 3 trigrams _ba, bad, ad_.

The repeated token approach offers relatively simple solutions to the problems discussed in Section 1.4.2. Words containing geminates and/or repeated letters and words which are the anagrams of other words can be represented without recourse to any special mechanisms.

However, there are a number of other problems associated with this type of model. For instance, in the case of geminates there is actually good evidence to suggest that they are not represented by two identical tokens. Furthermore, in the McClelland and Rumelhart (1981) approach, it is not obvious how the letters would be serially selected without also incorporating some form of activation gradient over the positional slots or an *ad hoc* pointer mechanism (e.g. Shaffer, 1975). Thus, the model begins to resemble a modified version of Rumelhart and Norman (1982). The Seidenberg and McClelland (1989; based upon Wickelgren, 1969) approach is also problematic. Although it can solve the repeated letter problem, this only leads to the 'repeated trigram' problem. For example, the word *banana* requires 2 instantiations of the *ana* trigram.

Also, as Houghton et al. (1994) note, determining the serial order for output of letters from trigrams is not straightforward.

Thus, although the repeated-token approach to orthographic representation offers some solutions to difficult computational problems they also result in an additional set of difficulties.

1.5 The Retrieval of Proper Names

1.5.1 Background

It is hard to give a full account of lexical retrieval without giving some consideration to the semantic mechanisms which are assumed to trigger the retrieval process. One issue which has received much recent interest is whether the mechanisms for retrieving a proper name are different from those required for common names (see Valentine, Brennan & Brédart, 1996, for a review).

The notion that proper names may be processed/represented differently to common nouns has its roots in philosophy (e.g. Kripke, 1980; Mill, 1843) and linguistics (e.g. Jackendoff, 1983). Proper names refer to an individual person, place or object (e.g. *Napoleon*, *London*, *Excalibur*) as opposed to a common noun which may refer to any one of all things denoted by the noun (e.g. *dictator*, *city*, *sword*), (Hartmann & Stork, 1972). Proper names lack number contrast and are often used without a determiner (e.g. not 'two Londons' or 'the London').

There is good psychological evidence to suggest that proper names are particularly susceptible to retrieval difficulties. In the normal population, proper names are commonly reported to elicit word finding difficulties in diary studies (e.g. Young, Hay & Ellis, 1985). In experimental studies on normal subjects, proper names are particularly efficient at eliciting a tip-of-the-tongue state (e.g. Brennen, Baguley, Bright & Bruce, 1990; Yarmey, 1973), and are harder to recall in serial recall tasks compared to frequency and length matched common nouns (Semenza, Nichelli & Gamboz, 1996). Difficulties in proper name retrieval are also particularly susceptible to effects of aging (e.g. Burke, MacKay, Worthley & Wade, 1991; Jones & Rabbitt, 1994). Evidence from brain-damaged patients converges on the view that proper names are, in general, more difficult to retrieve than common nouns and may be selectively impaired. This evidence is reviewed in the next section. The following section, however, suggests that task difficulty alone may not be able to explain the difference between proper names and common nouns.

1.5.2 Proper Name Anomia

Difficulties in retrieving proper names may, in some brain damaged patients, be secondary to a difficulty in recognition (e.g. of faces) or a difficulty in comprehension (e.g. Ellis, Young & Critchley, 1989; Kartsounis & Shallice, 1996). However, there is now a sizeable body of evidence to suggest that difficulties in proper name retrieval can occur in the face of intact recognition and comprehension and in the face of comparatively spared common noun retrieval (Carney & Temple, 1993; Fery, Vincent & Brédart, 1995; Flude, Ellis & Kay, 1989; Hanley, 1995; Harris & Kay, 1995a, 1995b; Hittmair-Delazer, Denes, Semenza & Mantovan, 1994; Lucchelli & De Renzi, 1992; McKenna & Warrington, 1980; Semenza & Zettin, 1988, 1989; Shallice & Kartsounis, 1993). The term 'proper name anomia' will be used here to refer to a word finding difficulty in the absence of notable recognition or semantic impairment.

As an illustrative example, patient LS (Semenza & Zettin, 1989) was unable to produce the names of places or famous people in fluency tasks (producing as many exemplars as possible within a limited time), in confrontation naming or in naming to definition. He was, however, able to provide detailed semantic/biographical information in all instances and showed no corresponding difficulty in naming common nouns. The anomia was found in both spoken and written output. Indeed, all patients that have been tested in both spoken and written output modalities have shown equivalent impairments in each (Fery et al., 1995; Hittmair-Delazer et al., 1994; Lucchelli & De Renzi, 1992; Semenza & Zettin, 1989).

1.5.3 Selective Preservation of Proper Names?

The preserved ability to comprehend familiar proper names (e.g. in matching tasks) relative to other semantic categories has been demonstrated in a number of patients (e.g. Forde & Humphreys, 1995; McNeil, Cipolotti & Warrington, 1994; Van Lancker & Klein, 1990 Warrington & McCarthy, 1987). However, the preserved ability to retrieve peoples names relative to common nouns in the face of good comprehension is apparently rare, and is disputed by some researchers (e.g. Brédart, Brennen & Valentine, 1997).

Semenza and Sgaramella (1993) reported the case of a jargon aphasic patient, RI, whose spontaneous speech consisted of neologisms interspersed with peoples names (friends and family names). RI's ability to name both proper names and common nouns to confrontation was poor. However, confrontation naming was substantially improved following a phonemic cue for peoples names but not for common nouns. Thus, there is some evidence for proper name preservation in both spontaneous speech and cued recall.

Cipolotti, McNeil and Warrington (1993) documented a patient (MED) with preserved recall of country and peoples' names over common nouns in written naming and writing to dictation (the patient was unable to spell nonwords and was presumably writing semantically). On a graded naming test (McKenna and Warrington, 1980) she was 3.6 standard deviations below the mean for common nouns but only 0.2 standard deviations below the mean for proper names. The only comprehension task given to MED involved spoken-written word matching at which she was unimpaired for both proper names and common nouns. Although this task is relatively undemanding, there is other evidence to suggest that MED was able to comprehend common nouns for which she could not produce. When asked to write a common noun she frequently substituted it for a semantically related proper name (e.g. scarecrow→*Wizard of Oz*, chopsticks→*Chinese*). Other studies have reported preserved naming of places relative to common nouns, but have not tested peoples names (McKenna & Warrington, 1978; Warrington & Clegg, 1993).

Within the category of 'proper names' itself, further dissociations may be possible. Some studies have reported preserved naming of places over people (Carney & Temple, 1993; Fery et al., 1995; Lucchelli & De Renzi, 1992; McKenna & Warrington, 1980; Shallice & Kartsounis, 1993). The reverse dissociation of preserved naming of people over places has not been documented, perhaps suggesting that the people-place distinction reflects task difficulty (Lucchelli & De Renzi, 1992). Within the category of 'peoples names' some patients may be good at naming friends and family but not famous people (Harris & Kay, 1995a, 1995b; Semenza & Zettin, 1989), and others may be good at recalling common first names, such as *John*, in fluency tasks but not specific names such as *John Major* (e.g. Semenza & Zettin, 1989; Shallice & Kartsounis, 1993).

1.5.4 Theories of Proper Name Retrieval

Before considering why proper names might be difficult to retrieve and/or represented differently it is important to make some assumptions about semantic representation and lexical retrieval in general. It is often assumed that semantic representations are composed of a cluster of primitive features (e.g. Jackendoff, 1983; Plaut & Shallice, 1993; Smith, Shoben & Ripps, 1974). Thus, there may be no single node in a network which corresponds to the concept <lion>, but the semantic representation of *lion* may be composed of, to differing degrees, the features <carnivore>, <cat>, <Africa>, and <mane>. Similar concepts may share similar features, so the semantic representation of *leopard* may include the first three of these features but also include <spots> instead of <mane>. Brain damage may often affect one semantic category more than another. This might imply that semantic features are clustered together according to similarity (e.g. Caramazza, Hillis, Rapp & Romani, 1990) or according to some other organising dimension (e.g. sensory v. functional; Farah & McClelland, 1991; Warrington & Shallice, 1984) or that the semantic system is indeed categorically organised. If one were to assume that the semantic features which represent familiar people were clustered within the semantic system, then it might be possible to selectively impair (e.g. Ellis et al., 1989) or spare (e.g. McNeil et al., 1994) this region.

One difference between the semantic representation of proper names versus common nouns that has been proposed, is that for proper names there is a single node within the semantic network which corresponds to that individual (a Person Identity Node, or PIN), (e.g. Burton & Bruce, 1992). Activation of this node would then make available the semantic features which describe the individual, e.g. <male>, <politician>, etc. However, other models do not make this assumption (e.g. Burke et al., 1991) and treat proper names at the semantic level in essentially the same way as common nouns.

Given this representational framework, how is a lexical item selected and retrieved for output following activation of the semantic description? It is often assumed that the semantic system does not activate a single lexical item but activates a cohort of candidates, and that there is then some form of competition as to which lexical item gets selected (e.g. Caramazza & Hillis, 1990c; Levelt, 1989[3]; Morton, 1969; Roelofs, 1992). For example, if the features <carnivore>, <cat>, <Africa>, and <mane> are activated then each feature may send activation to several lexical items. Summing all the activations together, *lion* might receive 0.8 units of activation, *leopard* might receive 0.6 units of activation, and *tiger* might receive 0.5 units of activation. In the case of a persons name, however, only a single PIN may be activated (e.g. Burton & Bruce, 1993). There is no summation of activation to the lexical level and this may result in proper names being more vulnerable to retrieval failure than semantic information and common nouns (e.g. Brédart, Valentine, Calder & Gassi, 1995).

The model of Burke et al. (1991) does not assume the existence of PINs and treats proper names in the same way as common nouns at the semantic level. However, this model also predicts that proper names should be susceptible to retrieval failure for essentially the same reason. Burke et al. (1991) assume that in the output lexicon, there is a name node (e.g. *Tom Jones*) which connects to two lexical items (*Tom* + *Jones*). Thus the lexical item still receives activation from only one node (the name node) without a summation of activation to this node. The latter account

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[3] The model of Levelt (1989) divides lexical retrieval into two discrete stages: 'lemma' retrieval and word-form retrieval. Whilst a cohort of lemmas are assumed to be activated in parallel by conceptual feature nodes (as in the other models), word forms are not activated in parallel but are only activated after selection of a lemma.

would also explain why place names are often easier than peoples names, because place names are usually composed of a single word. Thus one reason why proper names may be more difficult to retrieve is because of a 'unique' connection between the semantic level and the corresponding lexical item. However, Hanley (1995) has shown that difficulties in retrieving a proper name does not necessarily impair the ability to retrieve other unique information such as celebrity catchphrases. Thus uniqueness alone may not capture the representational differences between proper names and common nouns.

Many theories make use of the notion that proper names are 'arbitrary' referring expressions devoid of meaning (Kripke, 1980; Mill, 1843). Thus, when acquiring a new proper name, pre-existing semantic knowledge of other individuals may not be useful. For instance, learning the name 'John Baker' does not refer to any existing semantic knowledge in the same way as learning the persons occupation (e.g. 'baker') might (Cohen, 1990; McWeeny, Young, Hay & Ellis, 1987). Proper names may, therefore, be more difficult to retrieve and more susceptible to damage because the semantic associations between proper name items may be more 'arbitrary' than for common nouns (Lucchelli & De Renzi, 1992; Semenza 1995). In support of this hypothesis, some proper name anomics have been shown to be impaired at learning other arbitrary pairings such as learning semantically unrelated word associations (Lucchelli & De Renzi, 1992; Hittmair-Delazer et al., 1994; Semenza & Zettin, 1989), or at recalling previously learned arbitrary person-word pairings such as telephone numbers (Harris & Kay, 1995a; Hanley, 1995; Lucchelli & De Renzi, 1992).

It should be noted that current theories of proper name processing are (at least in part) reliant on the assumption that it makes theoretical sense to refer to 'proper names' as a categorical entity distinct from 'common nouns'. However, the emerging view in the literature is that there may be finer levels of dissociation other than a dichotomy between common nouns and proper names (see Section 1.5.3), for example between place names and peoples names. Any theory of 'proper name' processing must be able to take into account this apparent heterogeneity in the patient population.

Chapter 5 examines the ability of two patients to produce proper names. A 'deep dysgraphic' patient who writes semantically is found to produce proper names at least as well as common nouns. For comparison the ability of a 'deep dyslexic' patient to read proper names is reported who has a particular difficulty in reading proper names, but in other respects shows some similarities with the 'deep dysgraphic' patient. Implications for the representation and processing of proper names, in general, are discussed.

All experimental chapters have, or are intended to be, submitted for publication. The data on serial position effects presented in Chapter 2 has already been published in abstract form in *Brain and Language* and has been submitted for publication in *Neurocase*. The data from Chapter 3 is intended for publication in *Brain and Language*. The data from Chapter 4 concerning the connectionist model has been written in the form of a paper and is to be submitted to *Language and Cognitive Processes*. The data from Chapter 5 is intended to be submitted at a later date. There have been some modifications made to the manuscripts in order to accommodate them in the thesis. This has been largely in the interests of avoiding repetition.

2. SERIAL POSITION EFFECTS AND LEXICAL ACTIVATION

2.1 Introduction

Section 1.2 showed that serial position effects are a pervasive property of both the damaged and intact spelling system. Although only recently has substantial progress been made in understanding the mechanisms which may underlie such phenomena (e.g. Houghton et al., 1994; Page & Norris, submitted). This Chapter will examine the serial position effects produced in the spelling errors of an acquired dysgraphic patient (BA). It is hoped that the analyses carried out will shed light on both the functional locus of this serial position effect and the nature of the underlying mechanism which gives rise to it.

2.2 Case Report: Patient BA

BA is a 61 year old, right-handed woman who suffered a cerebro-vascular accident in 1993. A CT scan at 15 months post onset revealed a 5 cm x 3 cm area of cerebral atrophy within the left parietal lobe. A right sided hemiparesis diminished after several months to enable walking and writing. A profound global aphasia, with a spontaneous spoken vocabulary of around 20 words, was noted at onset and persisted throughout testing. Her main sources of communication are gesticulation and the use of some residual spelling ability. Observationally, BA is well orientated in space and time, and is able to follow conversations. She was above the 95th percentile for her age group on Raven's Standard Progressive Matrices (Raven, 1958).

This study was conducted over an 18 month period from February 1994, during which time her performance was considered stable. BA had previously been employed as a secretary in her husband's business and is reported to have been an excellent speller. BA's performance was assessed on a variety of general cognitive tasks and the results are detailed below.

Phonological Discrimination

BA has no peripheral deficit in audition. Her ability to discriminate phonemes in a same/different judgement task was very good (13/13). BA was given a word and nonword minimal pairs test containing equal and counter-balanced numbers of words and nonwords and requiring a same/different judgement (e.g. saster-soster, sister-soster, sister-sister, soster-soster). 'Different' pairs differed by only one phoneme. She scored 58/60 (96.7%) on this task. Thus any deficit in writing to dictation is unlikely to be secondary to a deficit in the acoustic analysis of input speech sounds.

Short-term memory

BA has a poor phonological short term memory. Digit span was assessed by reading aloud sequences of digits. She was then required to point to numbered tiles representing the digits 0-9 in the appropriate sequence. Her digit span was two (2 digits=5/5, 3 digits=1/5, 4 digits=0/5). Her spatial span was assessed using arrays of eight objects. The experimenter pointed to objects in sequence and then BA was asked to do the same. She was able to reproduce correctly sequences of up to five objects.

Lexical decision

BA was unimpaired in lexical decision. Sixty words and 60 nonwords taken from PALPA (test 25; Kay, Lesser & Coltheart, 1992) were presented for lexical decision in either the visual or auditory modality. The words consisted of both high and low frequency items and high and low imageability items. Nonwords were created by substituting one or more letters of the word, preserving phonotactic/orthotactic constraints. She scored 115/120 (95.8%, 4 false positives) in visual lexical decision and 116/120 (96.6%, 3 false positives) in auditory lexical decision, putting her within the normal range.

Reading

BA was unable to read most words aloud, due to her global aphasia. Her ability to derive internal (output) phonology from written words was also very impaired. She was administered a pseudo-homophone task in which she had to decide which written nonword, among a set of alternatives, sounded like a real word. Distractors were either visually similar (2 alternatives, e.g. yellot, yelloe) or visually dissimilar to each other (4 alternatives, e.g. oceam, karn, klok, pable). In both instances, BA was at chance (10/20 and 5/20 respectively). She was also impaired at a homophone decision task using real words (e.g. their-there; 24/39, 61.5%).

Sentence comprehension

A sentence-picture matching task was administered. For each sentence there was a choice of three pictures; one target and two distractors. Distractors consisted of subject/object reversals (e.g. *the cat is chasing the dog* v. *the dog is chasing the cat*) and semantic distractors (e.g. *the cat is chasing the dog* v. *the cat is biting the dog*). BA scored 53/60 (88%) and 44/60 (73%) on written and auditory versions respectively. This difference is not significant (χ^2 (1) = 3.44, *ns*). Five out-of seven (71.4%) errors in the written task were to reversal distractors, compared to 8/16 (50%) in the auditory task.

Semantic knowledge

BA was good at matching tasks involving pictures and high imageability words. She was given two matching tasks containing high imageability nouns. The first required her to match a spoken word with one of 4 written words (2 semantic distractors and 1 orthographic/visual distractor). The other (PALPA test 47) involved matching a spoken word to one of 5 pictures (2 semantic distractors, 1 visual distractor and 1 unrelated distractor). She was 95% (38/40) correct on the first task (her errors being to semantic distractors) and 100% (40/40) correct on the second. However, she was impaired on a spoken word - written word matching task involving function words (26/34, 76.5%; 3 function word distractors).

BA was also fairly good at the British Picture Vocabulary Scale (Dunn, Dunn, Whetton & Pintilie, 1982) which requires a spoken word to be matched to one of four pictures and contains some low frequency and/or low imageability items. Her raw score on the long form was 126 (vocabulary level = 15 years 4 months). In a modified version using written words she scored 123 on the long form (vocabulary level = 14 years 9 months).

BA's ability to derive knowledge of physical and perceptual attributes from words and pictures was also good. In matching a spoken word or line drawing to a visual colour chart (e.g. "lemon" = ?) she scored 12/13 (92.3%) and 18/21(85.7%) respectively. Her performance was flawless in deciding whether a physical attribute went with a word (e.g. cherry = red?, mountain = flat?) when written words were presented (84/84) but was impaired on auditory presentation (56/84 and 60/84 on two different presentations). This discrepancy may be attributable to her poor phonological short-term memory.

Finally, BA was given three tests requiring knowledge of semantic associations. The Pyramids and Palm Trees test (Howard & Patterson, 1992) requires a semantic association to be made between a given picture/word and one of two other pictures or words; for example, matching a pyramid to a palm tree and not a fir tree. BA was within the normal range for both written words (51/52, 98.1%) and pictures (50/52, 96.2%). In a second task using written words from PALPA (test 51), she had to point to the word closest in meaning to the target word ignoring 3 distractors (e.g. fog - mist, steam, bolt, lock). She scored 80% (12/15; 3 semantic foils) with high imageability words and 40% (6/15; 4 semantic foils and 5 unrelated foils) with low imageability words. This demonstrates some impairment in deriving semantic associations. This impairment is confirmed by performance on a third task involving synonym judgements (e.g. ocean=sea?; PALPA tests 49 & 50). With auditory presentation, BA scored 20/30 (66.7%) and 18/30 (60.0%) on high and low imageability words respectively. With written presentation she scored 26/30 (86.7%) and 24/30 (80.0%) on high and low imageability words respectively. Poorer performance for auditory presentation may, again, be due to her difficulties with phonological short-term memory.

Conclusion. BA presents with a mild semantic impairment which is not secondary to a difficulty in recognising words since she is good at lexical decision. This impairment consistently affects low imageability words more than high imageability words. For example, on spoken word - written word matching performance was better for high than for low imageability words and her performance was often unimpaired on tasks containing only high imageability items (e.g. Pyramids and Palm Trees). This pattern is consistent with some damage to the semantic system. The semantic representations of low imageability words may be specified by fewer semantic features and may, therefore, be more vulnerable to damage (e.g. Plaut & Shallice, 1993). An impairment in deriving semantic knowledge may be expected to affect BA's spelling performance since it will be shown that she is reliant on the lexical-semantic route for spelling.

2.3 General Spelling Assessment

BA is able to produce very few spoken words, so the writing of single words is an important part of her everyday communication. She is often able to retrieve only the first few letters of a word, but is usually able to use this information to look-up the correct entry in a dictionary. She is also able to demonstrate comprehension for many words which she cannot produce (e.g. by drawing or gesticulating). This is suggestive of a word finding/retrieval difficulty. BA often concentrates intensely before writing a word although the physical writing process is fluent. She is unable to write in sentences. When asked to describe the picnic scene from the Western Aphasia Battery (Kertesz, 1982) she produced a list of nouns. In order to investigate the origin of her impairment, a set of word lists for writing to dictation were administered. All the words used were monomorphemic nouns, unless otherwise indicated. Spontaneous corrections of misspellings were accepted.

Effect of word length

BA spelled correctly 72% (38/53) of 3-4 letter words and 49% (26/53) of 6-8 letter words matched for frequency and imageability (χ^2 (1) = 4.77, $p < .05$). On the length list from PALPA (test 39), she correctly spelled 79% (19/24) of 3-4 letter words and 46% (11/24) of 5-6 letter words (χ^2 (1) = 4.36, $p < .05$). However, no significant effect of length was found on the length list from Goodman and Caramazza (1986b). She correctly spelled 21% (6/28) of 4-5 letter words and 36% (10/28) of 7-8 letter words.

Effect of regularity

BA showed no significant effect of regularity in writing to dictation. Eighty words taken from PALPA (test 44 and 53) were used. Regular and exception words were matched for length, frequency and imageability. She scored 20/40 (50%) and 17/40 (42.5%) for regular and exception words respectively (χ^2 (1) = 0.20, *ns*). None of her errors in spelling exception words were phonemic regularisations (e.g. yacht→*yot*). Her errors consisted of lexical substitutions, morphological errors and nonword responses which demonstrated some word specific knowledge (e.g. yacht→*yath*). This suggests reliance on the use of the lexical-semantic route for spelling. If this is the case then nonword spelling should be impaired.

Nonword spelling and phoneme-grapheme conversion

BA was unable to write any nonwords correctly to dictation (0/16). Her errors consisted of lexicalisations (e.g. "cug"→*cook*), other nonwords (e.g. "hoach"→*ho*) or failures to give any response. When asked to write single letters from their characteristic phoneme she scored 15/21(71.4%), and when asked to write letters from letter names (e.g. "kay", "aitch") she scored 24/26 (92.3%).

Her ability to segment spoken words into smaller units (e.g. syllables, rimes) was also impaired. In an auditory rhyme judgement task she scored 20/30 (66.7%). In deciding whether a word contained 1,2 or 3 syllables she scored 5/20 (25%). Finally, she was poor in tasks requiring segmentation of initial or final sounds (PALPA test 16 & 17). She was presented with a spoken word/nonword and was asked to select which of 5 letters corresponded to the initial or final sound (e.g. "bread" - d, b, k, z, n). She scored 30/45 (66.7%) for initial sounds and 26/45 (57.8%) for final sounds. Performance was equivalent for words and nonwords.

Taken together, the results presented above suggest that BA has an impaired sublexical spelling route and must therefore attempt to spell lexically. If, indeed, BA is reliant on a lexical-semantic route then lexical and semantic variables such as word frequency, imageability, grammatical class and age-of-acquisition may be expected to influence her performance.

Effects of frequency and imageability

Words taken from PALPA, Goodman and Caramazza (1986b), and 160 words prepared by the authors were given for BA to write to dictation. Frequency ratings were taken from Carroll, Davies and Richman (1971). Two-hundred and twenty-eight words were used in total. They were grouped into four categories according to imageability (high or low) and frequency (high or low), and matched for length. The percentages correct were as follows: high frequency/high imageability = 71, high frequency/low imageability = 25, low frequency/high imageability = 48, low frequency/low imageability = 15. There was a significant effect of imageability, summing over frequencies (χ^2 (1) = 31.44, $p < .005$), and a significant effect of frequency, summing over imageability (χ^2 (1) = 4.85, $p < .05$).

Effect of grammatical class

Nouns, adjectives and verbs. A list of 177 words containing equal numbers of nouns, adjectives and verbs and matched for frequency and length were given to BA to write to dictation. Words which can function as either nouns or verbs were presented with a simple disambiguating phrase (e.g. "cut....to cut something"). She wrote correctly 54% (32/59) of nouns, 41% (24/59) of verbs and 27% (16/59) of adjectives (χ^2 (2) = 8.99, $p < 0.025$).

This result may be confounded by differences in imageability between words, since this factor was not controlled for. In order to assess the effect of imageability on this result, 30 subjects were asked to rate the words on a 0-7 scale according to imageability (as defined by Paivio, Yuille & Madigan, 1968). An analysis of covariance (with the mean imageability ratings for each word as the covariate) revealed that there was no significant effect of grammatical class on performance over and above the effect of imageability ($F(2,173)=1.18$, *ns*).

Function words. BA was only able to write correctly 10.8% (5/46) of function words.

Eight of her errors (19.5%) consisted of giving no response at all. The remaining errors consisted largely of function word substitutions (25/33, 75.8%; e.g. the-and), together with other lexical substitutions (6/33, 18.2%; e.g. every→*arrive*) and nonword responses (2/33, 6.1%; e.g. who→*wha*). Her ability to write function words was significantly worse than her ability to write nouns matched for length and frequency (functors: 5/25, 20%; nouns: 15/25, 60%; χ^2 (1) = 6.75, $p < .01$). Again, this result may be influenced by differences in imageability between the two groups.

Effect of age-of-acquisition

It has been suggested that representations which are acquired earlier in life may be less vulnerable to the effects of brain damage than those acquired later (see Hirsh & Ellis, 1994). A list of 80 words were prepared using ratings from Gilhooly and Logie (1980). Half of the words were acquired early and half of the words were acquired late. The two groups of words were closely matched for frequency, imageability and length. She scored 16/40 (40%) and 11/40 (27.5%) on early and late acquired words respectively (χ^2 (1) = 0.89, *ns*).

Regression Analysis

The variables of frequency, imageability, age-of-acquisition and word length tend to be highly intercorrelated. This can lead to difficulties in preparing suitable word lists in which all these factors are carefully controlled. A more sensitive way of investigating the effects of these variables may be to measure the effect of one variable whilst statistically controlling for the effect of all other variables. This can be done by squared semi-partial correlation (see Cohen & Cohen, 1983; Hirsh & Ellis, 1994). A squared semi-partial correlation for a given variable is significant if dropping it from the regression equation significantly lowers the proportion of variance accounted for. The effects of imageability, log-frequency, age-of-acquisition and word length were investigated on a sample of 243 nouns for which ratings were available. The only factors which came out to be significant in this analysis were imageability ($F(1,238) = 5.64$, $p < .025$) and log-frequency ($F(1,238) = 6.17$, $p < .025$). No effect of age-of-acquisition ($F(1,238)=1.34$, *ns*) or word length was found ($F(1,238) = 2.96$, $p < .1$).

Error types

Table 1 shows the number of correct and incorrect responses that BA made in writing to dictation. Errors may be divided into five categories: fragments, other nonword responses, lexical substitutions, morphological errors and failures to give any response. Fragments consist of nonwords in which the length of the response is at least two letters shorter than the target. Lexical substitutions consist of all word responses which are morphologically unrelated to the target, and include semantic and visual errors. Nonwords, fragments and lexical substitutions in which at least half of the letters in the response are correct and are in the correct relative order are classified as visually related.

The presence of lexical substitutions and morphological errors is consistent with the hypothesis that BA has damage to semantic and lexical-orthographic representations. It should be noted that a non-negligible number of BA's visual lexical substitutions (7/49, 14.3%) had strong orthographic similarity but minimal phonological similarity with the target (e.g. broom→*book*). However, errors which had strong phonological similarity with the target but little orthographic similarity (e.g. search→*surge*) were not found. This is consistent with the hypothesis that the locus of damage is indeed to the orthographic lexicon rather than a phonological component (e.g. the phonological lexicon). The presence of a high proportion of nonword and fragment responses may also be compatible with damage to lexical-orthographic representations if it is assumed that such representations may be incompletely activated on some occasions (e.g.

Miller & Ellis, 1987). This will be discussed in more detail in the following sections.

Table 1: Analysis of BA's responses in writing to dictation.

	%	N		Example
Correct Response	**39.8**	583		
No Response	**23.3**	341		
Fragments	**13.4**	196		
Correct			126	sulphur → *sulp*
Visually related			58	arrest → *arra*
Unrelated			10	bell → *t*
Semantic?			4	moth → *bu*
Non-words	**11.0**	161		
Visually related			144	dentist → *dentant*
Semantic?			8	bat → *tennet*
Unrelated			7	Thatcher → *Hillard*
Lexical Substitutions	**9.6**	141		
Visually related			49	human → *humid*
Semantic			30	ornament → *vase*
Functor substitution			25	when → *where*
Unrelated			24	oyster → *escape*
Mixed (semantic + visual)			13	high → *hill*
Morphological	**2.9**	43		
Derivational			22	England → *English*
Inflectional			21	copy → *copying*
	------	------		
	100%	1465		

2.4 The Functional Lesion: A Lexical Activation Hypothesis

The absence of regularisation errors in spelling irregular words and BA's inability to write nonwords suggests damage to phoneme-grapheme conversion procedures and reliance on the lexical-semantic route[4]. The presence of frequency and imageability effects, together with semantic errors suggests that this route is not intact. These effects can be explained by assuming damage to the orthographic (output) lexicon and, to a lesser extent, the semantic system resulting in difficulties in activating orthographic representations.

An effect of frequency can be explained if it is assumed that words which are used more often (and/or most recently) may be easier to activate than less frequent words due to lower activation thresholds or higher resting levels of activation (e.g. Monsell, 1985; Morton, 1969). High frequency words may therefore be less vulnerable to reductions in activation arising from brain-damage. The presence of an imageability effect can be explained by the fact that low imageability words in the orthographic lexicon may receive less activation from the partially-damaged semantic system than high imageability words, given that the semantic representations of low imageability words appear to have been particularly affected by damage.

The presence of a relatively high proportion of lexical substitutions also suggests damage

[4] Whilst it could be argued that some of her error responses in nonword writing reflect limited phoneme-grapheme conversion (e.g. "hoach"→*ho*), these responses could also be explained by assuming incomplete activation of similar representations stored in the lexicon (e.g. hoax, hope). The latter hypothesis is supported by the fact that many responses to nonword targets were indeed real words. The attempted use of the lexical route to write nonwords is, however, assumed to be a compensatory strategy rather than a reflection of normal nonword writing procedures (cf. Campbell, 1983).

to central components up to and including the orthographic lexicon. Semantic lexical substitutions can arise from damage to the semantic system (e.g. Hillis, Rapp, Romani & Caramazza, 1990). An alternative hypothesis is that semantic lexical substitutions can arise following damage to the orthographic lexicon used in spelling (Caramazza & Hillis, 1990c). Caramazza and Hillis (1990c) suggested that if the semantic system activates words in proportion to their degree of semantic similarity to the target word then several lexical candidates may become activated, and if the target lexical representation is damaged then a semantically related word may reach threshold first.

So far, BA's performance has been explained in terms of semantic and word/lexical levels of representation. However, it may also be useful to invoke the concept of a 'letter level' of representation which is shared by all words in order to explain other aspects of her performance. The letter level may be analogous to the graphemic buffer in that the nodes at this level are not word specific and are only temporarily activated during the output process. This is consistent with the connectionist models that will be discussed later (e.g. Houghton et al., 1994). It should be noted that there it is not necessary to assume that the letter level itself is damaged even though many of the phenomena reported in BA may be characterised at this level. BA's deficit, rather, can be envisaged as a reduction in the amount of activation delivered to this level as a result of damage to semantic and lexical-orthographic levels of representation, or the connections from them. An effect of word length may then be expected because the greater the number of letters in a word, the greater the probability that a letter will fail to be correctly activated during lexical retrieval. Visual lexical substitutions may arise out of an interaction between word and letter levels, such that a partially activated letter level may feed-back to activate orthographically similar words (see Dell, 1988, for similar arguments in spoken language).

Nonwords and fragments can also be explained by this hypothesis. A reduction in the amount of activation delivered to the letter level could result in inappropriate letters becoming selected (letter additions, substitutions and transpositions) or a failure to select letters (word fragments and single letter omissions). Furthermore, if it is assumed that the amount of activation that a letter node receives is related to its serial position within the word, this may have the potential to explain BA's serial position effect in spelling in which initial letters tend to be preserved.

2.5 Characterisation of the Serial Position Effect

Serial position effect and word length

A glance at BA's error corpus suggests that the initial parts of words are spelled more accurately than the latter parts. The probability of producing an error at a given position for various word lengths was first examined. The entire corpus of 1465 responses from writing to dictation was divided up according to the length of the target word. The number of letter mismatches between target and response in each letter position for each word length was counted. For example, giraffe→*giffif* was counted as a match at positions 1,2,5 and 6, and a mismatch at 3,4, and 7. Insertion of a letter(s) into a correct sequence (e.g. giraffe→*girtaffe*) was counted as a mismatch at the preceding position (position 3 in this instance). Failures to give any response were counted as a mismatch at every position, whereas correct responses were counted as a match at every position. The results are displayed in Figure 4.

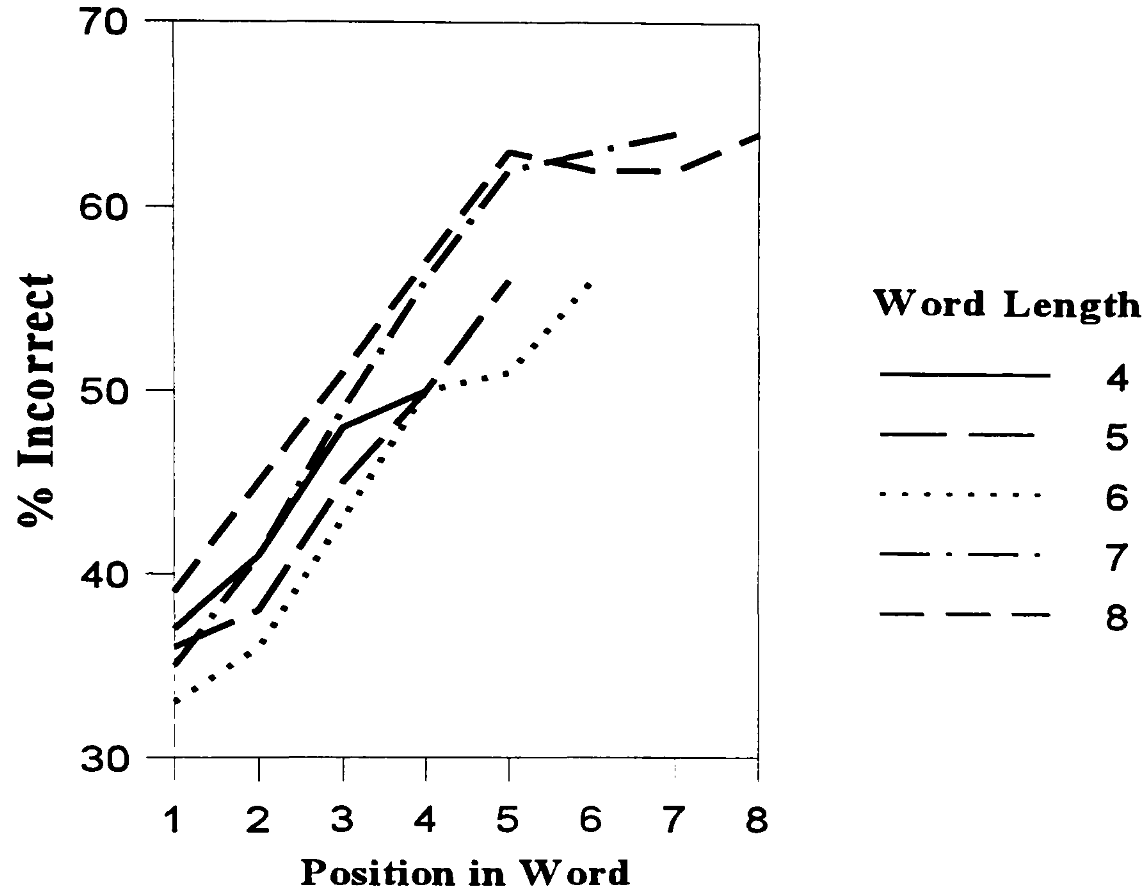

Figure 4: Percentage of letter mismatches at each position, for words of different lengths.

Errors were not evenly distributed over all positions in the word. The probability of producing an error at a given position within a word increased approximately linearly from word beginning to word end (for lengths 4 to 8 respectively, Jonckheere's τ = 1.0, 1.0, 1.0, 1.0, .86 p<.01). Furthermore, the probability of producing an error at a given position is independent of the overall length of the word, but dependent on the ordinal position within a word. That is, the probability of incorrectly producing the nth letter of a word does not increase with increasing word length (for positions 1 to 4 respectively, Jonckheere's τ = -.2, 0, 0.4, 0.4 ns; for position 5, τ =.67 p<.05; insufficient data for other positions).

Serial position effect and error type

Similar serial position effects were found in fragments, nonwords and visually related lexical substitutions. Considering fragments, words of lengths 5-8 gave rise to 107 fragments where all letters were correct and in the right order (e.g. sulphur→*sulp*). Average fragment lengths for words containing 5 to 8 letters were 2.53, 2.52, 2.73 and 2.93 respectively ($F(3,104)=0.50$, *ns*). That is, longer words did not give rise to longer fragments.

All subsequent analyses collapsed results from different word lengths to five normalised positions using the formula of Wing and Baddeley (1980). This was done because there were often too few errors to analyse according to different word lengths and it has already been established that similar serial position effects are found for different lengths. In this formula, position 1 always contains the first letter of a word and position 5 always contains the last letter, regardless of word length (see Appendix 1). The remaining letters are apportioned between the five positions so that they are symmetrically distributed about position 3. Examples being *banana* (b-a-na-n-a), *ostrich* (os-t-r-i-ch), and *homework* (ho-m-ew-o-rk). Percentage error rates are calculated by dividing the number of errors at that position by the total number of letters which have been assigned to that position. Several errors may be produced for each word, so the sum of the percentage error rates across all 5 positions need not add up to 100%.

Nonword responses were analysed according to single letter error types. Assignment of error position was straightforward for omissions and substitutions (for example, the error purple→*purlo* was classified as an omission of the fourth letter and substitution of the sixth letter). Addition errors were assigned to the preceding position (e.g. fast→*faste* was regarded as an addition at the position of the fourth letter). Transposition errors were classified as half errors on the two transposed letters. For this analysis, responses which contained more than 2 single letter errors were excluded because often they could not be unambiguously described in terms of substitutions, transpositions, etc., (e.g. giraffe→*giffif*). The results are presented in Table 2. Error probability increased from word beginning to word end for both additions, omissions and substitutions. For example, 66% of single letter additions occur in position 5 of the word. The lack of effect for transpositions could be due to the smallness of this sample.

Table 2: The percentage of a given error type falling in a particular position (N=number of letter errors).

	Position in Word					
	1	**2**	**3**	**4**	**5**	**N**
Additions	4	9	17	5	66	25
Omissions	5	11	26	17	40	53
Substitutions	4	2	16	38	40	67
Transpositions	0	21	33	35	11	8
Mean	4	7	21	25	43	153

A serial position effect was found for visual and mixed visual/semantic lexical substitutions (e.g. coin→*coil*, hill→*high*), similar to the ones described above. The percentage of letter mismatches increased from word beginning to word end as follows: 8>20>50>72>71. There were too few errors to analyse separately according to omissions, substitutions, etc.

Serial position effects in different spelling tasks

Finally, BA's serial position effect in a number of other spelling tasks was investigated. The details of these tasks are described below and the serial position effects are summarised in

Table 3. Unlike the word length analysis, the overall error rates at each position are not critical. What is more important is the relative distribution of errors across all positions in the word. For this reason, serial position effects were calculated by scoring letter mismatches between target and response only for the visually related responses (i.e. related fragments, related nonwords, and visual/mixed lexical substitutions). Other responses (i.e. visually unrelated responses, correct and omitted responses) can be excluded because they do not affect the relative distribution of errors across positions.

Typing to dictation. BA is experienced at using a QWERTY keyboard. She correctly typed 40/113 (35%) of words to dictation. Her errors consisted of 30 failures to give a response, 36 nonword/fragment errors and 7 lexical substitutions. Her visually related responses contained 105 letter mismatches.

Written picture naming. BA was not significantly worse at written picture naming (PALPA test 53; 30/40, 75%) compared to writing to dictation the same words (36/40, 90%; χ^2 (1) = 2.16, *ns*), suggesting little or no involvement of phoneme-grapheme conversion in writing to dictation. In total, BA was asked to write down the names of 129 pictures. She correctly wrote 80 of the names (62.0%). The same types of errors were observed in written picture naming as in writing to dictation (59.2% nonword/fragment, 24.5% no response, 8.2% semantic, 6.1% morphological, 2% miscellaneous; N=49). The 29 visually related responses contained 88 letter mismatches.

Arranging anagrams to dictation. BA was given all the letters needed to spell a word printed on letter tiles and arranged in a jumbled order (e.g. A, E, T, E, L, P, N, H). She was then given a spoken word ("elephant") and asked to arrange the tiles to spell the word. The words used in this task were generally longer than in other tasks to minimise the guessing component.

She scored 17/41 (41.5%). Her errors typically preserved the first letters and orthographic legality (e.g. aubergine→*aubereing*).

The serial position effects for this and the other tasks are given below. It can be seen that all these tasks produce a very similar error distribution.

Table 3: Percentage of errors at each position in different spelling tasks, for visually related responses.

	Position in Word				
	1	**2**	**3**	**4**	**5**
Writing to dictation	11 (55/514)	28 (110/397)	53 (257/482)	69 (272/397)	80 (411/514)
Typing to dictation	4 (2/47)	19 (7/37)	64 (25/39)	78 (29/37)	89 (42/47)
Written picture naming	2 (1/43)	28 (10/36)	42 (18/43)	58 (21/36)	88 (38/43)
Arranging anagrams (to dictation)	8 (2/24)	35 (6/17)	55 (11/20)	65 (11/17)	63 (15/24)

All the tasks described so far involve the production of an overt spelling. One way to test the ability to generate spellings without explicitly producing the spelling itself is to use a picture-letter judgement task. For example, responding 'yes' when confronted with a picture of a table and the letter E and responding 'no' if confronted with a picture of a table and the letter P. This task therefore requires the subject to generate an orthographic code (i.e. retrieve a spelling) in order to match it to the letter.

Picture-letter matching. BA was presented with 200 picture-letter pairs with equal numbers of 'yes' and 'no' trials. Most pictures were from the Snodgrass & Vanderwart (1980) set. All words were between 4 and 6 letters long. The letters for the 100 'yes' responses were randomly selected so that different serial positions were tested. In order to examine effects of serial position, only words with all-different letters were used (i.e. words such as apple and paper were excluded). The same set of letters used in the 'yes' condition were paired with another set of 100 pictures to form the 'no' condition. Each picture was used only once during the experiment to reduce any facilitation effects due to prior retrieval. Picture-letter pairs were presented centrally on a computer screen (with the letter below the picture) and BA was required to respond as fast and accurately as possible.

BA performed poorly on this task (131/200, 65.5%), particularly for letters at the end of the word. At the five Wing and Baddeley (1980) positions she scored 76% (16/21), 60% (12/20), 39% (7/18), 40% (8/20) and 43% (9/21). In the 'no' condition she scored 79% (79/100). The trend is not 'linear' over serial positions in the same way as is found in the other tasks because BA reaches chance quickly. However, the important point is that BA still shows a difficulty in retrieving letters at the end of a word even when no overt spelling production is required. An analysis of her reaction times was considered unfeasible due to the high error rate.

To summarise, spelling errors produced by BA in tasks such as writing to dictation were not uniformly distributed throughout the word but increased from word beginning to word end.

The same positional pattern was found for all word lengths tested, for different types of errors (i.e. visually related lexical substitutions, fragments and nonword responses), and in a number of different spelling tasks which require retrieval of lexical-orthographic representations. A series of further investigations were carried out to isolate the locus of this serial position effect.

2.6 Origin of the Serial Position Effect

Given the results presented so far, there are two hypotheses which can be eliminated as the locus of BA's serial position effect. The serial position effect cannot be due to impairments in selecting allographs or producing motor programmes for output since the same pattern is found in tasks which utilise different output procedures, such as typing and arranging letter tiles. A difficulty with letters at the end of a word is also found in a picture-letter matching task which does not utilise spelling output procedures at all. Also, it cannot be an artefact of residual phoneme-grapheme conversion. There are a number of reasons to suggest that this component plays little or no role in BA's spelling: (1) this component is severely impaired in BA (e.g. poor performance on rhyme judgement and syllable counting), (2) the same types of errors (including fragments) and the same serial position effect is produced in written picture naming where no phonology is provided, and (3) when writing to dictation words whose initial letters are unpredictable from phoneme-grapheme conversion (e.g. *psychology*, *wrist*; N=35) she produced orthographically related fragments (e.g. *psyos*, *wri;* N=17) but no phonologically plausible fragments (e.g. *sic*, *ri*). Taken together these results rule out the possibility that BA's serial position effect is an artefact of residual phoneme-grapheme conversion.

It has already been suggested that BA's pattern can be accounted for by incomplete activation of lexical-orthographic representations. However, two alternative hypotheses will also be considered. Firstly, that BA's serial position effect may reflect loss of information from the graphemic buffer, and secondly that BA attends to certain parts of the orthographic representation more than others (so-called neglect dysgraphia).

2.6.1 Damage to the graphemic buffer ?

There are some similarities between BA and patients with damage ascribed to the graphemic buffer: she shows equivalent performance in a number of different tasks (written naming and writing to dictation) across a number of different output mechanisms (e.g. typing and handwriting) and she does produce some single letter errors, as do graphemic buffer patients. However, there are also a number of significant differences. Unlike graphemic buffer patients most of her errors can be classified as word fragments or lexical substitutions. Moreover, damage to a graphemic buffer with limited capacity should produce a disproportionate length effect. For example, in patient LB the "effect of stimulus length remains even when we scale the probability of an error on a word by the number of letters in that word" (p.67, Caramazza et al., 1987). In BA, the effect of word length is weak; just reaching significance on two out of three occasions using matched lists and just failing to reaching significance using regression analysis. Finally, BA's serial position effect does not resemble the bow-shaped function which is generally associated with damage to the graphemic buffer.

Whilst the weight of evidence from BA points to a locus of damage other than the graphemic buffer there is still a need for caution. Not all patients with damage ascribed to the graphemic buffer are alike. This heterogeneity may arise because of differences in the stimulus material presented to patients or because of additional damage to other components which may qualitatively affect the functioning of the graphemic buffer. For example, some graphemic buffer patients have preserved sublexical spelling routes and others do not. More worryingly, the graphemic buffer itself might be damaged in qualitatively different ways giving rise to different patterns of performance and different serial position effects in different patients. In particular, Katz (1991) suggested that temporal decay from the graphemic buffer could give rise to a serial position effect similar to the one reported here. There is already some evidence to suggest that this is not the case: BA was impaired at picture-letter decision for final letters even though there is no temporal delay due to having to produce other letters first. The temporal decay hypothesis was, however, examined in another task in BA.

Backwards writing to dictation

If there is rapid temporal decay from the graphemic buffer then performance might relate to the order in which letters are written and not necessarily on the position that they occupy. Katz (1991) found that performance on end letters improved dramatically when they had to be spelled first as in backwards writing.

BA was first asked to write backwards some 'easy' practice words (e.g. her name, her husband's name) to ensure that she understood the instructions and could comply with them. She was then asked to write 40 words backwards to dictation; for example, the letters of the word *bone* should be produced in the sequence E, N, O, B. Half of the words were written left-to-right (so that the final stimulus should be *enob*) and half of the words were written right-to-left (so that the final stimulus should be *bone*).

Results and discussion. BA managed to write 47.5% of words correctly. The manipulation of writing from right-to-left or left-to-right did not produce an effect (10/20 and 9/20 respectively), so the results were combined. Her 21 errors consisted of 1 semantic error (goat→*donkey*), 1 visual error (computer→*comment*), 1 mixed error (fabric→*fibre*), 1 no response and 17 nonword/fragment type errors. Her errors showed the same serial position effect as normal writing to dictation. For example, the word *bone* was misspelled as I, N, O, B (*boni*). Her percentage error rates for visually related responses at each position were: 0>17>41>44>73. Thus, temporal decay from a peripheral buffer cannot explain her serial position effect, since end letters were spelled no more accurately when written first.

Further evidence that BA's serial position effect arises from damage to a lexical rather than a buffer component may come from a task which places a strong demand on one component but not the other. Delayed copying is one such task which requires temporary storage of an orthographic representation but does not require lexical access. If BA's serial position effect does indeed arise from damage to the orthographic lexicon then a different pattern might be expected in this task. This would show that different serial position effects can be linked to different cognitive components within the same patient, depending on task requirements.

Delayed copy transcoding

BA was given a written word or nonword to memorise for as long as she liked. Immediately after it was removed from sight she was asked to write it down. Words typed in upper case were to be copied into lower case and *vice versa*. The stimuli consisted of matched lists of 109 words and 109 nonwords, and an additional list of 104 items. Nonwords were matched to words for length and consonant-vowel structure, and were all phonotactically/orthotactically plausible. Nonwords were created from the words by substituting two or more letters (e.g. catholic - cosholik), and the positions were varied so that errors were not biased to occur in certain positions. The stimuli were typed on individual cards and presented in random order. Half of the items were in upper case and half in lower case.

Results and discussion. A number of characteristics of performance support the hypothesis that errors in this task stem from loss of information from the graphemic buffer and not from a deficit in lexical activation. First of all, in contrast to writing to dictation, BA showed no significant advantage for words over matched nonwords (words =66.9%, 73/109; nonwords =60.6%, 66/109; $\chi^2(1) = 0.71$, *ns*) and an effect of word frequency did not reach significance. The mean frequency of words copied correctly (from Carroll et al., 1971) was 79.7 (SD=293, median=13.0) and the mean frequency of words copied incorrectly was 30.6 (SD=62, median=11.0); (t(171)=1.88, *ns*)[5]. This is consistent with these errors arising from the graphemic buffer (Caramazza et al., 1987). Also, the quality of her performance differed from writing to dictation. Whilst writing to dictation was slow and effortful, delayed copying was fast with few pauses. This dissociation is reflected in the fact that her overall performance in delayed copying was better. The mean length of words in delayed copy was 7.26 and she copied them with 70.2% accuracy. Whereas 7-letter words were written to dictation with only 28.4% accuracy. Patients with damage to the graphemic buffer should produce quantitatively similar performance in these two tasks (Caramazza et al., 1987).

Finally, but most importantly, delayed copying resulted in a different serial position effect from that found in writing to dictation. Ninety-seven and 91 single letter errors were made in copying words and nonwords respectively. The positional distributions of these errors did not

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[5] The mean frequency of words spelled correctly is high due to the inclusion of two function words in this set.

differ ($\chi^2(4) = 2.51$, *ns*), so results from words and nonwords were combined. BA's percentage error rates for the five Wing and Baddeley positions were: 4>17>26>33>19. This right-skewed bow-shaped function is common amongst patients with damage attributed to the graphemic buffer (e.g. De Partz, 1995; Jonsdottir et al., 1996).

Taken together, these results support the hypothesis that delayed copying taps a different level of representation to the tasks that give rise to the linear serial position effect. A linear serial position effect may result from impaired lexical activation whereas a bow-shaped serial position effect may result from a straining of memory resources in a graphemic buffer or temporarily activated letter level. Thus, BA's main difficulty in tasks such as writing to dictation appears to be in lexical activation.

It should be noted that the bow-shape function observed in delayed copying need not reflect a separate impairment but may reflect the fact that BA, unlike normal subjects, cannot rely on lexical-orthographic representations or phonological recoding to support this task. Indeed, when an age matched control was asked to delay copy 90 nonwords (7-8 letters long) under conditions of articulatory suppression (to discourage phonological recoding) his performance was quantitatively similar to BA (56.7%, 51/90) and he showed a similar serial position effect (percentage error rates at each position: 1>8>10>13>9).

2.6.2 An attentional/neglect deficit ?

It has been shown that an attentional (or neglect) deficit can interact with the spelling system to produce a serial position effect in which spelling errors are concentrated on one side of the word (e.g. Baxter & Warrington, 1983). BA also produces more errors on one side of the word. However, this need not reflect an attentional/neglect impairment. In the reading literature, for example, some studies have reported errors concentrated at certain positions but have explained this in terms of properties of the orthographic representations themselves rather than deficits of visuo-spatial processing (Katz & Sevush, 1989; Patterson & Wilson, 1990). This general approach will also be applied to BA. However, first of all it is important to consider in what ways BA differs from so-called 'neglect dysgraphic' patients reported in the literature.

Caramazza and Hillis (1990a) have argued that if a patient is 'neglect dysgraphic' then spatial processing deficits should be manifest in all types of spatial tasks (linguistic and non-linguistic), provided that these tasks tap the same level of representation. However, no spatial bias was found in any non-spelling tasks. BA showed no signs of clinical neglect in standard tasks such as cancellation, drawing from memory, complex figure copying, or line bisection (she was within the range of norms reported by Marshall & Halligan, 1990). There were no observed spatial effects in visual lexical decision. Words with a low N-count (i.e. few lexical neighbours differing by only one letter; Clotheart, Davelaar, Jonasson & Besner, 1977) were used and nonwords were created by altering the initial or terminal letter of a word (e.g. homfortable, conductov). The items (N=124) were scattered randomly onto 4 sheets of paper. BA correctly circled 59/62 (95.2%) of the words and did not mistake any of the nonwords for real words. Her ability to process spatial representations was also unaffected by the introduction of time constraints. In a task requiring her to determine whether a letter B is present within an 8 letter consonant string (e.g. QWXSTBVP), she scored 127/128 (99.2%). The 'B' was present on half of the trials and its position within the string was counterbalanced across all positions. Her mean reaction times were 772msec (sd=108) for the first four positions and 868msec (sd=153) for the last four. These results suggest that BA does not suffer from a general spatial deficit.

In contrast to Caramazza and Hillis (1990a), Baxter and Warrington (1983, 1990) have argued for the existence of spelling-specific attentional mechanisms. They cite the case of patient ORF who made spelling errors predominantly on the left side of words but did not show any clinical signs of neglect. ORF did, however, make a few left-sided errors in reading and was apparently not tested on more demanding tests of neglect (e.g. line bisection). Thus, it seems premature to assume the existence of spelling-specific attentional mechanisms. However, even if one were to make this assumption there are other reasons for believing that BA does not have spelling-specific neglect.

BA's serial position effect is different from that reported for patients with neglect dysgraphia. In neglect dysgraphia, patients have difficulty in processing one side of a word-centred representation (e.g. HB- Hillis & Caramazza, 1995; NG- Caramazza & Hillis, 1990a, 1990b) and, thus, word length is a crucial factor in determining where errors are likely to occur (since the centre of a word changes position with word length). For HB and NG (both right-sided neglect dysgraphics) error rates on the fourth letter in words of length four to eight were 28, 15, 11, 13, 3 and 15, 8, 4, 4, 1. This reflects the fact that the fourth letter moves towards the non-neglected side with increasing word length and so fewer errors are made at this position. BA did not show this tendency (the corresponding error rates, from Figure 4, were 50, 50, 50, 56, 57).

Furthermore, although neglect dysgraphic patients often do preserve the beginnings of words they also tend to preserve the length of the word (e.g. knife→*knith*), i.e. they typically don't produce fragments (e.g. Baxter & Warrington, 1983; Caramazza & Hillis, 1990a; Hillis & Caramazza, 1995).

Finally, it has been suggested that attentional mechanisms interact with spelling at the level of the graphemic buffer (Hillis & Caramazza, 1989). Therefore the same pattern should be found in all spelling tasks that tap this level, including delayed copying. It has already been demonstrated that this was not the case in BA. Either this hypothesis is wrong or BA's deficit does not reflect damage to an attentional mechanism.

In conclusion, there are a number of aspects of BA's performance at odds with the hypothesis that she has a neglect impairment which interacts with spelling at the level of the graphemic buffer. To explain the deficit in terms of an attentional/neglect impairment one needs to hypothesize a spelling-specific, task/level-specific attentional resource which is not word-centred. A more coherent explanation can be offered in terms of incomplete activation of orthographic representations.

2.6.3 Incomplete activation of orthographic representations

This Chapter has, so far, shown BA's data to be inconsistent with current graphemic buffer and neglect dysgraphia hypotheses. This section will provide more positive evidence for an incomplete activation hypothesis and will aim to elucidate the nature of the underlying lexical retrieval mechanisms.

<u>Repetition with training</u>

Aliminosa, McCloskey, Goodman-Schulman and Sokol (1993) outlined one way in which a lexical deficit may be distinguished from an output or graphemic buffer deficit. If the locus of damage is to an item-specific (e.g. lexical) level of representation then providing the patient with training on a set of items might be expected to improve performance for these items but not untrained items. However, if the damage is to a more general processing resource (e.g. reduced buffer capacity/ damaged letter level) then any improvement might generalise to untrained items. This hypothesis was examined in BA.

Procedure. Four matched lists of 20 words were prepared. Words were matched on a one-to-one basis across all four lists for length, frequency, imageability and grammatical class. Words that had been encountered previously in other testing sessions were not used. The aim of this task was to determine whether prior exposure to a word would facilitate the amount of orthographic information that BA was able to obtain. In the first session, BA was asked to write down the 20 words in list 1. If she was unable to correctly write a word then she was asked to copy it from sample. Ninety minutes later she was asked to write to dictation list 1 again together with a novel list (list 2). Since words on list 2 are matched exactly to words on list 1, any superiority of list 1 over list 2 is attributed to an item-specific 'boost' in activation due to training. Items from the two lists were presented in randomised order and BA was again asked to copy from sample any incorrect response. The same process was repeated using two more novel lists. List 3 was presented one week later together with lists 1 and 2. List 4 was presented two months later together with lists 1, 2 and 3.

Results and discussion. The number of letters correct was measured as well as the number of words, since many words showed a clear improvement despite remaining incorrect. For example, *ornament* was misspelled as *vase*, *orma* and *ornment* on three successive occasions. The results are summarised in Table 4.

BA was significantly better with repeated/trained lists compared to the novel lists in 5 out of 6 instances, considering the number of letters correct. Within an incomplete activation framework, practice can be envisaged as increasing the level of activation of trained items (by strengthening connections or increasing resting levels). However, training does not seem to boost activation in general since improvements did not extend to novel/untrained words. According to Aliminosa et al. (1993) this is more consistent with a damage to a word-specific level of representation than a level of representation shared by all words (e.g. letter, allograph levels).

Table 4: The effects of repetition and training at various time intervals: a) number of letters correctly retrieved (out of 135), b) number of words correctly spelled (out of 20).

a)

	Time 0	*90 Minutes*	*1 Week*	*2 Months*
List 1	**70**	103^{**}	90^{**}	97^{**}
List 2		**43**	88^{**}	91^{*}
List 3			**57**	74
List 4				**71**

b)

	Time 0	*90 Minutes*	*1 Week*	*2 Months*
List 1	**8**	9	8	10
List 2		**4**	9^{*}	10
List 3			**3**	6
List 4				**7**

Figures in bold are for novel lists. Statistical comparisons are made between the novel list and the primed lists within a given session. ** *$p < .005$,* * *$p < .05$.*

However, it is not clear from this analysis whether training has boosted a diminished level of activation or reinstated a completely lost representation. If, instead of training, BA is provided with a suitable cue then she may be able to recover more information spontaneously. This is consistent with diminished activation but inconsistent with permanent and complete information loss (e.g. Shallice, 1988; Warrington & Shallice, 1979).

Cueing

Since there is reason to believe that BA's main difficulty lies in lexical retrieval (as opposed to, say, semantic retrieval) orthographic cues were used. Cueing consisted of providing her with single letters from either the beginning or end of the word.

Procedure. Words were given to BA to write to dictation. If after 1 minute she had failed to retrieve any letters then she was presented with progressively more orthographic information until she felt able to retrieve some letters. Letters were presented, one at a time, in either a 'forwards' direction (e.g. s____, sh___, she__, shee_) or in a 'backwards' direction (e.g. ___p, ___ep, __eep, _heep). After each letter, she was given 30 seconds to make a response. If no response was made the next letter was given to her, and so on. There were 108 words for which no initial response was made (64 were forward cued and 39 were backward cued). Although words were not matched on an item-by-item basis there was no difference between the words used in the forwards and backwards conditions in terms of length (5.73 and 5.49), frequency (65.4 and 71.8; from Carroll et al., 1971) or imageability (71% and 79% of items judged to be low imageability).

Results and discussion. In the forwards condition, giving BA 1 or 2 letters resulted in a retrieval attempt in 56% (36/64) of instances. In 16/36 (44%) of these instances she was able to retrieve the whole word correctly. In 11/36 (31%)of these instances she retrieved just a few letters more and in the remaining 9 (25%) instances she produced an unrelated response. In the backwards condition, giving BA 1 or 2 letters resulted in a retrieval attempt in only 10% (4/39) of instances.

Since cueing was often only partially successful, a better measure might be to count the number of letters correctly retrieved. For example, BA was asked to spell *reason* (6 letters) and, after producing no response, she was cued with *r* (1 letter) and she retrieved *eas* (3 letters). This was scored by adding 1 to the total number of letters given by experimenter, adding 3 to the total number of letters retrieved by BA and adding 6 to the total number of letters in words cued. The ratio of letters given to letters retrieved in this instance is 3/1. Table 5 shows the results of this analysis when applied to all words. BA requires significantly less information to be given by the experimenter to elicit a retrieval attempt in the forwards condition relative to the backwards condition ($\chi^2(1)=54.0$, $p<.001$). Conversely, BA is able to retrieve more information herself in the forwards condition relative to the backwards condition ($\chi^2(1)=14.3$, $p<.001$). These results suggest that there is a real effect of cueing over and above the fact that this procedure gives her more time to recover information. If time were the only relevant factor then, if anything, backwards cueing may be expected to be more successful since beginning letters seem to be easier for BA to spontaneously retrieve.

Although this was not included in the analysis, it was noted that on 5 occasions cueing could be successfully applied at 2 different stalling points. For example, when asked to spell *planet* she produced no response, but after the cues *p* and *l*, she wrote down *a* but no other letters. When given the letters *n* and *e* she wrote down *t*. The process of retrieval in BA appears to be very piecemeal.

Table 5: The effect of single letter cueing in terms of number of letters retrieved by BA.

	Forwards	**Backwards**
Number of words cued	64	39
# of letters in words cued	368	214
# of letters given by experimenter	165/368 (44.8%)	163/214 (76.1%)
# of correct letters retrieved by BA	108/368 (29.3%)	33/214 (15.4%)
Ratio of letters retrieved to letters given	0.65 (108/165)	0.20 (33/163)

This experiment has demonstrated that BA has more lexical-orthographic knowledge than she is often able to produce. This supports the hypothesis that orthographic representations are incompletely activated rather than permanently and completely lost from storage. The 'forwards' advantage is consistent with the notion that different parts of the orthographic representation become available at different times. The retrieval of letters at the beginning of a word may enable boosting of the activation of subsequent letters or, alternatively, release them from inhibition. This will be returned to in the Discussion (Section 2.8).

Some previous studies have claimed that cueing may be indicative of an access rather than storage impairment (e.g. Shallice, 1988; Warrington & Shallice, 1979). The notion of access versus storage will be discussed in the next section and particularly with regards to consistency of responding.

Access versus storage and spelling consistency

Warrington and Shallice (1979) proposed a set of criteria for distinguishing between loss of storage of information and a failure to access otherwise intact information (see also Cipolotti & Warrington, 1995; Shallice, 1988; Warrington & McCarthy, 1983, 1987). The idea being that if a representation is lost from storage it should remain inaccessible at different points in time and regardless of task conditions. Thus effects of cueing/priming should have little effect and the patient should have consistent difficulties with the same items on different testing occasions. If a patient has difficulties in accessing an intact representation then cueing/priming may have some effect and the patient should be inconsistent over time.

One way of measuring consistency is to score whether a word is consistently spelled correctly or not. Consistency at a word level may imply complete loss of whole lexical representations. In this instance, the patient may consistently generate no response at all when asked to spell a word on different occasions. However, if there is a permanent but partial level of degradation to a lexical representation then a certain amount of information may be retrieved, but this should not vary across occasions. For example, the patient may consistently produce the response *tob* when asked to spell *tobacco*. In this case, spelling consistency at the level of letter report may be important.

In the total corpus of 1465 words, 154 words had been written on 2 different occasions and 69 words had been written on 3 different occasions. If responses are classified as to whether they are spelled correctly (✓) or not (✗), then BA tended to misspell the same words on different occasions (2 responses: ✓✓=48, ✓✗=35, ✗✗=71; 3 responses: ✓✓✓=21, ✓✓✗=20, ✓✗✗=13, ✗✗✗=15). These values differed significantly from their expected binomial distribution ($\chi^2(2)=44.0$ and $\chi^2(3)=27.2$, $p<.001$). This implies consistency (see McNeil et al., 1994); i.e., the same words tended to be misspelled on different occasions. However, if responses are classified according to whether they contained the same amount of lexical-orthographic knowledge or not

(Table 6), it can be seen that for incorrect responses BA has a tendency to produce different amounts of lexical-orthographic knowledge on different occasions.

Table 6: BA's consistency of responding when the same target word is presented twice (a) or three times (b).

a)

	Correct Consistent	Incorrect Consistent	Incorrect Inconsistent	
	tobacco tobacco	tob tob	tob tobac	
N	48	21	85	(=154)
%	31.2	13.6	55.2	(=100%)

b)

	Correct Consistent	Incorrect Consistent	Incorrect Inconsistent (2 same)	Incorrect Inconsistent (all different)	
	tobacco tobacco tobacco	tob tob tob	tob tob tobac	tob tobac tobacc	
N	21	5	26	17	(=69)
%	30.4	7.3	37.7	24.6	(=100%)

This result is incompatible with a storage impairment that has selectively and permanently damaged all or part of the lexical representations since the level of letter report varies across occasions. However, it might be unwise to describe BA as having an 'access' deficit simply by default. The theoretical and empirical basis of this distinction has been challenged (Forde & Humphreys, 1997; Humphreys, Riddoch & Quinlan, 1988; Rapp & Caramazza, 1993). For instance, Rapp and Caramazza (1993) have pointed out that an effect of cueing can arise from a 'storage' impairment if information has been reduced in activation rather than lost. This alternative explanation is compatible with the results from BA. In order to accommodate some of these criticisms, Warrington and Cipolotti (1996) revised the distinction.

The original distinction between 'storage' and 'access' impairments was essentially framed in terms of damage to 'boxes' and 'arrows' respectively (Warrington & Shallice, 1979). More recently, however, Warrington and Cipolotti (1996) have framed the distinction in terms of qualitatively different impairments to the same underlying system (see also Forde & Humphreys, 1997). Storage impairments are considered to reflect permanent loss of information, whereas 'access' impairments have been described as a temporary unavailabilty of the representations themselves.

Observationally, the latter description appears to 'sum-up' BA's spelling behaviour. In BA's case, unavailability seems to apply to part of the orthographic representation rather than the whole representation. Closer inspection, however, suggests that refractoriness may not be the best characterisation of her impairment. BA shows a significant effect of word frequency which Warrington and Cipolotti (1996) argue is not a characteristic of a refractory impairment. If the refractoriness occurs at a letter level of retrieval, however, then an effect of word frequency could be construed as an incidental impairment. In this case, the more letters that are retrieved the more refractory the system may become and the higher the error rate. However, on this account it is not clear why end letters should be error prone in tasks such as backwards writing and picture-letter judgement. It will be suggested that the notion of gradients of activation over the letters together with a general lowering of activation offers a more satisfactory account. It remains to be determined whether it is possible, empirically and theoretically, to discriminate reduced activation from increased inhibition or refractoriness.

Summary

The results from this section are consistent with the hypothesis that BA has sustained damage to lexical-orthographic representations which results in a reduced ability to activate a letter level of representation. The fact that training improves performance only for trained items is consistent with damage to a lexical/word level of representation. The fact that training increases the number of letters retrieved but has little impact on the number of words retrieved is consistent with damage in terms of reduced flow of semantic-to-lexical-to-letter activation. It is unlikely that BA has selectively and permanently lost all or part of the lexical representations. Her inconsistency in terms of number of letters retrieved and her ability to be cued rule out this strong-form of the storage hypothesis. Both these observations are, however, consistent with a reduced level of lexical activation which fluctuates over time and may be boosted by cueing. Whether this reduced activation reflects a lowering of the activations of the representations themselves (a weak-form of the storage hypothesis) or a reduction in the activation supplied to them, cannot be determined at this point.

It is important to attempt to link this incomplete activation account with BA's serial position effect which was discussed earlier. It is suggested that the serial ordering of letters in spelling may be an emergent property of lexical activation. In skilled spelling, lexical representations may activate letters such that the first letter is initially the most active, the second letter is the next most active, and so on such that an activation gradient or 'competitive queue' is set-up (e.g. Houghton et al., 1994; Rumelhart & Norman, 1982). In BA, a general lowering of this activation gradient may result in some letters remaining above a selection threshold and others falling below it. The important point being that the probability of selection will be a function of serial position. This has been shown to be the case in BA in all spelling tasks which require lexical-semantic spelling.

The next section assesses wether similar serial position effects are found in non-spelling tasks requiring processing of orthographic strings in input. This may shed light both on the locus of BA's impairment and on the relationship, if any, between orthographic processing in input and output tasks.

2.7 Serial Position Effects in tasks with Orthographic Input

It has already been shown that BA produces a linear serial position effect in tasks requiring lexical-orthographic output. This section will investigate whether similar patterns are found in tasks requiring orthographic input. Better performance and a different serial position effect has already been found in one such task - delayed copying. However, delayed copying requires both orthographic input and output, thereby making the results less straightforward to interpret.

The expected pattern of association or dissociation between input and output depends upon whether the same orthographic representations are used for both input and output and the precise locus/nature of BA's lesion. For example, if there is unitary orthographic lexicon for recognition and production (Allport & Funnell, 1981; Behrmann & Bub, 1992; Coltheart & Funnell, 1987) and the representations themselves have been compromised (see Figure 5a) then a similar serial position effect to that found in spelling should be found in tasks requiring orthographic input. Performance in recognition tasks need not be as quantitatively impaired as performance in production (since recognition tasks are generally considered to be easier) although similar qualitative patterns would be expected (i.e. poor performance with ends of words). However, if the lesion affects the retrieval of orthographic representations from a semantic code (Figures 5d and 5e), rather than loss of information from the representations themselves then a dissociation in performance between recognition and production is to be expected since written word recognition does not require obligatory semantic mediation.

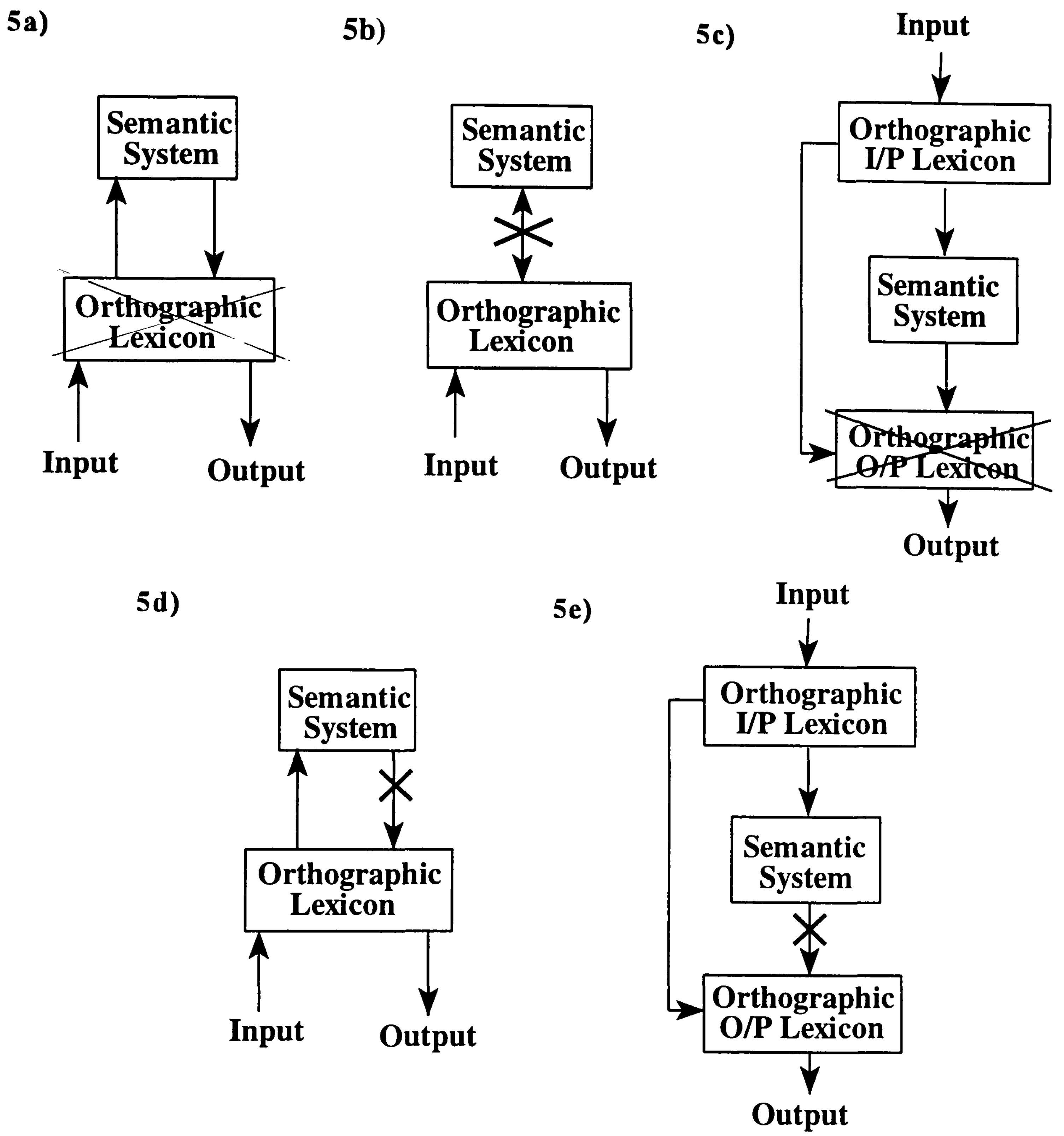

Figure 5: Possible loci of damage (X) within either a unitary lexicon (Figures 5a, 5b and 5d) or a dual lexicon (Figures 5c and 5e) framework.

<u>Lexical decision and serial position</u>

In Section 2.6.2 it was reported that BA was good at lexical decision even when the ends of words had been altered. However, BA may take much longer to process word endings relative to word beginnings in this task and so measures of error rate alone might belie a genuine difficulty with processing word endings in orthographic input. Therefore, a similar experiment was carried out taking reaction time measures.

Method. Forty 8 letter words with a low N-count were selected. From this set, 120 nonwords were created by substituting the initial, medial or final letter (e.g. computer → *homputer, combuter, computem*). All nonwords were orthotactically/phonotactically plausible. The experimental items consisted of 240 stimuli (see Appendix 2); 120 nonwords (40 initial, 40 medial and 40 final mismatches) and 120 words (the basic set of 40 words was repeated three times). Items were presented centrally, in randomised order, in lower case letters on a computer screen following a 1000msec fixation. The subject was required to respond as fast and accurately as possible by making a keypress (the dominant hand used for 'no' responses). The stimulus remained present until a response was made. There were three blocks of 80 items following a practice block of 10 items.

Results and discussion. BA's results and those of 10 student controls and 1 age and education matched control are reported in Table 7. Outliers which were more than 3 standard deviations above the mean were treated as errors. BA produced 4 outliers and the controls produced between 2 and 6. The control subjects were marginally worse at detecting spelling errors in the middle of words (in terms of errors and response times) but there was no difference between detecting spelling errors at the beginning versus the end of words. This is consistent with previous findings in the literature (e.g. Holmes & Ng, 1993). BA showed a similar pattern to the controls with regards to the number of errors made (falling at the low end of the normal range). In terms of response times, she was actually faster at detecting errors in the middle relative to other positions. This could be due to a speed-accuracy tradeoff and/or a tendency to treat these items as if they were real words (and hence respond faster). However, the most important condition is BA's ability to detect spelling errors at the ends of words. In this respect her performance was similar to the controls: she produced very few errors and was no slower in this condition relative to the word-initial condition. Thus BA does not show the same serial position effect in lexical decision (an orthographic input task) as she does in spelling tasks (orthographic output tasks). Although BA was considerably slower than the student controls it cannot necessarily be concluded that she is impaired since these controls were not matched. Indeed, the age and education matched control did produce response times of a more similar magnitude to BA.

Table 7: Performance of BA and controls on a lexical decision task, varying the serial position of the spelling error.

	Errors				**Response Time (msec)**			
	Nonwords (/40)			Words	Nonwords			Words
	Initial	Medial	Final	(/120)	Initial	Medial	Final	
BA	3	12	5	13	1851	1535	1842	1166
Student Controls:								
Mean	1.2	2.9	2.3	7.2	600	611	600	585
Min.	0	0	0	2	488	493	471	486
Max.	5	9	5	18	750	763	743	722
Matched Control:	0	2	1	6	1132	1255	1226	1256

One potential difficulty with this experiment is that the words that were used to create the nonwords were presented during the task. It is possible that presentation of the real word may prime the lexical representation, enabling more efficient rejection of the nonwords. However, similar results are found even if the nonwords are derived form words other than those used as targets. The experimental procedure was the same as before, except that 96 different 5 letter words were used (with no repetitions) and a set of 96 nonwords were created from a different pool of low N-count 5-letter words (32 left, middle and right changes). BA's error rates for left middle and right changes were 9% (3/32), 6% (2/32) and 15% (5/32), and for the real words 22% (21/96). The corresponding RT's were 2477, 1985 and 2274 msec for the nonwords and 1123 for the words.

The missing letters task

The task of filling-in a missing letter of a word fragment (e.g. *_nail* [snail], *gr_sshopper* [grasshopper]) may proceed using only lexical-orthographic information, i.e. non-semantically (Figure 6). This task may, therefore, provide information on the integrity of orthographic representations rather than on the ability to retrieve orthographic representations from a semantic code. If BA's difficulty lies in the latter then performance on this task should be good and producing letters at the end of the word should be relatively spared (see again Figure 6). If, however, BA's main difficulty lies in loss of information from the orthographic representations themselves then performance on this task should be poor and end-letters should remain a source of difficulty.

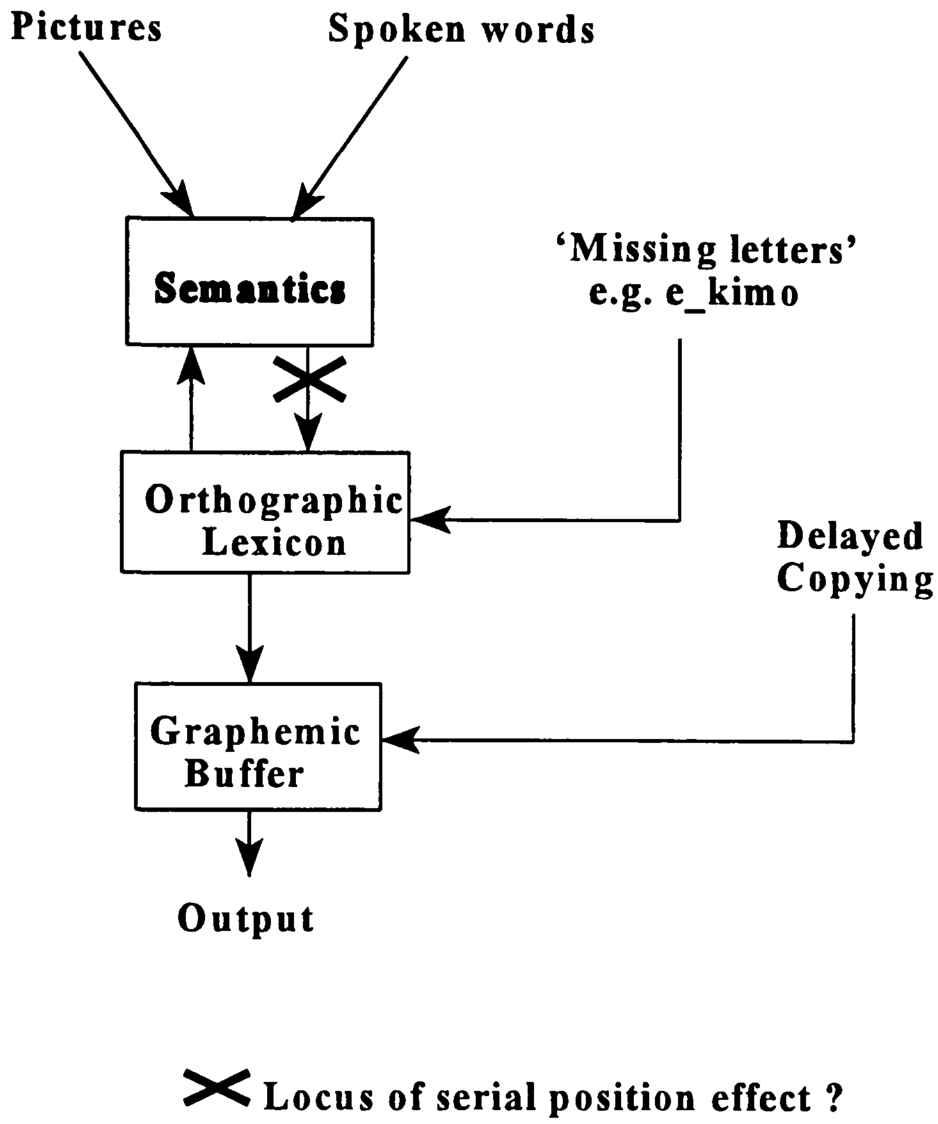

Figure 6: Flow diagram showing how different tasks depend on different components of the spelling system. (For simplification, a unitary orthographic lexicon is shown).

In the first test, BA was provided with a concrete word with one letter missing and asked to fill the letter in. In order to examine any semantic effects in this task the same word fragments were also given to BA but this time paired with a disambiguating cue (a picture or spoken word). In order to confirm that performance on this task is not critically dependent on semantics, a second test was given using abstract words which are normally very difficult for BA to spell (e.g. *so_ium* [sodium], *roma_ce* [romance]), with or without an additional cue (a spoken word).

Method. For the first test, 300 line drawings were selected. Most pictures came from the

Snodgrass and Vanderwart (1980) set. The names of four of the pictures were changed from American into British English (alligator-crocodile, clothespin-peg, lock-padlock, baby carriage - pram). The position of the missing letter was chosen by random assignment. Word frequency (Carroll et al., 1971), word length and N-count (in this instance, the number of words that could be formed by filling-in the missing letter) were also recorded. The pictures were arranged randomly onto 29 sheets of A4 paper. Underneath each picture the orthographic cue was written in large (size 24) lower case letters. In the spoken cue condition, BA was presented with a spoken word (e.g. "snail") immediately followed by a written fragment (*_nail*). In the 'no cue' condition only the written fragment was presented and BA was instructed to complete it with a single letter so that it resulted in any real word. The 300 fragments were presented in all 3 conditions (i.e. a total of 900 items). One hundred items were presented in each session and the condition was varied between sessions.

For the second test, 190 abstract words were chosen. Words were matched on a one-to-one basis to a subset (N=190) of the concrete words used above. Items were matched for word frequency (Carroll et al., 1971), N-count, grammatical class (all nouns), word length and position of missing letter (e.g. *ener_y* [energy] was matched to *circ_e* [circle]). All items had an N-count of one to avoid situations where a fragment could be completed to give either an abstract or concrete word (e.g. *gon_* → *gong* (concrete) or *gone* (abstract)). Each item was presented in two conditions: immediately after a spoken word (i.e. a semantic cue condition) and on its own (i.e. a no-cue condition). Blocks of 95 words were presented with the conditions rotated over two sessions according to an AB-BA design.

Results. Table 8 shows BA's scores and error types in the three conditions for the concrete items. For a patient who is severely dysgraphic in almost all other spelling tasks, her performance in this task was remarkably good. BA did not write down several alternative spellings and then use her unimpaired lexical recognition system to judge which one was correct. Her performance on this task was fluent with few self-corrections and she claimed to find the task easy. She was able to retrieve missing letters for many uncommon words (e.g. *ostric_* [ostrich], *tr_wel* [trowel]) even when no other cue was provided. In fact, her performance did not differ significantly between conditions ($\chi^2(2) = 4.86$, *ns*). Her scores are slightly lower than those obtained from 3 age-matched controls with similar educational backgrounds (no-cue condition: 95.0%, 99.0% and 99.0%), although these subjects may benefit from being able to use phonological constraints which are unavailable to BA.

Table 8: Scores and error types for missing-letters task with concrete words.

	Picture		**Spoken word**		**No Cue**	
	N	%	N	%	N	%
SCORE (/300)	267	89.0	275	91.7	282	94.0
ERRORS						
Letter repeated	14	42.4	8	32.0	12	66.7
ax_ (axe) → axa						
Unrelated letter	7	21.2	10	40.0	3	16.7
bro_m (broom) → broum						
No Response	6	18.2	3	12.0	3	16.7
Lexical substitution	5	15.2	3	12.0	(37)	
f_y (fly) → fry						
Lex sub. + repeat	1	3.0	1	4.0	(3)	
be_r (bear) → beer						

Lexical substitutions in the no-cue condition are not classed as errors because BA was instructed to make any real word in this condition. However, these numbers give an indication of how many lexical substitutions she would make in the other conditions if she were to ignore the picture/spoken word cue. It may therefore be concluded that presenting BA with a cue in this task reduces the number of lexical substitutions but does not facilitate retrieval of the correct letter since the overall score is not improved. The orthographic cue may generate a cohort of lexical candidates and the semantic system may be used in this task to select the correct one.

Comparing the words which BA got right with those that she got wrong, there was no significant effect of word frequency (picture: t=1.28, *ns*; spoken: t=1.90, *ns*; no-cue: t=1.76, *ns*) and an effect of word length was found only in the no-cue condition (picture: t=0.84; spoken: t=1.47, *ns*; no-cue: t=3.06, $p<.01$). That is, longer words are easier to match to a lexical representation but only in the absence of any additional information.

BA's ability to provide the missing letter of an abstract word was also good. In fact, it was not significantly different from concrete words. In the no-cue condition she scored 86.3% (164/190). Her errors consisted of nonword responses (N=9) and failures to give any response (N=17). Lexical substitutions were not found because an N-count of 1 was used throughout. With spoken word cues she scored 90.5% (172/190; 13 nonwords and 6 no responses). Thus, presenting the fragment with a spoken word cue did not produce a significant effect ($\chi^2(1) = 1.65$, *ns*). Her scores for the matched subset of concrete words were 91.6% (174/190) and 90.5% (172/190) in the no-cue and spoken word cue conditions respectively. Her abstract word score is not substantially worse than those obtained from 3 age/education matched controls (no-cue condition: 93.6%, 98.9% and 96.8%).

BA does not exhibit any notable serial position effect in this task (Table 9). BA's good performance in spelling missing letters at the ends of words supports the hypotheses that (1) her serial position effect in lexical-semantic spelling tasks arises from a failure to activate lexical/word representations from the semantic system; when the input code to the orthographic lexicon is orthographic (as in this task) she does not show this serial position effect, and (2) that she possesses more lexical-orthographic knowledge than she is often able to retrieve during spelling attempts.

Table 9: Serial position effects (% error) in missing-letters task.

	Position in Word				
	1	**2**	**3**	**4**	**5**
Concrete	3.8 (8/210)	10.0 (15/150)	10.0 (18/180)	14.3 (21/147)	6.6 (14/213)
Abstract	10.3 (7/72)	12.1 (8/66)	10.0 (9/90)	16.2 (12/74)	11.5 (9/78)

2.8 Discussion

This chapter has documented an acquired dysgraphic patient who produced a linear serial position effect in all spelling tasks requiring lexical access from the semantic system. Spelling tasks which do not require semantic mediation such as delayed copying and filling-in missing letters (e.g. completing *so_ium)* do not show this serial position effect and performance is considerably better in these tasks. Similar serial position effects were found for different word lengths and different kinds of errors. The serial position effect was hypothesised to arise from a reduction in the amount of activation delivered at a letter level of representation as a result of damage to higher levels of representation. This damage is not well characterised by a permanent loss of information since cueing is beneficial and the amount of information retrieved varied on each retrieval attempt. Before considering how these results may constrain models of lexical processing, a comparison with other dysgraphic patients in the literature will be made.

Comparisons with other Patients

It was argued above that BA differs from previous patients with damage ascribed to the graphemic buffer or neglect dysgraphia (see Sections 1.2.2 and 1.2.4) since she produces different types of errors (many fragments), shows a different serial position effect and does not have the same difficulty with all spelling tasks. Two other patients, however, have been reported who produce a similar serial position effect to BA (see Section 1.2.3), although different interpretations were offered in both instances. Katz (1991) suggested that his patient's errors arose from temporal decay from the graphemic buffer, whereas Bub et al. (1987) argued that his patient's errors arose from temporal decay from an allographic buffer since performance was better for oral compared to written spelling. Temporal decay is considered unlikely in BA because she shows equivalent patterns in forwards and backwards spelling, her performance in delayed copying is good (which requires temporal storage) and her performance in picture-letter matching is poor (which requires little temporal storage). Observationally, at least, the hypothesis of poor lexical retrieval in BA is supported. BA concentrates intensely, often pausing after each few letters and often giving no response at all despite frequently being able to demonstrate understanding of the word (e.g. by gesticulating).

A very similar explanatory framework to the one outlined here was proposed by Ellis and colleagues (Ellis, Miller and Sin, 1983; Miller & Ellis, 1987) to explain the performance of their dysgraphic patient. RD produced spelling errors which preserved some lexical knowledge (e.g. thumb→*thunb*) suggesting a dysfunctional lexical-semantic route. However, in contrast to BA, no serial position effect was found. The authors assume that activation spreads from a semantic representation to a word node, and from a word node to a number of letter nodes: a reduction in the amount of activation supplied to the letter nodes results in incorrect letter selection. There are a number of reasons why there could be a discrepancy between BA and RD. One possibility is that RD may have reduced activation of lexical representations but the nature/locus of the lesion may differ to BA. For instance, in a framework such as that of McClelland and Rumelhart (1981), BA may have reduced activation for particular positions whereas RD may have a slight lowering of activation at all positions. Alternatively, RD's deficit may reflect damage which is not related to incomplete activation of lexical representations. For example, a difficulty in selecting allographs since many letter substitutions were apparently between graphically related letters (e.g. m/n). It is not possible to determine which , if any, of these explanations is the most feasible. Nevertheless, the study of BA has demonstrated unambiguously that a linear serial position effect can, in some patients, arise from difficulties in lexical retrieval. These results may then be used to constrain models of lexical processing.

Implications for Models of Lexical Processing

Black-box and arrow architectures in which the mechanisms of processing are not specified cannot readily provide a motivated account for the existence of serial position effects in spelling (see Shallice et al., 1995). In the case of our patient, these architectures can enable us to locate the locus of BA's serial position effect but without a description of how letters become activated the model cannot explain why such an effect should be found.

One model which does offer an explanation of how words/letters are activated is the logogen model (e.g. Morton, 1969; 1980). In this model, each word has an associated logogen which fires when enough evidence consistent with that word has been gathered. The activation level of each logogen may vary as a function of word frequency and recency. Once a threshold has been reached then all the letters corresponding to the word become available in a response buffer. If the threshold is not reached then none of the letters become available. However, to assume lower activation or a higher threshold at the word or logogen level does not explain BA's pattern where only certain letters are available and others are not. Thus, it is possible to identify one constraint on lexical processing which is needed in order to account for our data. Separate word and letter levels of representation must have their own levels of activation and thresholds. To have activated the right word node does not guarantee activation of the corresponding letter nodes.

The activation of letter nodes may, to some extent, depend on the amount of activation in higher levels of representation. Thus, letter activation may depend on the frequency of the word and its imageability. However, another property of letter activation stems more directly from BA's serial position effect. The results suggest that the level of activation of letter nodes may also be related to letter position. It is this property of lexical activation which gives rise to the serial position effect found in BA and is an important constraint on models of lexical processing.

There are several models in the literature which may have the potential to explain BA's pattern. Positional slot models based on the reading model of McClelland and Rumelhart (1981; see Margolin & Goodman-Schulman, 1992, for spelling) may be lesioned at the letter level to produce serial position effects which are related to ordinal positions. If it is assumed that position *n+1* has been damaged more than position *n* (where *n*=1,2,3...) then this would produce the serial position effect observed in BA. It seems quite unlikely, however, that such a pattern would emerge if all positional slots were initially equally susceptible to the effects of brain-damage. Instead, brain-damage may have revealed a pre-morbid activation gradient. One possibility is that positional slots have different levels of activation because of a frequency effect: beginning positions may have lower thresholds because they are used more often. For example, all words in the lexicon will use position 1 but only words longer than 3 letters will use position 4. Positional slots may also have different levels of activation in order to facilitate serial retrieval of letters. If letters in beginning positions become available before letters at later positions this may help in the production of letters in the correct order.

There are, however, a number of difficulties with this model. Letter duplication is uneconomical and leads to some counter-intuitive predictions (e.g. *table* and *able* would have no letters in common in this model). The model also cannot easily explain the task-dependent existence of different serial position effects in BA. The model also fails to account for other serial position effects reported in the literature. Neglect dysgraphia cannot be explained unless one assumes that the slots are ordered according to word-centre (i.e. ..n-2, n-1, n, n+1, n+2,.. n= word centre), but then this cannot account for ordinal serial position effects. Without further specification of the model, it also fails to predict the bow-shaped function found in graphemic buffer patients.

The model of Rumelhart and Norman (1982) postulated that letter activation would be a function of letter position (see Section 1.4.2). The activation gradient being established through learned inhibitory links at the letter level. A general lowering of activation may result in fragments if spelling simply stops when the activation of the letters falls below some threshold. However, the model is unsuited for modelling other aspects of spelling. Since the inhibitory links are word specific the model cannot represent words which contain the same combinations of letters (e.g. *slit*, *list*).

The competitive queuing model of Houghton et al. (1994) and Shallice et al. (1995) also assumes that letter activation is a function of letter position. Rather than inhibitory links, though, the ordering of letters in a word is determined by the strength of weights to two sequencing nodes (I and E nodes). The I-nodes are primarily responsible for activation of letters at the beginning of words and the E-nodes for letters at the ends of words. One possible lesion to the model, therefore, could be to the E-nodes (or connections to/from them). This would have the effect of reducing the overall amount of activation delivered to the letter level, but particularly for letters at the ends of words. However, other lesions may also produce a similar result. For instance reducing the amount of activation that both nodes supply to the letter level. This would have the effect of reducing the activation level of the whole 'queue' so that only the initial letters are activated above threshold. The model may also be able to explain other aspects of BA's performance. For instance, the fact that cueing is particularly effective when it consists of letters at the beginning of a word. This is consistent with this model in that the selection of letters towards the end of a word may be contingent on being able to select letters earlier on in the word. Furthermore, the model is able to offer an account of other patients reported in the literature. Houghton et al. (1994) found that adding noise to the letter level reproduced many phenomena associated with damage to the graphemic buffer, including single letter errors, a strong length effect and a bow-shaped serial position effect.

The model of Houghton et al. (1994) is implemented and discussed in full in Chapter 4.

What is important, at this point, is to recognise that the potential of all these models to explain BA's pattern resides in the fact that they enable letter activation to be a function of serial position. This may serve as the driving mechanism for serial recall in skilled spelling and may be the mechanism which underpins the so-called 'graphemic buffer' of traditional models of spelling. It should also be noted that the models of Houghton et al. (1994) and Rumelhart and Norman (1982) make a different claim with regards to the encoding of serial position than, say, the model of McClelland and Rumelhart (1981). Namely that the serial order of letters in a word is an emergent property of lexical activation and is not explicitly encoded in any position-based representational units.

The Input-Output Distinction

BA shows a dissociation between her ability to process orthographic representations for input and output. In output/spelling tasks she is generally severely impaired and shows a difficulty in retrieving letters at the end of a word. In input/recognition tasks she shows little or no impairment and no difficulty with letters at the end of a word. If anything, she shows some difficulty with word middles, which is the normal pattern (e.g. Holmes & Ng, 1993). Although recognition is often considered to be easier than production, the extent and nature of the dissociation is large enough to discount an explanation based purely on task difficulty. It suggests, instead, that brain damage has selectively impaired a mechanism dedicated to processing lexical-orthographic representations for output.

In terms of models of lexical processing, two hypotheses seem unlikely. Firstly that there is a unitary lexicon for both recognition and production and that loss of information from the representations within this lexicon are giving rise to BA's dysgraphia (see Figure 5a). This is unlikely because she shows no evidence of an associated impairment in recognition tasks, such as lexical decision. The second hypothesis that is unlikely is a lesion to bidirectional links connecting a unitary orthographic lexicon to the semantic system (Figure 5b). This hypothesis predicts good performance in written word recognition (e.g. lexical decision) but poor performance on written word comprehension tasks (e.g. picture-word matching), which is not found. The other hypotheses are hard to distinguish between: namely that there is damage to the representations in an output lexicon but not an input lexicon (Figure 5c) or that there is a difficulty in retrieving lexical-orthographic representations from a semantic code but not from an orthographic code (Figures 5d and 5e). BA's good performance on the missing letters task is not readily explicable by selective damage to representations in an output lexicon (Figure 5c), since this task is assumed to tap this component. This hypothesis could only be accommodated if the orthographic input lexicon could be used to spell in this task; for example, if it were to connect to output procedures (i.e. allographic and graphic motor pattern selection) via an intermediate component (such as the visuo-spatial sketchpad in Baddeley's, 1986, model), thereby circumventing the orthographic output lexicon.

Therefore, it seems reasonable to conclude that the locus of BA's damage is to the procedures which access lexical-orthographic representations from a semantic but not a visual/orthographic code, in either a unitary or dual lexicon (Figures 5d and 5e). On the basis of the evidence that has been presented, it is not possible to determine which of these alternatives is correct. However, the unitary account (Figure 5d) is favoured over the dual lexicon account (Figure 5e) because (a) it is more parsimonious (b) on balance, the weight of evidence from cognitive neuropsychology points to a unitary orthographic lexicon (Allport & Funnell, 1981; Behrmann & Bub, 1992; Coltheart & Funnell, 1987; but see Monsell, 1987, for an alternative view).

This chapter has assumed that lexical-orthographic representations used in spelling consist solely of units corresponding to words (or morphemes) and single letters. The next chapter will investigate whether other representational units may exist.

3. THE STRUCTURE OF ORTHOGRAPHIC REPRESENTATIONS

3.1 Introduction

Chapter 2 presented a single case study of a dysgraphic patient whose difficulty was attributed to a failure to adequately activate representations in the orthographic lexicon. This Chapter will extend this work by investigating whether orthographic representations in spelling consist of representational units other than the single letter and whole word. Specifically the Chapter will examine evidence for ortho-syllables and consonant-vowel encoding.

There is some evidence for the claim that letters are marked for consonant-vowel (CV) status. Preservation of CV status in letter substitution errors has been found in both transparent orthographies (Caramazza & Miceli, 1990; Cubelli, 1991; Schonauer & Denes, 1994) and opaque orthographies (Jonsdottir et al., 1996; Kay & Hanley, 1994). Thus consonants tend to substitute for consonants (e.g. table→*taple*) and vowels tend to substitute for vowels (e.g. table→*tuble*). Patients who make errors almost exclusively on vowels (Cubelli, 1991) or consonants (Kay & Hanley, 1994) have also been documented. This double dissociation suggests that this effect is not an artefact of task difficulty, but reflects different representational properties associated with each.

The question of whether ortho-syllables exist in spelling, is more controversial with one study providing relatively strong evidence (Caramazza & Miceli, 1990) and two studies claiming to provide evidence against (Jonsdottir et al., 1996; Kay & Hanley, 1994). The issue hinges on whether the effect observed by Caramazza and Miceli (1990) arises because of a transfer of information from phonological syllables in a phonological buffer to the orthographic system or whether it reflects the presence of ortho-syllables in orthography itself. The effect may not have been observed in English speaking patients (Kay & Hanley, 1994; Jonsdottir et al., 1996) because the transfer from phonology to orthography is less efficient owing to the opaque nature of English orthography. The evidence from BA could be informative because, besides being an English-speaker, she has severely impoverished sound-to-spelling skills, thus reducing the possibility of a phonological artefact.

An alternative explanation to apparent effects of ortho-syllabic structure and CV status is that this may not reflect the existence of explicit representational units encoding ortho-syllables or CV status. One 'reductionist' account is that these effects arise out of statistical regularities in the language. One way in which statistical regularities may be encoded is in terms of frequency sensitive multi-letter units such as bigrams or trigrams (e.g. Brown & Loosemore, 1994, Seidenberg, 1987). Thus, an error such as *table* → *tCble* (C = a consonant) may be prevented by knowledge that not many words contain *tCb* sequences.

The data that will be analysed in this section was obtained from patient BA (see Section 2.2 for case details). The error corpus that will be analysed consists of the writing-to-dictation corpus (N=1465) that was described in Chapter 2, together with a further 535 responses which were collected in subsequent studies (June 1996 to February 1997). The patient's performance was observed to be relatively unaltered in this period and the same error types were produced as in the earlier investigation. This corpus is listed in the Appendix.

3.2 Preliminary Analysis

BA's corpus of 2000 responses contained 188 nonword errors which preserved length to within 1 letter. BA's corpus also contained 85 fragments which were orthographically related to the target word (e.g. arrest →*arra*) and contained single letter errors. Of these 273 responses, 53 contained more than 2 single letter errors or could not be unambiguously described in terms of single letter errors and were excluded from the analysis (e.g. dress→*drad*, costume→*coster*, secret→*senial*). The remaining 220 responses contained 269 single letter errors which were scored according to error type and whether the error occurred on a consonant or vowel. Table 10 shows the results of this analysis. Errors were classified according to parsimony; thus, the error apricot→*aprocit* was classified as an exchange error although it could conceivably be described as two separate single letter substitutions. BA produced few movement errors (transpositions, shifts and exchanges). There was a trend towards producing more errors on consonants than vowels, although the effect was not pronounced. If BA was reliant on phoneme-grapheme conversion for spelling then more errors on vowels than consonants may be expected because there are more ways of mapping a sound to spelling for vowels than for consonants (Hanna, Hanna, Hodges & Rudorf, 1966). Moreover, of the 220 responses only 11% (25/220) were phonologically equivalent to the target (e.g. ribbon→*ribben*, tobacco→*tobb*).

This analysis provides the basis for a more detailed investigation of the effects of orthographic structure.

Table 10: Distribution of single letter error types made by BA and proportion of errors made on consonants and vowels.

	Errors (C+V) % N	CV Distribution C % N	V % N	Example
Substitutions	51.3 (138)	52.8 (73)	47.1 (65)	hold → *hald*
Omissions	27.9 (75)	65.3 (49)	34.7 (26)	golf → *gof*
Additions	12.6 (34)	58.8 (20)	41.2 (14)	swim → *swimp*
Transpositions†	4.5 (12)	45.8 (5.5)	54.1 (6.5)	lawnmower → *lawnmowre*
Shifts	2.2 (6)	50.0 (3)	50.0 (3)	autumn → *auntum*
Exchanges†	1.5 (4)	25.0 (1)	75.0 (3)	apricot → *aprocit*
MEAN		56.3 (151.5)	43.7 (117.5)	

† Transpositions and exchanges were classified as half errors on each participating letter.

3.3 CV status

The existence of consonant and vowel status may be a prerequisite for the formation of supra-segmental structures such as ortho-syllables (e.g. Caramazza & Miceli, 1990). It is generally assumed that there is not a one-to-one correspondence between consonant-vowel structure in phonology and orthography. For example, the word *thumb* would have the consonant-vowel structure CVC in phonology but CCVCC in orthography. Also, there are occasionally instances in which a letter may take the role of either an orthographic consonant or vowel depending on context (e.g. the letter Y in *yacht* [CVCCC] and *rhythm* [CCVCCC]). The corpus of substitution and transposition errors considered below did not contain ambiguous letters and only the letters A, E, I, O and U were classified as vowels for the purpose of this analysis.

There are two strands of evidence which have been put forward to support the consonant-vowel distinction in spelling: (1) spelling errors preserve CV status (e.g. Caramazza & Miceli, 1990) and (2) the ability to spell consonants or vowels may be selectively impaired (e.g. Cubelli, 1991). These hypotheses were examined in BA. The evidence from this patient could be informative because it is unlikely that any consonant-vowel effects could arise from phoneme-grapheme conversion.

Letter substitutions

Of the 138 single letter substitutions, consonants substituted for consonants on 64 occasions and vowels substituted for vowels on 57 occasions. Thus, CV status is preserved in 87.7% (121/138) of substitutions. Letter substitutions could be explained, within Caramazza and Miceli's (1990) framework, by a loss of information at the identity tier but not the CV tier, as below:

CV tier	CVCVCV	→	CVCVCV	→	CVCVCV
Identity tier	c a m e r a		c m e r a		c o m e r a

BA's level of preservation of CV status is comparable to the English-speaking patients reported by Kay and Hanley (1994) and Jonsdottir et al. (1996) who preserved CV status in 92.9% and 92.0% of substitutions, respectively, and the Italian patient reported by Schonauer and Denes (1994) who preserved CV status in 87.3% of substitutions. The Italian patients reported by Caramazza and Miceli (1990) and Cubelli (1991) preserved CV status in 99.3% and 98.8% of substitutions respectively.

Preservation of CV status does not appear to be mediated by other factors (e.g. phonological or graphic similarity). Vowel-vowel substitutions are necessarily closely phonologically related. However, the same need not apply to consonant-consonant substitutions. Indeed only 31% (20/63) of C-C substitutions were between phonemes differing by one phonological feature (e.g. d/t, l/r). A slightly higher proportion of the substituted consonants were classed as graphically related (41%; e.g. l/t, n/r), but the effect was not striking and was lower than the 61% reported by Kay and Hanley (1994) in their graphemic buffer patient. Preservation of CV status does not appear to be related to letter anticipations or perseverations. Of all the substitutions, 29.7% (41/138) consisted of letters found elsewhere in the word (23 anticipations, 18 perseverations). In contrast, the graphemic buffer patient, LB (Caramazza & Miceli, 1990) substituted letters from elsewhere in the word on 68% of occasions.

The letter substitutions on the missing letters task (see Section 2.7) were analysed in a similar fashion. Letter substitutions preserved consonant-vowel status on 77.9% (67/86) of occasions.

Even though the probability of preserving CV status in BA and other patients is high, it is worthwhile to consider the likelihood that CV status could be preserved by chance. The alphabet consists of 21/26 (80.8%) consonants and 5/26 (19.2%) vowels. However, it would seem inappropriate to use these values to estimate the probability that CV status could be preserved by chance since not all letters are equally represented in actual spellings. In fact, there is a tendency for some vowels to be over-represented (e.g. the letter 'e') and many consonants to be under-represented (e.g. the letter 'x'). In order to calculate letter frequencies, 9996 different words were obtained from the Oxford Psycholinguistics Database (Quinlan, 1992). Words were selected according to the following criteria: inflected forms were excluded (e.g. -ing, -s), words containing a hyphen or apostrophe were excluded (e.g. half-way, don't) and a Kucera and Francis (1967) frequency greater than 2 (to prevent the list from being unmanageably large). The total number of occurrences of each letter was counted. It was found that consonants made up 61.28% of letters, and vowels made up the remaining 38.72% (see Appendix 3)[6]. That is, selecting a letter randomly from a sample of different words there is an approximately 60% chance of it being a consonant and a 40% chance of it being a vowel. Thus, BA's error rates for substituting consonants (52.8%) and vowels (47.2%) are similar to that expected from their statistical 60/40 distribution in English orthography. That is, there is no evidence for a selective impairment for spelling consonants versus vowels.

However, the probability that a consonant will substitute for a consonant and a vowel will substitute for a vowel is given by:

$$(0.6128 * 0.6128) + (0.3872 * 0.3872) = 52.54\%$$

Using this estimate to calculate the expected values for a chi-square test, it can be seen that BA's preservation of CV status in writing to dictation is significantly higher than that expected by chance ($\chi^2(1)=66.19$, $p<.001$), and similarly for the missing-letters task ($\chi^2(1)=21.24$, $p<.001$).

Letter transpositions

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[6] Baddeley, Conrad and Thomson (1960) also scored how often each letter of the alphabet (and bigram) is encountered in a sample of written text. Their word corpus was derived from newspaper stories so that certain words were heavily over-represented (e.g. the, and, then). However, they found a similar proportion of consonants (61.74%) to vowels (38.26%).

Other dysgraphic patients in the literature have a tendency to swap C-C or V-V letter pairs (e.g. Caramazza & Miceli, 1990; Jonsdottir et al., 1996). In BA, errors in which the order of letters were swapped were rare and were usually accompanied by other errors. BA made four exchanges of nonadjacent letters (e.g. apricot→*aprocit*), all of which were between C-C or V-V pairs. She made 12 transpositions of adjacent letters (e.g. fear→*fae*) but only 3 of these (25.0%) were between CC or VV pairs. However, 4/12 (33.3%) of the other transpositions were ambiguous because the transposed consonant of the C-V pair may take the place of an omitted consonant (e.g. planet→*palet*) as below:

CCVCVC	→	CCVCVC	→	CCVCVC	→	CVCVC
p l a n e t		p l a e t		p a l e t		p a l e t

If one accepts these errors as preserving CV status then 69% (11/16) of her misorderings preserve CV status. This is comparable to the patients reported by Caramazza and Miceli (1990) and Jonsdottir et al. (1994) who preserved CV status in 80% and 62% of misorderings respectively.

In summary, BA has a tendency to preserve CV status in single letter substitutions and transpositions. In the case of substitutions, at least, CV status is more likely to be preserved than expected by chance, even assuming sensitivity to letter frequencies and does not seem to be mediated by another variable (e.g. graphic/phonological similarity) or strongly associated with letter anticipation/perseveration. Thus, in order to explain BA's preservation of CV status one may need to postulate the existence of representational units other than the single letter (e.g. consonant and vowel 'nodes') and/or representational units larger than the single letter (e.g. ortho-syllables) which specify which letter combinations are permissible.

3.4 Ortho-syllables

Ortho-syllables are supra-segmental structures which group together sequences of letters (and/or consonants and vowels), and hence specify which letter combinations are orthotactically legal. They differ from other multi-letter units such as bigrams/trigrams in a number of respects. Firstly, ortho-syllables specify not only which letter combinations are permissible but also at which positions they are permissible. Trigrams/bigrams specify which letters can neighbour one another (e.g. *nt* is a legal bigram) but not, for example, that *nt* can only be found at word/syllable endings (e.g. Brown & Loosemore, 1994; Seidenberg, 1987). Secondly, ortho-syllables may themselves have an internal structure consisting of an onset (initial consonants), a nucleus (vowels) and a coda (final consonants).

There appears to be little consensus in the literature over the precise definition of an ortho-syllable. Caramazza and Miceli (1990) suggested that ortho-syllables should be defined only in terms of permissible consonant and vowel sequences and not on actual letter combinations. Taft (1979) suggested that the first ortho-syllable should capture as many consonants as is orthotactically possible (e.g. *figure* would be syllabified as *fig.u.re* or *fig.ur.e*), whereas others (e.g. Badecker, 1996; Prinzmetal et al., 1986) would syllabify it according to onset maximisation (i.e. *fi.gu.re*). Another possibility is a more strict comparison with phonology in which, for example, the final-'e' would be part of the preceding vowel (e.g. *fi.g[u-e]r*). There are many other unclear cases. For instance, the 'CV' digraph *qu* might be an onset unit since it must necessarily be followed by a vowel, and *q* generally cannot be followed by any other letter.

The definition of ortho-syllables used here is based on Badecker (1996) and is analogous to that used for phonological syllables, such that the onset of a syllable should contain as many consonants as orthotactic and morphological constraints allow. Thus *phantom* would be ortho-syllabified as *phan.tom* since *phant.om* does not maximise the onset of the second syllable and other syllabifications (e.g. *pha.ntom*) may result in illegal letter sequences in onset or coda positions. Most English words may be assigned an ortho-syllable structure in a straightforward manner. However, some syllabifications require further assumptions. It is assumed that words containing the letter Y are syllabified as they would be in phonology (e.g. *body* is syllabified as *bo.dy*), and thus the assignment of CV status to the letter Y will be context dependent (e.g. *body* [CVCV], *yacht* [CVCCC]). There are, however, a number of discrepancies between phonological and orthographic syllabification. It will be assumed, where necessary, that 'final-e' is ortho-syllabified with preceding consonants (e.g. *page*→*pa.ge*; Badecker, 1996). It will also be assumed that cases in which essentially the same CV structure may represent a different number of phonological syllables (e.g. *heard* [1 phonological syllable] versus *beard* [2 phonological syllables]) will be syllabified according to the least number of ortho-syllables (see Badecker, 1996; Prinzmetal, Hoffman & Vest, 1990).

If BA does possess ortho-syllable type units then her spelling errors may be expected to result in letter sequences which can be parsed into legal ortho-syllables.

<u>Orthotactic legality</u>

Of the 220 responses containing single letter errors which have been considered in the analyses so far, 99.5% (219/220) had a legal CV sequence, in that the CV sequence of the nonword response was shared by at least one other real word in the corpus. The illegal response being *crddle* [cradle]. Furthermore, 95.5% (210/220) of the nonword responses consisted entirely of legal letter sequences. A strict scoring criteria was used, in that letter sequences were classed as illegal if they occupied an illegal context/position - i.e. if they cannot be ortho-syllabified. For example, *castl* [castle] was classified as illegal because *tl* is not a legal word ending even though *tl* is a legal letter sequence and the response has a legal CV sequence (CVCCC).

A similar pattern is observed if one considers each single letter error type in isolation. Of the errors reported in Table 10, all of the single letter additions (34/34, 100%), shifts (6/6, 100%) and exchanges (4/4, 100%) resulted in orthotactically legal letter sequences. Substitutions, omissions and transpositions preserved legality in 97.8% (135/138), 97.3% (73/75) and 83.3% (10/12) of instances respectively. In order to estimate a chance level of legality preservation, a series of pseudo-random single letter errors were generated using BA's responses and taking into account factors known to influence BA's performance (including serial position). Each simulation was carried out 10 times for each error type. BA's movement errors were not simulated because they were few in number and because the procedure would be less straightforward than for the other error types.

Additions. For BA's single letter additions (e.g. swim→*swimp*, palace→*palance*) the responses were divided into 'stems' (e.g. *swim_*, *pala_ce*) and added letters (e.g. *p*, *n*). The letters and stems were then randomly paired and each letter was inserted in the same absolute position which it occupied in the error. Thus the letter additions had the opportunity to generate orthotactically legal (e.g. *palarce*) or illegal (e.g. *swimg*) forms. Since this method uses the same set of letters (and hence CV proportions) that BA produced and also the same serial positions, these factors are controlled for.

Omissions. For BA's omission errors (e.g. golf→*gof*), the random pairings were generated between 'stem' forms (e.g. golf) and ordinal positions (e.g. 3). Thus, if *golf* is randomly paired with 2 then this will result in an orthotactically illegal response (*glf*), but not if it is paired with 4 (*gol*). If pairings were not possible (e.g. golf-8) then the items were placed back in the pool until a suitable pairing was found. This method uses the same serial positions as BA, so this factor is controlled for. Although the proportion of consonants and vowels that were omitted was not directly controlled for, a post-hoc analysis revealed that the average proportion of omitted consonants (60%) was similar to the rate produced by BA (65%).

Substitutions. For BA's substitution errors (e.g. track→*trank*), the random pairings were again between 'stem' forms (e.g. *tra_k*) and substituted letters (e.g. *n*), thereby controlling for serial position. An additional constraint was that substitutions should preserve CV status at the same level as BA (87.7%). Thus tra_k was biased towards substitution of a consonant (e.g. *trapk* - illegal, *trank* - legal).

Results. The additions resulted in orthotactically legal forms on 83% of occasions, on average (sd=5.73, range=76.5-91.2). Using these values as expected values, 7 simulations produced significantly worse performance than BA (who preserved legality in 100% of additions) and it was not possible to calculate significance for the remaining 3 since the expected value was too low (E<5, which violates the chi-square assumptions). The omissions resulted in orthotactically legal forms on 78% of occasions on average (sd=2.31, range=74.7-81.3). All of these simulations were significantly lower than BA's score (97.3%). The simulation tended to produce orthotactically legal forms for substitutions because it was constrained to preserve CV status in most instances. Nevertheless, BA's level of legality preservation (97.8%) was still higher than any of those produced by the simulation (mean=91%, sd=2.09, range=88.4-94.9).

In summary, BA's nonword responses show sensitivity to the constraints of English orthography and her single letter errors tend to preserve orthotactic constraints more often than would be expected (particularly for additions and omissions). A CV tier alone cannot explain the fact that BA's errors show sensitivity to actual letter combinations rather than just combinations of consonants and vowels. Similarly, bigrams/trigrams which are insensitive to positions within the word may have difficulty in accounting for BA's good preservation of legality: responses such as *castl* are composed entirely of legal bigrams/trigrams, but were rarely produced by BA.

Can bigram/trigram frequency account for orthotactic legality?

If BA preserves legality because when the target sequence of letters is unavailable she replaces it with a more common sequence of letters, i.e. there should be an increase in bigram/trigram frequency.

Mean bigram and trigram frequencies were calculated for both target words and responses for the 220 errors which were described in Section 3.2. Calculations were based on the sample of 9996 words from the Oxford Psycholinguistics Database (see Section 3.3). For example, the word *pig* consists of 4 bigrams (_p, pi, ig, g_). Some bigrams (e.g. *th*) were very frequent whereas others (e.g. *df*) were never encountered. The correct spellings had a mean bigram count of 514 (sd=171) and her incorrect responses had a mean bigram count of 485 (sd=186), which actually suggests that the responses were composed of bigrams lower in frequency than the target words ($t(219)=2.20$, $p<.05$). For the trigram analysis, the correct spellings had a mean trigram count of 68.2 (sd=48.4) and her incorrect responses had a mean trigram count of 63.6 (sd=58.3), ($t(219)=1.03$, *ns*). Thus, although BA's errors are orthotactically legal they are no more orthotactically frequent than the target word.

Table 11 shows that similar results are found if one considers each single letter error type in isolation. In no instance did responses have a significantly higher bigram/trigram frequency. In fact, responses containing omissions and substitutions actually had a lower bigram frequency than the target.

In short there is little evidence that the constraints which are imposed on BA's errors arise because of the influence of frequency sensitive bigram or trigram units. The following sections will investigate an alternative hypothesis: the ortho-syllable hypothesis.

Table 11: Mean bigram and trigram frequencies for targets and responses (sd in brackets).

	BIGRAM			**TRIGRAM**		
	Target	**Response**	**t, p**	**Target**	**Response**	**t, p**
Addition	535 (147)	553 (151)	-.63, *ns*	77 (46)	75 (53)	30, *ns*
Movement	530 (164)	502 (137)	.75, *ns*	65 (50)	46 (25)	2.01, *ns*
Omission	504 (160)	459 (182)	2.18, <.05	63 (43)	59 (59)	.54, *ns*
Substitution	520 (174)	474 (187)	2.47, <.05	76 (54)	68 (59)	1.03, *ns*

Do fragments respect ortho-syllabic structure?

If letters are retrieved in syllable-sized units (or sub-syllable units; onset, coda, etc.) then fragments may be expected to terminate at these boundaries. Instances in which BA produced a word fragment which was correct in all respects were examined (e.g. book→*b*, but not elephant→*elpe*). The number of instances in which a fragment terminated at an ortho-syllabic boundary were counted (e.g. camera [ca.me.ra] →*ca*). Fragments which terminated around a geminate pair (e.g. puppet → *pupp*; N=3) were excluded from the analysis because it is not clear how such sequences should be syllabified in orthography (*pup.pet* or *pupp.et*; Badecker, 1996).

Only words with more than one ortho-syllable were included in the analysis since it is not possible to err in this way for monosyllables. 33.3% (52/156) of fragments terminated at an ortho-syllabic boundary. In order to estimate the probability that a fragment will fall on an ortho-syllabic boundary by chance, the 156 target words were randomly paired with the 156 fragment lengths. For example, for the target word *paradise* BA produced a 4 letter fragment (*para*) and for the target word *holiday* she produced a 2 letter fragment (*ho*). A random pairing may result in the combination *paradise*-2, which in this case does coincide with an ortho-syllabic boundary (*pa.ra.di.se*). Pairings in which the fragment length exceeded the word length (e.g. *cup*-4) were placed back into the pool until a suitable match was found. Repeating this procedure three times resulted in ortho-syllabic boundary hit-rates of 27% (42/156), 29% (46/156), and 31% (48/156). Thus BA does not terminate fragments at ortho-syllabic boundaries any more than is expected by chance.

The fact that there is no evidence that words are retrieved syllable by syllable, however, does not imply that letters are not organised into syllables at any level. For instance, fragments may be sensitive to other constraints, such as preserving consonant clusters (onsets and codas). Considering the corpus of words which gave rise to fragments, 39 words began with a CC cluster (e.g. *brick*, *thermometer*) and 129 words began with a CV sequence (e.g. *bench*, *computer*). Whereas 32.5% (42/129) of fragments on words beginning with CV consisted of only one letter (e.g. bench→*b*), only 10.3% (4/39) of fragments on CC words consisted of one letter (e.g. brick→*b*), ($\chi^2(1)=7.49$, $p<.01$). Thus, there is some evidence to suggest that BA is reluctant to break-up word onsets. This is unlikely to reflect the fact that CC clusters often represent a single phoneme, since the same effect remains when the items beginning with the regular phonemes/bigrams *th*, *sh*, *ch* and *ph* are removed (13.3%, 4/30; $\chi^2(1)=4.38$, $p<.05$). Thus, the preservation of CC clusters appears to have an orthographic origin.

Seidenberg (1987) argued that apparent effects of ortho-syllabic structure may arise because of differences in bigram frequencies at the critical boundaries. Thus *bamboo* may 'appear' to show the syllabic structure *bam.boo* because *mb* is an infrequent bigram. In the above analysis, the CC bigrams had a mean frequency of 174 (sd=104) and the CV bigrams had a mean frequency of 299 (sd=222). If anything, the prediction would be that CC clusters would be more likely to be broken up because they tend to be less frequent. However, the opposite was found suggesting that bigram frequency cannot account for this finding.

Effects of ortho-syllabic structure were also examined over the first four letters of words (words shorter than 4 letters were excluded). Only certain CV sequences were represented in sufficient numbers to be analysed. These consisted of the sequences CCVC-- (e.g. chin, brick, phantom), CVCC-- (e.g. bump, bench, cactus) and CVCV-- (e.g. joke, cider, holiday). The probability that a fragment of length 1, 2 or 3 would be produced was determined. The results are displayed in Table 12. This table shows, once again, the tendency to preserve consonant clusters at word onset. In the case of the CC cluster in CVCC--, the CC cluster may be ortho-syllabified either hetero-syllabically (the CC cluster is split between 2 syllables, e.g. *nerve* [CVC.CV]) or tauto-syllabically (the CC cluster is part of the same syllable, e.g. *bench* [CVCCC]). In fact, BA was significantly more likely to split the word at the third position for hetero-syllabified words compared to tauto-syllabified words, ($\chi^2(1)=9.32$, $p<.01$). Thus, fragments are sensitive to the structure of codas as well as onsets[7].

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[7] There was insufficient data to analyse whether the CCVC-- fragments show the equivalent effect (i.e. CCV.C-- verses CCVC--), and the CVCV --fragments can only be syllabified in one way (considering only the first 3 boundaries, i.e. CV.CV--).

Table 12: The probability that a fragment will be produced at different positions in the CV sequence (%).

	Length of Fragment			
	1	**2**	**3**	**Other (3+)**
	% N	% N	% N	% N
CCVC--	11.4 (4/35)	28.6 (10/35)	37.1 (13/35)	22.9 (8/35)
CVCV--	24.5 (12/49)	32.7 (16/49)	26.5 (13/49)	16.3 (8/49)
CVCC--	31.7 (19/60)	26.7 (16/60)	23.3 (14/60)	18.3 (11/60)
CVC.C--			40.0 (12/30)	
CVCC.--/CV.CC--			6.7 (2/30)	

It is unlikely that this pattern could arise out of differences between the stimuli material. Although the words were not initially matched, the CCVC--, CVCC-- and CVCV-- words did not differ in terms of letter length (6.5, 6.3 and 6.0 respectively), imageability (66%, 60% and 53% of words were judged to be high in imageability), or word frequency (15.4, 18.3 and 32.0 from Carroll et al., 1971).

Thus, there is some evidence for letter clusters corresponding to syllabic components in spelling. It has been suggested before that effects of ortho-syllabic complexity may provide additional evidence.

Does ortho-syllabic complexity influence performance?

Caramazza and Miceli (1990) found that their patient was significantly better at spelling words composed entirely of consonant+vowel syllables (e.g. *figure* = CV.CV.CV) compared to those containing consonant or vowel clusters (e.g. *chance* = CCVC.CV). They cited this as evidence for ortho-syllables in which simple-CV sequences such as *figure*, have a more optimal configuration compared to other sequences (termed complex-CV). This finding has been replicated in another Italian dysgraphic patient (Schonauer & Denes, 1994). However, two further studies with English-speaking dysgraphic patients have failed to replicate this finding (Jonsdottir et al., 1996; Kay & Hanley, 1994).

The corpus of words from writing to dictation (N=2000) were analysed according to their CV sequence. Words consisting entirely of CV sequences were classed as simple-CV and other sequences were classified as complex-CV. BA's performance on the two types of words is summarised in Table 13. Only sequences with more than 15 exemplars are listed, the remainder are grouped into the category 'other'. BA showed no advantage in spelling simple-CV words relative to complex-CV words for both 4 and 6 letter words. In fact, she showed a non-significant trend in the opposite direction.

Table 13 : Performance on complex-CV and simple-CV words for words of length 4 and 6 (% words correct).

	Complex			Simple		
Length						
4	CVVC	66.7	(52/78)	CVCV		
	CVCC	48.6	(67/138)			
	CCVC	47.5	(19/40)			
	VCVC	38.1	(8/21)			
	Other	48.5	(16/33)			
		52.3	(162/310)		41.7	(40/96)
6	VCCVCC	19.0	(4/21)	CVCVCV		
	VCCVCV	26.7	(4/15)			
	CVVCVC	43.8	(7/16)			
	CVCVVC	30.0	(9/30)			
	CVCVCC	18.2	(4/22)			
	CVCCVV	64.7	(11/17)			
	CVCCVC	44.2	(68/154)			
	CVCCCV	37.1	(13/35)			
	CCVVCC	33.3	(6/18)			
	CCVCVC	38.9	(14/36)			
	CCVCCV	40.9	(9/22)			
	Other	48.5	(32/66)			
		40.0	(181/452)		30.9	(17/55)

BA also shows no tendency for different single letter error types to be associated with simple-CV versus complex-CV words. The proportions of each type of single letter error on simple-CV and complex-CV words respectively were:- substitutions: 45% (10/22) and 49% (45/91); omissions: 23% (5/22) and 26% (24/91); additions: 27% (6/22) and 14% (13/91); misorderings: 5% (1/22) and 4% (4/91). Thus the data from BA more closely resembles that of Jonsdottir et al. (1996) and Kay and Hanley (1994) than that of Caramazza and Miceli (1990).

Both Jonsdottir et al. (1996) and Kay and Hanley (1994) attributed the differences between LB (Caramazza & Miceli, 1990) and their patients to cross-linguistic differences; namely that LB is more able to utilise information from phonological syllables owing to the transparency of Italian orthography and that, therefore, there is no reason to propose the existence of ortho-syllables. However, a more neutral interpretation may be state that their data provides no evidence for ortho-syllabic complexity (at least as defined by Caramazza & Miceli, 1990). It is possible that articulatory difficulty provides the motivation for ranking of syllabic complexity in phonology, but there is no equivalent motivation for complexity ranking in the orthography. However, there is a motivation for syllabic structure which helps to maintain order both in phonology and in orthography. It is possible then, that the patients reported by Kay and Hanley (1994) and Jonsdottir et al. (1996) produced orthotactically legal responses more often than chance without showing effects of complexity, as has been reported here.

3.5 Discussion

This Chapter has provided evidence to suggest that orthographic representations used in spelling consist of more than just a pool of letter identities connected to a word (or morpheme) level of representation. Previous studies have suggested that the fact that patients substitute and transpose consonants for consonants and vowels for vowels provides evidence for a separate CV level of representation (Caramazza & Miceli, 1990; Cubelli, 1991; Kay & Hanley, 1994; Jonsdottir et al., 1994; Schonauer & Denes, 1994). BA also exhibited this pattern. This is unlikely to reflect the use of phonological spelling which is impaired in BA. It also cannot be attributed to random letter substitutions even assuming sensitivity to letter frequency.

BA's errors are heavily constrained by orthotactic principles. These constraints are unlikely to be derived from phonological principles since many of her responses were phonologically unrelated but orthotactically plausible (e.g. dress→*drad*, jacket→*jackage*, valour→*vatle*). Orthotactic constraints cannot easily be explained by reference to letter or word levels alone. Excitatory and inhibitory connections between letter units could introduce biases in letter selection giving rise to plausible letter sequences. For example, activation of the letter *q* may send strong activation to the letter *u* but not to other letters. However, this mechanism would not be able to account for more complex constraints, such as the fact that the letters *ck* can be found at the end of a word but not at the beginning.

Letter bigrams or trigrams which are sensitive to statistical probabilities but insensitive to position cannot offer a complete account of BA's performance since her errors did not increase bigram/trigram frequency and fragments appear to be sensitive to the syllable-based concepts of onset and coda. In BA, it appears to be the case that letters are retrieved in chunks which correspond to sub-syllable units (e.g. brick→*br+i+ck*) rather than ortho-syllables themselves since fragments respect these boundaries rather than ortho-syllabic boundaries.

It is unlikely that orthotactic constraints could be derived solely by a principle of lexical analogy. Acquired surface dysgraphic patients who are poor at utilising lexical-orthographic information also show sensitivity to orthotactic constraints such as placing *-ck* at word endings but not beginnings (e.g. Goodman & Caramazza, 1986a). It remains to be determined whether these units are common to both lexical and sublexical routes or whether the information is represented redundantly in each route. At this stage, the former hypothesis is to be favoured on the basis of parsimony. Figure 7 shows a simplistic model which incorporates a syllable-like frame. In this model, there are no separate consonant and vowel units although an additional level could be added. Nevertheless, there is a tendency for consonants and vowels to form sub-regions within the syllable frame raising the possibility of selective impairment (e.g. Cubelli, 1991) and within-class substitutions

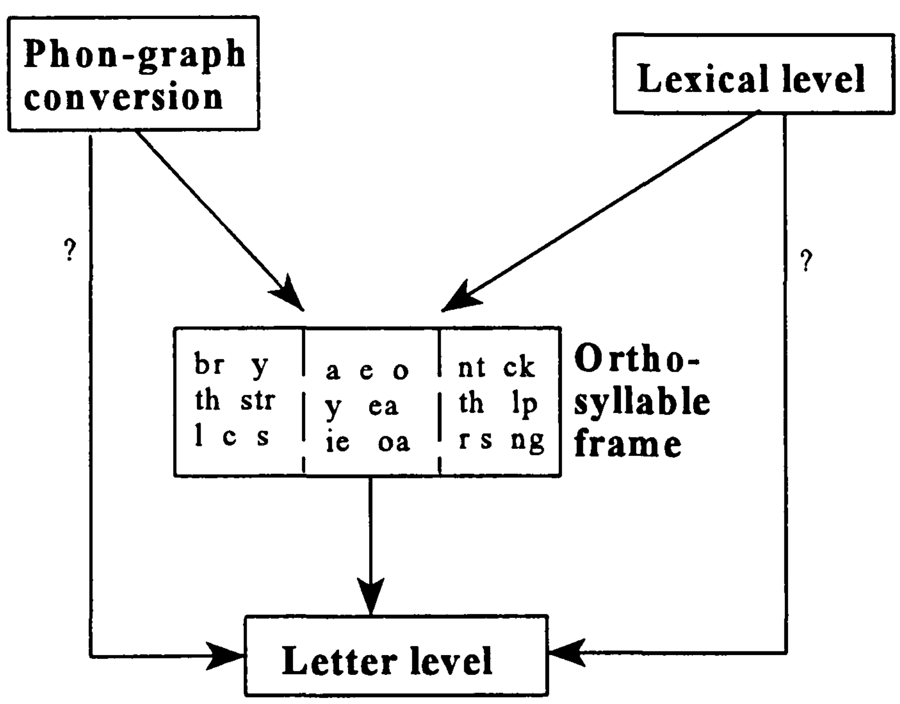

Figure 7: Flow diagram showing how an ortho-syllable level may be incorporated into a model of spelling.

One potential difficulty with any theory which postulates the existence of ortho-syllable type units (or any other unit larger than the single letter) is the question of why whole letter clusters tend not to participate in spelling/writing errors (e.g. substitution of a complex onset), even though analogous errors are commonplace in speech errors (e.g. Fromkin, 1973). These errors may not be found in BA because they tend to occur between words, whereas she was only given single words to produce. Another possibility is that these types of errors may be more likely to be edited out in the case of writing because of the slower time course.

In summary, this chapter has shown that there is some evidence for the existence of representational units larger/other than the single letter which may provide a source of constraint on error types and may also serve as units of retrieval.

4. LESIONING A CONNECTIONIST MODEL OF SPELLING

4.1 Introduction

Chapters 2 and 3 documented a dysgraphic patient (BA) whose difficulty was attributed to incomplete activation of lexical orthographic representations. This chapter will attempt to model certain aspects of her performance. It is hoped that the modelling enterprise will provide not only a test of an existing connectionist model of spelling, but also that it will provide insight into some of the general problems faced by any computational model of spelling. It is unfeasible to model the entire pattern of performance produced by BA. For example, the modelling of imageability effects, semantic errors and other lexical effects would entail both the implementation of a semantic system and some form of competition/interaction between lexical nodes. I will restrict myself to model serial position effects, non-lexical error types and certain effects of orthographic structure.

The model that will be lesioned essentially consists of that described by Houghton et al. (1994; described in Section 1.4.3). This model was selected because it contains the components which appear to be implicated in her deficit, i.e. an orthographic lexicon consisting of word and letter levels and no influence of phoneme-grapheme conversion. Furthermore, the model has already been shown to be able to account for other patients reported in the literature (see Shallice et al., 1995). For this last reason, any modifications made to the model will be minimal. The testing of the model will, however, be extended in a number of ways. For example, by examining effects of cueing and performance with repeated letters which have not been examined in previous implementations. Specifically, the model will be assessed according to its ability to reproduce the following aspects of BA's performance which have already been documented in the thesis.

(1) A serial position effect in which errors increase from left to right (a) and which is characterised by ordinal position (b).

(2) The production of word fragments (a), in which the length of the fragment is not proportional to the length of the word (b).

(3) The production of single letter errors in nonword responses (a), which also tend to increase from word beginning to word end (b).

(4) A weak effect of word length (better performance for shorter words).

(5) An effect of cueing in which supplying single letter cues facilitates retrieval of subsequent letters.

The model may be expected to be able to reproduce certain aspects of this pattern without the actual need for implementation and lesioning. For instance, that the model could produce fragments and nonwords is to be expected since there is no scope for producing lexical errors. Similarly, more errors on longer words is to be expected since the greater the number of letters the more scope for error. However, it is not clear whether the model could reproduce other aspects of BA's performance without explicit testing of the model. For instance, the fact that fragment length does not increase with word length, that serial position effects are related to ordinal positions, and the proportions of each type of single letter error made.

In addition to those criteria listed above, the model makes testable predictions regarding performance on words with consecutive repeated letters (geminates; e.g. a**pp**le) and non-consecutive repeated letters (henceforth repeated letters; e.g. **p**a**p**er). Specifically it suggests that geminate pairs should behave differently from equivalent non-geminate pairs, since the former are represented using a specialised geminate node. Although the model does not employ any specialised mechanism for handling other repeated letters, there is reason to believe that these sequences will behave differently to non-repeated letter pairs. After the first occurrence of the letter to-be-repeated has been produced it is strongly inhibited. However, its activation level may rise again since it continues to receive activation from the sequencing nodes (particularly from the E-node since the second repeat must occur more towards the end). If BA does have reduced activation from word (or sequencing) nodes to letter nodes then she may have a particular difficulty in spelling these words, since she will be less able to boost the activation of inhibited letters in order to output them again. These predictions were therefore examined in BA, and may be used to provide further sources of constraint on the attempts to lesion the model.

4.2 Performance on Geminate and Repeated Letters in BA

In order to assess whether BA was worse at spelling words with repeated letters and treated geminate letters differently, her overall levels of performance with these words was first considered and then a second analysis looked at her responses to more carefully matched items and sequences.

Overall performance

BA's corpus of 2000 responses in writing to dictation contained 1184 words with no geminates or repeats (e.g. dog), 468 words with a repeated letter but no geminate (e.g. text), 258 words with a geminate but no other repeat (e.g. book) and 90 words containing both geminate and repeated letters (e.g. sleeve). BA's performance on these word types was investigated at various word lengths. There is no motivated reason for assuming that words containing repeated letters or geminates should differ in imageability or frequency compared to control words containing all-different letters, averaging over a sufficiently large sample of words. The results of this analysis are given in Table 14. There was insufficient data for words shorter than 4 or longer than 8 letters in length and for the words containing both geminates and repeats. Considering the number of words spelled correctly, BA was significantly better at spelling words with geminates compared to words with all-different letters, but only for shorter words. There was no significant difference between her ability to spell words with repeated letters compared to words with all-different letters at any word length. This suggests that words containing geminate letters may be represented/processed differently from those containing all-different letters. The data also suggests that geminates are not 'special' simply by virtue of the fact that they contain more than one occurrence of the same letter since this advantage was not found for words with non-geminate repeats (see also Tainturier & Caramazza, 1996). The next analysis shows that similar results are found using more closely matched items.

Table 14: BA's performance on different word types as a function of word length.

Word Length	All-different %	N	Repeated %	N	Geminate %	N
4	46.4	(156/336)	44.4	(8/18)	75.0	(39/52)**
5	42.7	(146/342)	34.4	(31/90)	56.2	(41/73)*
6	33.2	(80/241)	38.4	(58/151)	53.3	(46/86)**
7	31.5	(34/108)	27.7	(26/94)	39.1	(9/23)
8	33.3	(9/27)	23.3	(17/73)	23.1	(3/13)

** $p<.001$, * $p<.05$; comparing with control words containing all-different letters.

Geminate letters

An analysis of errors made on words with geminates suggests that geminate pairs are represented differently from other letters. Of the 348 words containing geminates, 207 (59.5%) responses correctly contained the geminate sequence, 68 (19.5%) were failures to give any response at all, 33 (9.5%) were lexical substitutions or morphological errors (e.g. sheep→*lamb*), 20 (5.7%) were fragments which excluded the geminate (e.g. spoon→*sp*), 4 (1.1%) were unrelated responses (e.g. jelly→*chiver*) and only 16 (4.6%) involved some transformation of the geminate itself. These 16 errors consisted of deletions (N=8; bullet→*bult*, alligator→*aig*), movement errors (N=3; tobacco→*tobbise*, giraffe→*gifarre*), substitutions (N=2; valley→*vettl*), pseudo-substitutions (N=2; lesson→*leason*) and a geminate split error (N=1; Lloyd→*Loyl*). Of the 1652 words not containing a geminate, 8 (0.5%) responses created a geminate sequence (e.g. melon→*mellon*).

The pattern of errors on geminates differs from that reported for BA's errors on single letters (see Table 10) in that there were few instances in which the identity of the geminate was substituted. Instead, BA's pattern is characterised by a tendency to produce geminate sequences correctly (e.g. puppet→*pupp*) or not at all (e.g. spoon→*sp*). The pattern is also different from some graphemic buffer patients who produce many movement errors on geminate sequences (e.g. puppet→ *pupee*). The patients reported by Caramazza and Miceli (1990) and McCloskey et al. (1994) made geminate movement errors in 56% and 32% of instances.

A more informative analysis may be to compare performance on individual sequences (e.g. arrow v. shirt) between carefully matched word-pairs. Three lists of words were prepared. One list contained words with geminates. The other two lists contained words with no geminates[8]. All three lists were matched (item-for-item) for frequency, imageability and grammatical class. Word length was varied so that one control list was matched according to number of letters (e.g. arrow v. shirt) and the other was matched according to the number of letters minus the number of geminate pairs (e.g. arrow v. shoe). Each list contained 75 words and was given to BA to write to dictation.

BA's performance on the geminate list (40/75, 53%) was similar to her performance on the list containing shorter words (37/75, 49%) and somewhat better than her performance with the length matched words (29/75, 39%; although this just failed to reach significance, $\chi^2(1)=3.25$, $p=.07$). Evidence to suggest that the double letter sequence is treated differently from other letter pairs can be found if one contrasts her ability to produce the geminate letters themselves with equivalent letters from matched words (e.g. comparing *rr* and *hi* from *arrow* and *shirt*). These

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[8] Some of the matched words did contain non-consecutive repeated letters (e.g. clock) because of a difficulty in finding matched items and because this analysis was carried out before repeated letters were given consideration. Fortunately, this is unlikely to be critical because all of the analyses suggest that words with repeated letters behave in the same way to words with all-different letters.

letter pairs were scored according to whether one, both or none of the letters were present in her response. Table 15a summarises this data. BA is significantly more likely to produce one letter of a non-geminate sequence (e.g. shirt→*sh*) compared to equivalent geminate sequences (e.g. arrow→*ar*), ($\chi^2(1)=7.87$, $p<.01$). In fact, the two occurrences in which the geminate was split were both lexical substitutions and hence not true geminate errors (Molly→*Olive*, hell→*help*).

In summary, there is good evidence from BA to suggest that double letters behave differently from other letter sequences. For the present purposes, this observation appears consistent with the notion of a geminate node. However, the Discussion will consider whether other explanations may account for the data.

Table 15: Percentage of occurrences in which one, both or none of the letters in geminate pairs (e.g. arrow) or repeated letter pairs (paper) were produced compared to equivalent non-geminate letter pairs (e.g. shirt, table).

		Both letters	**One Letter**	**No letters**
		% N	% N	% N
a)	Geminate	60.0 (45)	2.7 (2)	37.3 (28)
	Non-geminate	46.7 (35)	16.0 (12)	37.3 (28)
b)	Repeated	46.7 (35)	18.7 (14)	34.7 (26)
	Non-repeated	44.0 (33)	24.0 (18)	32.0 (24)

Repeated letters

BA's performance in spelling words with repeated letters was analysed in a similar way to the words containing geminates. From the corpus of words which she had previously written, 2 lists of 75 words were extracted. Items were matched pairwise for frequency, imageability, grammatical class and word length. One list contained words with repeated letters (e.g. *paper*, *hedge*, *award*) and the other list contained words with all-different letters (e.g. *table*, *grape*, *angle*). None of the words contained a geminate. BA was no worse at writing words with repeated letters (25/75, 33%) compared to words with all-different letters (23/75, 31%). Table 15b shows that this pattern was also found when the incorrect responses were analysed according to whether one, none or both of the repeated or matched letters were produced. If a word contained several letter repeats (e.g. *alcohol*) then only the first repeated pair was considered (in this case, the *o* repeat). None of her errors in spelling words with repeated letters suggested that these letters behave as if they were a single representational unit (errors such as tint→*dind* or these→*thses* were not found). She was equally likely to produce one letter of a repeated pair as of a different pair ($\chi^2(1)$=0.52, *ns*).

Therefore, two more criteria may be added to the list (see Introduction) on which the model may be tested. These are stated below.

(6) A tendency for words with geminates to be spelled better than length matched words(a) and a lack of geminate deletions (e.g. apple→*ap*) compared to matched letter pairs (b).

(7) Words with repeated letters are spelled as well as length matched words (a) and repeated letters are no more likely to be omitted/replaced than matched letters (b).

It is to be expected that the model will have difficulty in reproducing (7), hence this is an important test of the model, although it is not clear how well the model will produce (6) without attempting the lesion.

It is suggested that these 7 criteria (and sub-criteria) are sufficient in diversity and number to constitute a meaningful test of the model. The performance of the model will be assessed primarily according to its ability to produce qualitatively similar spelling behaviour to the patient, rather than producing a close statistical fit. This is because BA's errors at a quantitative level are influenced by factors beyond the scope of this model (e.g. imageability), whereas the qualitative nature of her errors is considered to be well within the scope of the model.

4.3 Setting-up the Model

Architecture

The architecture was the same as that described by Houghton et al. (1994; see Figure 3, Chapter 1) with the exception of the competitive filter. Layer 1 consisted of 1000 pairs of word/sequencing nodes (see Training Corpus). Layer 2 consisted of 26 letter nodes and a geminate node with total connectivity between layer 1 and layer 2. In the original model, the competitive filter (layer 3) was implemented by an iteration of a peak-picking routine, based on self-excitation and strong mutual inhibition of layer 3 nodes. In this version, the competitive filter was simulated using a procedure devised by Glasspool (Personal Communication). This was achieved by setting the activation of the layer 3 node corresponding to the winning letter node to +1.0 and all other layer 3 nodes to -1.0, without implementing the peak-picking algorithm. This has the advantage of simplifying and, hence, speeding-up the code and can also be used to reduce the number of trials needed to correctly learn a spelling (see below). This modification, however, does not affect the overall functioning of the model.

One further change made to the functioning of the competitive filter was that the magnitude of back-inhibition from layer 3 to layer 2 was reduced from 4.0 to 3.0 (Houghton et al., 1994, and Shallice et al., 1995, used a value of 4.0 throughout). This was done to enable more efficient learning of words with repeated letters (since strong inhibition makes reactivation of letters more difficult).

Training Corpus

The model was trained on 1000 different words. These were selected at random from the larger corpus of 2000 words given to BA to write to dictation. The only criterion used was that words should be less than 9 letters in length, since this is the maximum length that the model is currently capable of learning. An analysis of the training corpus revealed that there were 660 words containing neither geminates nor repeats (e.g. *dog*), 130 words containing a geminate but no other repeated letter (e.g. *book*), 189 words containing a repeated letter but no geminates (e.g. *tint*), and 21 words containing both a repeated letter and a geminate (e.g. *sleeve*). The corpus used in the study of Houghton et al. (1994) used only words from the first two of these categories, ie repeated letters were excluded.

Learning

Learning consisted of two phases: one-shot Hebbian learning followed by a period of supervised training (the practice phase). In the first phase, both the sequencing nodes and the letter nodes were activated (externally, i.e. by the experimenter) in order to establish an initial set of weights (such that initial letters connect more strongly to the I-node and final letters connect more strongly to the E-node). In the practice phase, only the sequencing nodes were externally activated and the letter nodes were allowed to find their own activation levels using the existing set of weights. An incorrect selection at the letter layer was corrected by modifying the existing weights (the equations governing these procedures are given in Houghton et al., 1994). There was no over-learning (i.e. no further adjustments to weights were made after correct recall in the practice phase).

During the practice phase, a 'self-editing' procedure was used (Glasspool, Personal Communication). When an error occurred, after modifying the weights, the competitive filter was set up as though the correct letter had won (by setting the layer 3 node which should have won to +1.0 rather than the layer 3 node that actually won). If this is not done, an error earlier in the word could result in errors later due to the incorrect letters being inhibited which changes the environment for up-coming letters. The weight modifying rules would then be inappropriately applied to these 'artefactual errors', which would slow learning.

The model was able to learn all of the words (N=660) containing no geminates or repeated letters in only 37 epochs. The model reached asymptote at 28 epochs with the words containing geminates, and was still unable to learn 21/130 of the words (16.2%) after 3000 epochs. For the words with repeated letters, the model reached asymptote at 65 epochs and was unable to learn 25/189 words (13.2%) at 3000 epochs. The words containing both repeated letters and geminates were the most poorly learned of all (asymptote at 78 epochs; 8/21 (38.1%) words not learned at 3000 epochs). The words which the model failed to learn are listed in Appendix 4 and were excluded from all further analyses of the model. A glance at the unlearned words suggests that the model had difficulty learning words with repeated letters when there was only one intervening letter (e.g. *autumn*) and particularly if these letters occur in the middle of longer words. The model also appeared to have difficulties producing a geminate at the end of a word, resulting from a tendency to prematurely activate the geminate node (e.g. guess→*guees*).

Producing stopping behaviour

If the model consisted only of the activation supplied by the sequencing nodes and a mechanism for selecting-then-inhibiting the most strongly activated letter node then the model would produce an indeterminably long letter string since any differences in activation at the letter layer, however small, would result in the output of a letter. One therefore needs an additional mechanism to indicate when output should stop. One possibility is to stop when the E-node reaches its maximum activation, thus the E-node may also function as an end-of-word marker. This mechanism was employed during the practice phase. However, this method has difficulties in modelling letter insertions and omissions which necessarily alter the number of timesteps before stopping. An alternative method is to have a separate node which, when activated, signals that the end of the word has been reached (Houghton et al., 1994). This node would have to be learned like any other letter, thus a three letter word (e.g. dog) would be encoded by four nodes at layer 2 (dog*, *= stop). A third possibility which has been used in this implementation is to stop when the total activation of the letter layer drops below some threshold value (Houghton, 1990). This method was selected since it has the most potential to produce fragments[9]. The actual equation used to implement stopping is given below (A_n is the activation of letter node *n*, [] indicates that only positive activation levels are counted, and the constant on the right-hand side is the threshold value). This may be implemented via an inhibitory control circuit which sets the activations of the letter nodes back to zero when activation falls below threshold (see Houghton,

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[9] The introduction of a different stopping mechanism after training is not necessarily problematic, since in this instance it constitutes removal of supervision. During training the model was specifically told to stop after a given number of letters. This constraint was then removed after training and the model was left to find its own stopping point, which in most cases it was able to do.

1990).

$$\sum_{n=1 \text{ to } 26} [A_n] < 0.42$$

The threshold value of 0.42 was empirically determined on the basis that it produced the most efficient stopping behaviour. If the threshold is too low then trailing letters are produced (e.g. woman→*womanw*). If the threshold is too high then stopping may occur prematurely (e.g. bachelor→*bac*). This mechanism produced flawless stopping behaviour for geminates (109/109) and words without any repeats (660/660). However, it resulted in incorrect stopping for 14.8% (25/169) of words with repeated letters and 15.4% (2/13) of words with both a repeated letter and a geminate. These words are listed in Appendix 4 and were excluded from any further analysis. They tended to consist of longer words and/or words containing multiple repeats (e.g. *banana*, *language*) since in these instances activations are summed over a smaller set of units resulting in premature stopping.

Thus, the initial corpus of 1000 words has been reduced to 919 words: 54 words were not learned correctly and a further 27 words were learned correctly but could not be recalled accurately using the letter-threshold stopping mechanism that was selected. Having eliminated these items, this leaves a trained model of spelling which is suitable for lesioning.

4.4 Lesioning the Model

As a preliminary investigation into the relative importance of the I and E-nodes, the model was lesioned by completely abolishing one sequencing node (reducing its activation to zero at all timesteps) whilst leaving the other node intact. Complete abolition of the E-nodes resulted in a failure to spell any words correctly. The model was, however, able to spell the first few (2-3) letters correctly in all instances. This suggests that the E-node only starts to exert a noticeable influence on spelling behaviour after the first 2-3 letters have been produced. In contrast, after abolition of the I-nodes the model was unable to produce any output at all due to the overall lack of activation at the letter layer, i.e. global dysgraphia. Thus, complete abolition of either (or both) sequencing nodes will not capture BA's performance since she was able to spell many words, including some longer ones.

This section will investigate the effects of two lesions carried out on the model. The first lesion affected only the functioning of the E-nodes (henceforth, the E-lesion). This was achieved by reducing the maximum activation that the E-nodes were allowed to reach during each recall attempt by a random amount between 0.0 and 1.0, with a mean of 0.5. The I-nodes retained their maximum activation value of 1.0. The second lesion affected both sequencing nodes (henceforth, the I+E lesion). The maximum activation that both the I-nodes and the E-nodes were allowed to reach was varied by a random amount between 0.0 and 1.0, with a mean of 0.5. Both lesions were implemented by adjusting the constants A_{maxE} and A_{maxI} in the equations governing the operation of the sequencing nodes (18.1 to 18.3 in Houghton et al., 1994; see below). The principal motivation for lesioning the model by reducing the activation rather than, say, addition of noise was that this type of lesion is more likely to result in the production of fragments.

$$A_I(t_0) = A_{maxI}$$
$$A_I(t+1) = 0.6 * A_I^{(t)}$$
$$A_E(t) = A_{maxE} * 0.6^{(t-1)}$$

$A_I(t)$ and $A_E(t)$ are the activations of the sequencing nodes at time t, and 0.6 is the value of the decay rate. These lesions may be conceptualised as either a reduction of the activation properties of the lexical/sequencing nodes themselves or a reduction in the activation supplied to the nodes by the environment; where the environment, in this instance, consists of the experimenter but in a fully-implemented model would consist of the semantic system. Although the letter layer was not lesioned directly, both lesions have the net effect of reducing activation at this level. This is entirely consistent with the interpretation offered of BA (see Section 2.4).

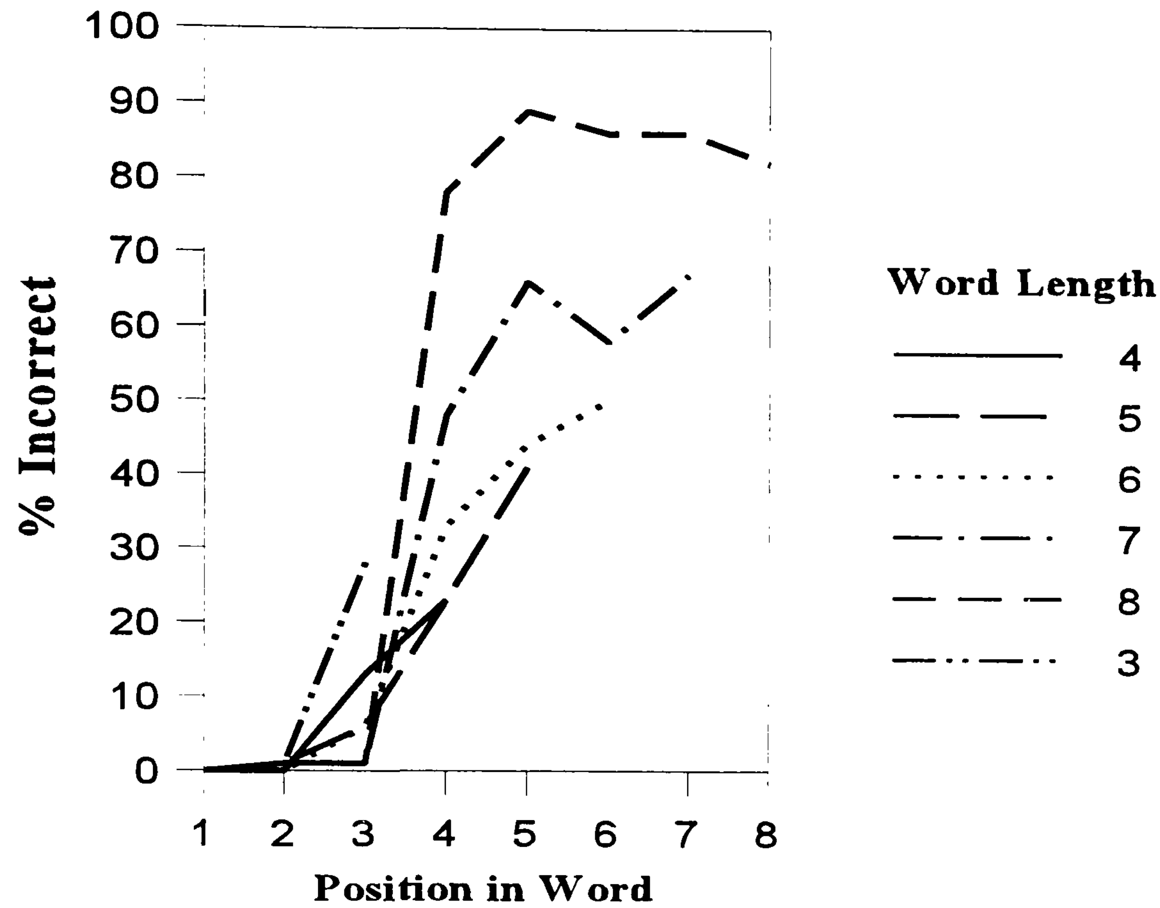
The corpus of 919 trained words was presented 5 times in each of the lesion conditions to generate a large corpus of errors. The E-lesion resulted in 56.9% (2615/4595) of words spelled correctly. 86.1% of the words (791/919) resulted in the production of an incorrect response at least once. All of the incorrect responses were orthographically related to the target (i.e. shared more than 50% of letters) and the model always managed to produce at least 2 letters of the word. The errors consisted of fragments (N=1141; 57.6%) and nonword responses (N=839; 42.4%).

The I+E lesion resulted in only 14.9% (683/4595) of words spelled correctly. All of the words (919/919) resulted in the production of an incorrect response at least once. The errors consisted of fragments (N=1589; 40.6%), nonword responses (N=1047; 26.8%) and failures to produce any response (N=1276; 32.6%). Again, all of the incorrect responses were orthographically related to the target. The model's performance on the seven criteria is described below.

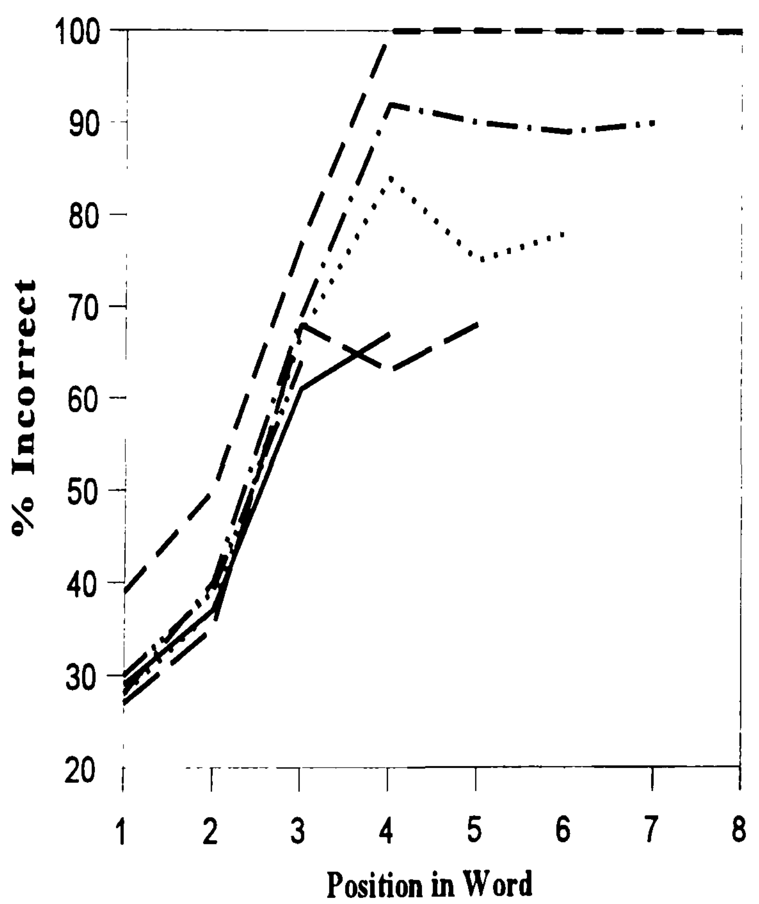
(1) *Serial position effect.* There are two aspects of the serial position effect which are particularly important. Firstly, does the error rate increase from word beginning to word end? Secondly, is it a function of ordinal position? All of the incorrect responses from the E-lesion (N=1980) and the I+E lesion (N=3912) were scored for letter mismatches between target and

response. Data from different word lengths were pooled using the formula of Wing and Baddeley (1980). The error rate was calculated by dividing the number of errors at that position by the number of letters occurring at that position (failures to respond were excluded for both BA and the model). The serial position effect (% error) was: 0, 1, 38, 69, 89. With the exception of position 2, this is a good approximation to BA's data from written picture naming (2, 28, 42, 58, 88) and writing to dictation (11, 28, 53, 69, 80). Performance was particularly good for the first few letters because the I-node activation was always sufficient to activate the first 2-3 letters of a word, whereas BA often produces only the first letter of a word, and hence more errors at position 2. For the I+E lesion, the serial position effect (% error) was - 3, 22, 59, 71, 80. Thus, both lesions were able to produce a serial position effect characterised by an increase in error rate from word beginning to word end, which closely resembles BA's.

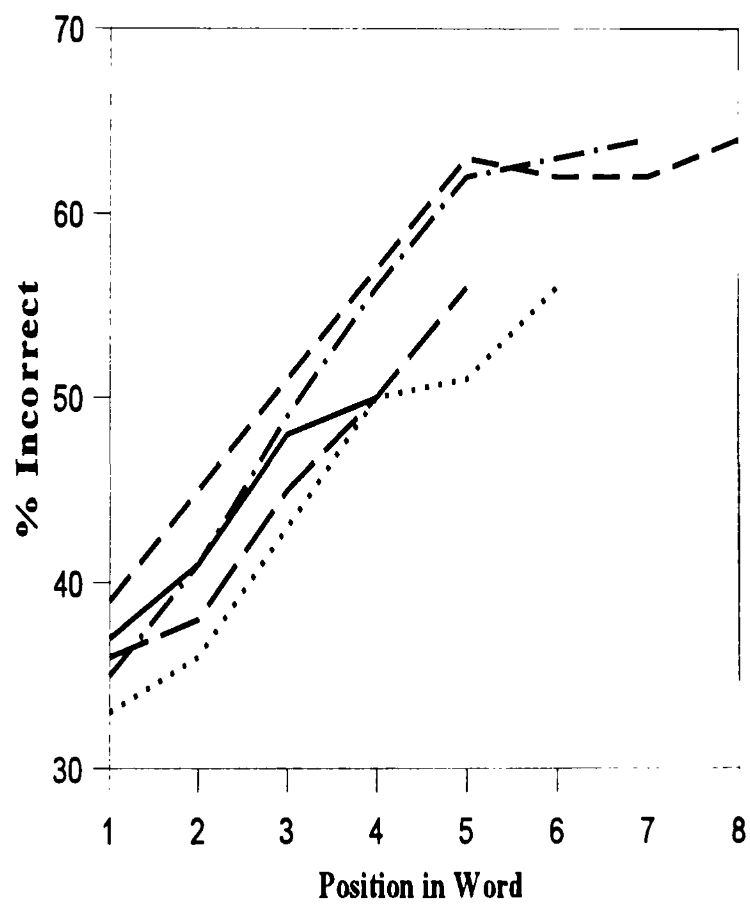
The results relating to ordinal positions are displayed in Figure 8. For the E-lesion, there was some overlap between error rates as a function of ordinal position for words of lengths 4 to 6, but not for 7 and 8 letter words, in which there is a sharp increase in error rate beyond position 3. This is more typical of a right-sided 'neglect dysgraphia' (e.g. Caramazza & Hillis, 1990a) than of BA. The I+E lesion produced a closer approximation to BA's data. Similar error rates were found for most ordinal positions, except for end positions in longer words; although there was some evidence for a similar trend in BA.



a) E Lesion



b) I+E Lesion



c) BA's data

Figure 8 : Serial position effects produced by the lesioned model and BA for various word lengths.

(2) *Fragments.* The E-lesion produced both 'correct' fragments containing the right letters in the right order (e.g. stable→*sta*; N=1084) and orthographically related fragments (e.g. elephant→*elpe*; N=57), as did the I+E lesion (1506 correct fragments, 83 related fragments). Both lesions produced fragments as their main error type, as was also found in BA (excluding her failures to give any response). Furthermore, both lesions were able to reproduce the fact that the length of the fragment is unrelated to the length of the word. Considering the correct fragments produced from the E-lesion, the average fragment lengths for words of 5 to 8 letters were 3.24, 3.20, 3.29, and 3.03. These fragments were slightly longer than those produced by BA, although the overall pattern was the same (2.53, 2.52, 2.73 and 2.93 respectively). The I+E lesion produced somewhat shorter fragments (2.09, 2.13, 2.16 and 2.19 respectively). But again there was little trend for longer words to produce longer fragments. Thus both lesions are able to produce a good approximation to BA's performance with regards to fragments.

(3) *Nonword responses.* The model also produced some nonword responses which (to within one letter) preserved the length of the target word. The E-lesion produced, in total, 839 of these responses. 36 of these were related only to the geminate (e.g. narrow→*narow*) and 102 responses could not be unambiguously described as 1-2 single letter errors. The remaining 701 responses contained 783 single letter errors (see Table 16). The I+E lesion produced, in total, 1047 nonword responses. 74 of these were related only to the geminate and 9 responses could not be unambiguously described as 1-2 single letter errors. The remaining 964 responses contained 1055 single letter errors. The types of single letter error produced by the lesioned model and BA are shown in Table 16. Although both lesions produced the same types of errors as BA, there was little similarity in terms of the proportions of each error type made.

Table 16: Types of single letter error made by BA and the lesioned model on nonword responses.

	BA		E-lesion		I+E lesion	
	%	N	%	N	%	N
Substitutions	44.3	(78)	20.2	(158)	3.9	(42)
Omissions	26.7	(47)	62.4	(489)	56.3	(594)
Additions	19.3	(34)	4.3	(34)	0.5	(5)
Transpositions	4.5	(8)	13.0	(102)	20.4	(216)
Shifts	3.4	(6)	0.0	(0)	14.3	(151)
Exchanges	1.7	(3)	0.0	(0)	4.4	(47)

One difficulty with both lesion conditions was an inability to reproduce the pattern of single letter additions. There are a number of reasons for this. Firstly, there can be no intrusion of letters from outside the word (e.g. pencil→*peancil*), only perseverations (e.g. pencil→*pepncil*) or anticipations (e.g. pencil→*peincil*) of existing letters. This is because the sequencing nodes only activate the letter identities comprising the word, with all other letters being less active. In contrast, only 12% (4/34) of BA's additions consisted of anticipations (N=2) and perseverations (N=2). The second reason is related to the stopping mechanism that was employed, which acts to prevent the word length from being increased. Indeed, all 'additions' that the model produced consisted of a perseveration and an omission of the last letter (i.e. word length preserved), as in butcher→*butcbhe*.

For the E-lesion, the serial position effects were - transpositions: 0, 8, 31, 42, 20; substitutions: 0, 0, 5, 55, 40; additions: 0, 0, 100, 0, 0; omissions: 0, 0, 0, 4, 96; (% chance that an error falls in a given position, for the Wing and Baddeley, 1980, positions). The overall serial position effect being - 0, 1, 12, 21, 66. Thus, the trend is the same as BA's (see Table 2).

For the I+E lesion, the serial position effects were - transpositions: 0, 1, 18, 42, 39; substitutions: 40, 43, 0, 12, 6; additions: 0, 0, 0, 100, 0; omissions: 0, 3, 32, 14, 52; shifts: 0, 2, 96, 1, 3; exchanges: 8, 38, 11, 0, 43 (% chance that an error falls in a given position, for the Wing and Baddeley, 1980, positions). The overall serial position effect being - 2, 7, 37, 16, 39. The I+E lesion had a stronger tendency to produce errors in initial positions than BA or the E-lesion. This is because, in this lesion condition, the I node (which primarily activates intial letters) often has reduced activity and so letters which normally appear at the end of the word may jump the queue.

Thus, the E-lesion offered the closest approximation to BA in terms of proportions of single letter errors made and their serial distribution, although neither lesion is entirely adequate.

(4) *Word length effect.* Figure 9 shows that both lesions resulted in better performance for shorter words than longer words. The performance of the model after the E-lesion was generally better than BA for short words, but worse than BA for longer words. Whereas, the I+E lesion resulted in poorer performance than BA at all word lengths. However, a more meaningful comparison maybe to consider the strength of the length effect (the steepness of the gradient), rather than absolute levels of performance (which, in BA, is a result of many factors). The E-lesion results in a very strong length effect (with the exception of 3 letter words). However, both BA and the I+E lesion produce a weak length effect in which performance drops-off gradually with increasing length. This issue will be returned to with a more comprehensive range of lesions.

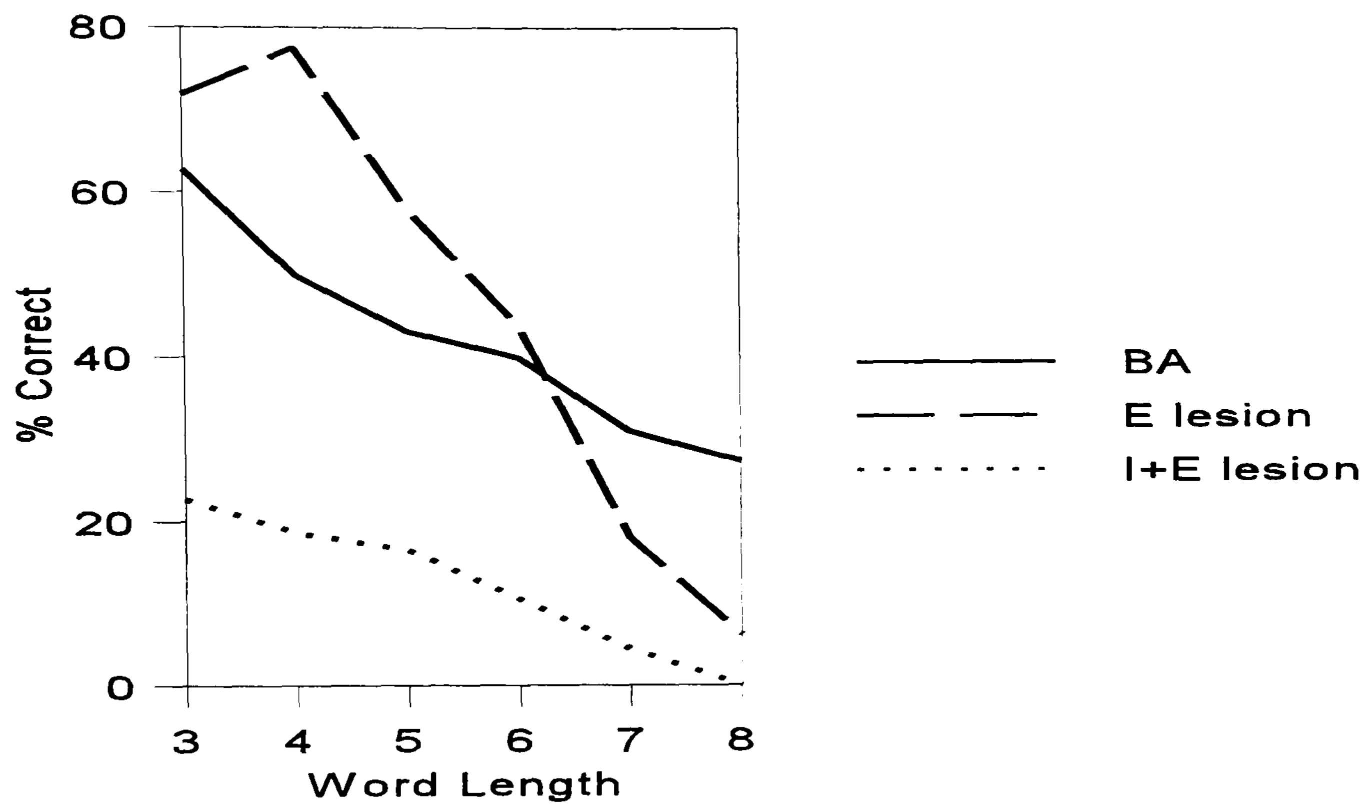


Figure 9 : Word length effect for BA and the lesioned model.

(5) *Cueing.* BA was cued after producing a correct fragment or no response by presenting her with single letters, one at a time, until she felt able to generate letters by herself (see Section 2.6.3). This either resulted in complete retrieval of the word (e.g. s**u**ede and **ji**gsaw, where the highlighted portion was supplied by the experimenter and the remainder was supplied by the patient), retrieval of part of the word (e.g. **ch**ur**ch**) or no effect at all.

The model was cued in a similar fashion. Words were cued if the model had produced a correct but partial response (e.g. church→*ch*) or if the model had produced no response at all. Cueing was achieved by setting the activation of the layer 3 (competitive filter) node corresponding to the next letter in the word (in this case, u) to +1.0 and the other nodes to -1.0. If this failed to produce a response, the next letter (in this case, r) was triggered at layer 3, and so on. In the case of geminates, both the geminate and the letter node were triggered at layer 3.

Thus, the activation of uncued letters (or indeed any layer 2 node) was not directly manipulated. Rather, the cue has the effect of bypassing the stopping mechanism which would normally prevent a layer 3 node from being triggered in cases where the general activation in the system was too low. The effect of cueing was investigated by running each word through this modified version of the model following both the E-lesion and the I+E lesion.

The results are presented in Table 17. The model also showed a benefit of cueing although the effect was more pronounced after the I+E lesion. The model also showed a tendency to retrieve only a few more letters, rather than the whole word, although this effect was more pronounced than in BA.

Table 17 : Effect of cueing (%) in BA and the lesioned model.

	BA	**E-lesion**	**I+E lesion**
Instances in which cue retrieved more letters	56 (36/64)	12 (20/161)	29 (128/446)
Complete (e.g. lice**ns**e)	44 (16/36)	15 (3/20)	20 (26/128)
Partial (e.g. l**im**li [limit])	31 (11/36)	65 (13/20)	80 (102/128)
Incorrect (e.g. ca**na**c [canal])	25 (11/36)	20 (4/20)	0 (0/128)

(6) *Geminate letters.* Figure 10 shows the number of words spelled correctly as a function of increasing word length, the 'control' words contained all-different letters. Words with repeated letters will be discussed in the next section. BA was generally better at spelling words with

geminates than matched words without. Following the E-lesion, performance on spelling words with geminates was only significantly better than controls for 7-letter words ($\chi^2(1)=52.97$, $p<.001$). There was no significant difference ($p>.05$), at any word length, between geminates and control words following the I+E lesion. Thus, neither lesion was adequate in this respect.

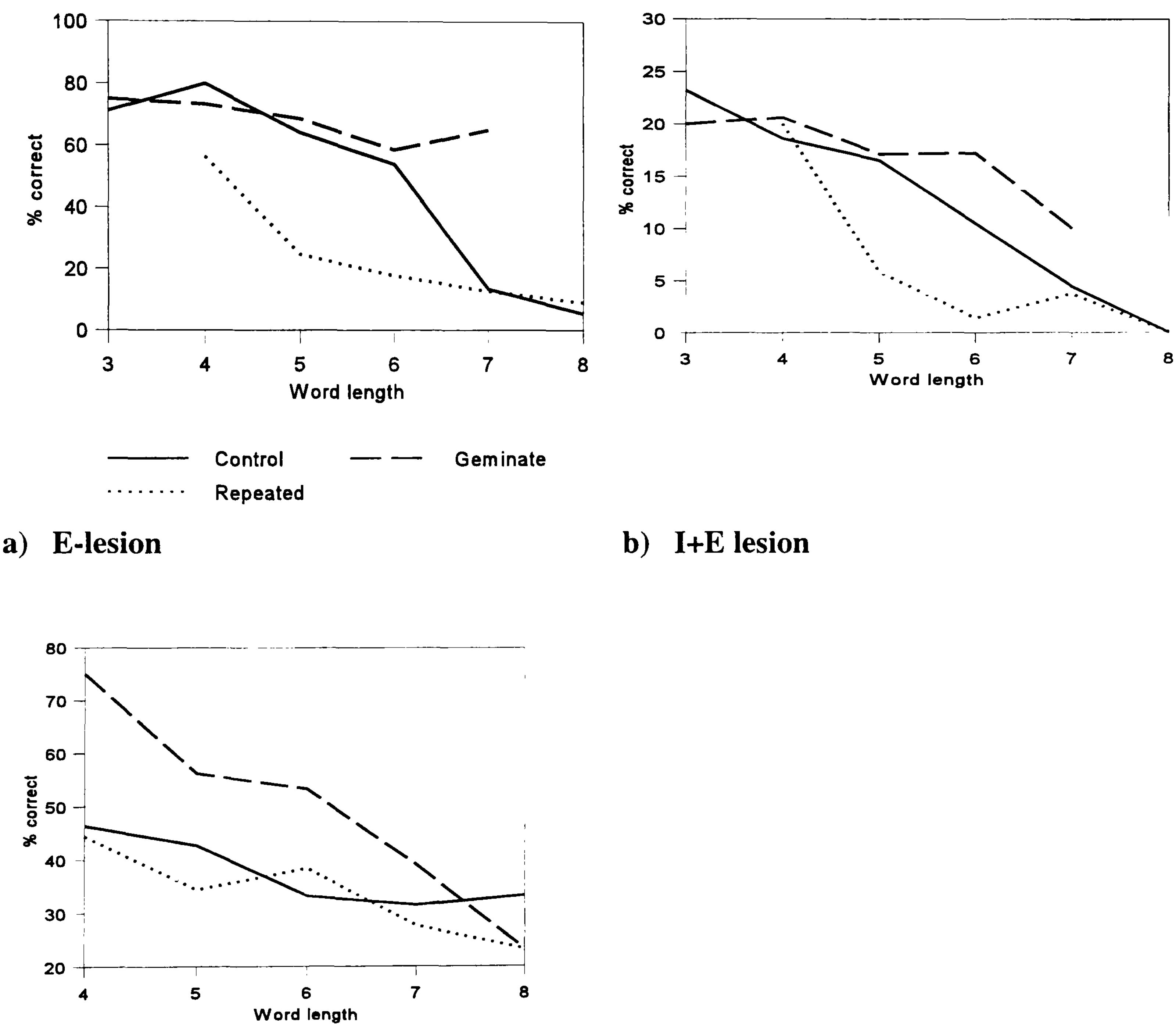


Figure 10 : Performance (% words correct) on different word types as a function of word length for the lesioned model and BA.

The model was also tested by comparing 40 geminate words with 40 length-matched words which contained no repeated or geminate letter sequences (each word was presented 5 times generating 200 responses). Letter pairs occupying the same serial positions were compared (e.g. apple v. black), and were scored according to whether both letters, one letter or none of the letters were present in the response (all 200 responses were considered). The results are displayed in Table 18. Following the E-lesion, the model was significantly more likely to produce one letter identity of a geminate pair than of matched pairs ($\chi^2(1)=14.99$, $p<.001$). This was due to a high proportion of geminate shifts (e.g. apple→*aplle*; 31/57, 54.4%) and omissions (e.g. aple→*aple*; 26/57, 45.6%). In contrast, the I+E lesion produced the reverse effect in that the two letter identities of a geminate are less likely to be broken-up than for matched pairs ($\chi^2(1)=9.14$, $p<.01$). This pattern is the same as BA's.

Table 18: Performance with geminate and matched sequences in the lesioned model and BA.

			# Letters Correct % (N)	
	# errors /200	**Both**	**One**	**None**
E-lesion				
Geminate	76	66.5 (133)	28.5 (57)	5.0 (10)
Control	92	84.0 (168)	13.0 (26)	3.0 (6)
I+E lesion				
Geminate	170	41.0 (82)	7.5 (15)	51.5 (103)
Control	171	28.5 (57)	17.5 (35)	54.0 (108)
BA	**/75**			
Geminate	35	60.0 (45)	2.7 (2)	37.3 (28)
Non-geminate	46	46.7 (35)	16.0 (12)	37.3 (28)

(7) *Words with repeated letters.* This is a critical test for the model since BA shows no effect of repeated letters whereas the expectation is that the model will perform poorly. The lesioned model's ability to recall words with repeated letters as a function of word length is shown in Figure 10 (above). The E-lesion significantly reduced the model's ability to spell words with repeated letters, but only for words of length 4 to 6 ($\chi^2(1)$=17.6, 124.3 and 80.5 respectively, p<.001). The I+E lesion was also significantly worse at spelling words with repeated letters, but only for words of length 5 to 6 ($\chi^2(1)$=24.1 and 22.8 respectively, p<.001). Longer words may be less vulnerable because the distance between repeated letters will (on average) be greater for longer words (cf. baby v. empire), and will thus require less activation from the sequencing nodes to be reselected.

In attempting to compare BA's pattern of no difference between words with repeated letters and all-different letters to the pattern produced by the model it is important to introduce one statistical caveat - namely the difficulty in attempting to 'prove' a null hypothesis and the low power associated with detecting a small effect. However, it can be seen from Figure 10 that the order of magnitude of the difference between repeated letter and all-different conditions is sufficiently large to suggest that the model is not producing an adequate approximation to the data. This suggestion is further bolstered by the results of a qualitative analysis of the responses and by a more extensive range of lesions (described below) which also suggest that the model is unable to produce 'no difference' (loosely defined) between repeated letter and all-different conditions.

As with the geminates, the model was also tested on its ability to produce both letters of a pair (40 words with repeated letters, 40 length-matched words with no repeats or geminates). Letter pairs occupying the same serial positions were compared (e.g. paper v. black) and all 200 responses were scored according to whether both letters, one letter or none of the letters were present in the response. The results are displayed in Table 19. After the E-lesion, the response was more likely to contain only one of the repeated letters compared to matched pairs ($\chi^2(1)=6.76$, $p<.01$) and similarly after the I+E lesion ($\chi^2(1)=14.77$, $p<.001$). Thus neither lesion could reproduce this aspect of BA's pattern.

Table 19: Performance with repeated letters and matched sequences in the lesioned model and BA.

			# Letters Correct % (N)		
		# errors /200	**Both**	**One**	**None**
E-lesion					
	Repeated	142	56.0 (112)	42.5 (85)	1.5 (3)
	Control	92	70.0 (140)	30.0 (60)	0.0 (0)
I+E lesion					
	Repeated	184	13.5 (27)	52.0 (104)	34.5 (69)
	Control	171	31.0 (62)	33.0 (66)	46.0 (72)
BA		**/75**			
	Repeated	50	46.7 (35)	18.7 (14)	34.7 (26)
	Non-repeated	52	44.0 (33)	24.0 (18)	32.0 (24)

Interim Summary

In short, both lesions have been able to reproduce many aspects of BA's performance, although neither lesion has been able to reproduce the whole pattern. This is summarised in Table 20. On balance, a reduction in the activity of both sequencing nodes (the I+E lesion) offers the best characterisation of BA's performance of the two lesions considered. In the instance in which the model performed poorly, a more extensive range of lesions were carried out to assess the generality of this effect.

Table 20: Summary of the lesioned models performance in the 2 lesion conditions.

		I+E lesion	**E-lesion**
1a	Errors increase from L->R	✔	✔
1b	Errors related to ordinal position	✔	▬
2a	Production of fragments	✔	✔
2b	Fragment length unrelated to word length	✔	✔
3a	Types and proportions of single letter errors	✘	▬
3b	Single letter errors increase L->R	▬	✔
4	Weak word length effect	✔	✘
5	A benefit of cueing	✔	▬
6a	Words with geminates spelled better	✘	✘
6b	Geminate pairs aren't split	✔	✘
7a	Words with letter repeats spelled as well as words without	✘	✘
7b	Repeated letters are split as often as non-repeated letter pairs	✘	✘

✔ able to reproduce this charcteristic well
▬ able to reproduce this characteristic weakly
✘ unable to reproduce this chacteristic

Further Lesioning

It is important to ascertain whether instances in which the model was unable to adequately reproduce the pattern of data reflect a general difficulty with the model or just a difficulty which arises at the particular lesion levels that were chosen. To this end a more extensive range of lesions were carried out, in which the maximum activation of the I node varied about the values 1.0, 0.75, 0.5, 0.25 and 0.0 in combination with E node lesions of 1.0, 0.75, 0.5, 0.25 and 0.0 (25 conditions in total). On each recall attempt, the activation was allowed to vary randomly around the lesion level within a 0.25 range at either side (with the constraint that the activation never falls outside the 0 to 1 range). The results of these lesions are given in Appendix 5 and are summarised below.

(4) *Word length effect.* The previous lesioning attempts had shown that it was possible to produce a weak effect of word length but at a reduced performance level (the I+E lesion) or a similar performance level but with a strong effect of word length (the E-lesion). The further 25 lesions were not able to produce a much closer fit to BA's performance. This is largely because the model has particular difficulties in spelling the longer words in the set (7-8 letters) at all lesion levels, so increases in overall performance tend to be associated with increases in the strength of the length effect. The lesion which produced the closest fit was I=0.75/E=1.0. In this condition, the model was able to spell correctly words of length 3 to 8 at levels (%) of 90, 45, 45, 31, 25, and 4. The comparable rates for BA were 64, 46, 41, 39, 28 and 26.

(5) *Geminates.* BA was generally better at spelling words with geminates compared to those with all-different letters (Figure 10). This effect was particularly prominent for shorter

words. None of the 25 lesions produced better performance for words with geminates at all word lengths. Performance across word lengths tended to be of a more unpredictable nature. For example, in the I=1.0/E=0.25 condition performance was better for words with geminates at lengths 3 and 7, performance was worse for words with geminates at a length of 4 and there was little difference between words with geminates and all-different letters at lengths 5 and 6. A full understanding of this pattern is not obtainable at present. What is to be noted at this stage is that the model still has some difficulties in accounting for BA's good performance with geminates even after a wider range of lesions.

(6) *Repeated letters.* BA is able to spell words with repeated letters as well as those with all-different letters at all word lengths tested. Out of the 25 lesion conditions tested the only ones which produced equivalent performance for words with repeats and words with all different letters were those where performance was at floor - i.e. the model was unable to spell at all regardless of word type. Of the remaining lesion conditions (N=12), 11 were characterised by poorer performance for words with repeats compared to those without. Interestingly, one condition resulted in superior performance for words with repeats - this corresponded to a comparatively strong E-node (I=0.5/E=1.0) which serves to highlight the role that this particular feature of the model plays. However, it should also be noted that apparently good performance with words with repeated letters in this condition may arise only because a significant number of items were excluded from the test phase because the model was unable to learn them in the first place.

Responses were analysed qualitatively according to whether they contained both letters, one letter or no letters from the critical pair (e.g. **p**a**p**er) relative to matched letters from a word containing all-different letters (e.g. **t**a**b**le) as described before. Again, the only conditions in which performance with repeated letters was equivalent to control pairs were those in which the overall performance of the model was at floor or at ceiling. In all other conditions, there was a strong tendency for repeated letter pairs to be reduced to one letter relative to control pairs. Thus a wider range of lesion conditions failed to reproduce the pattern of repeated letters producing an equivalent outcome to non-repeated sequences (both quantitatively and qualitatively).

4.5 Discussion

It was suggested that BA's impairment should be able to be accounted for by connectionist models which attempt to simulate lexical-orthographic activation (and this in turn will be reflected when activation is passed to a graphemic buffer or letter level). This pattern was considered to be within the scope of at least one existing connectionist model (that of Houghton et al., 1994) which was therefore implemented and lesioned. The ability of the model to account for the data also constitutes, in effect, an independent test of the model since it was not specifically designed to account for this particular pattern. This differs from many other connectionist modelling enterprises where the to-be-explained data often motivates important design features of the model.

Although the performance of the model on certain criteria may have been easily predicted without having to lesion the model other criteria were not easy to predict. For instance, the fact that fragment length does not tend to increase with word length and the fact that the model may be cued to 'release' more letters without having to resort to a chaining explanation is not an obvious outcome of lesioning. Thus the model was able to account for less intuitive aspects of BA's performance. It will be suggested that the difficulties faced by the model are not sufficient to abandon the 'competitive queuing' approach altogether, although several modifications to the model may be desirable.

Difficulties faced by the model

In the instances where the model did not adequately reproduce the pattern of data it is important to decide whether this is a reflection of relatively 'malleable' features specific to the model's implementation (e.g. the free parameters), whether it reflects the limited scope of the model or whether it reflects a more fundamental design problem in the model (e.g. the choice of representation).

The first problem with the model is its inability to learn the entire corpus of words. Within the current competitive queuing framework, certain words (e.g. those with repeated letters) will always be difficult for the model to learn, but not necessarily impossible to learn. One exception to this, is that the model could never learn words with consecutive geminates (e.g. tattoo, committee) without a more fundamental design change or *ad hoc* modifications, since the geminate node is immediatelt inhibited each time it is selected. The model also has severe difficulties in spelling words with many repeats of letters (e.g. banana, alcohol) because the summed activation of letters is necessarily low, thereby precipitating premature stopping. Unfortunately, an analysis of how normal spellers learn such words may not be informative because learning to spell is likely to entail a phonological component (e.g. Frith, 1985) which is not simulated by the current model.

The second problem is that many of the errors produced by the model do not closely resemble those produced by BA or other patients reported in the literature. The model produced a high proportion of order errors (e.g. transpositions) which are very common in tasks such as immediate serial recall (e.g. Conrad, 1965) but tend to be an infrequent error type in spelling (e.g.

Wing & Baddeley, 1980). In addition, the model was not able to produce spelling errors which involve intrusions by letters not already found in the word (e.g. pencil→*pancil*). The model also produces many errors which violate orthotactic constraints (e.g. pencil→*penlci*). The model needs to be extended in order to give an account of the influence of phonological factors in spelling (which may explain intrusions) and to take into account orthotactic constraints/regularities in the orthography. Only after the model has been developed in such a way will it be possible to judge whether it is capable of producing more 'realistic' spelling errors.

The most problematic criteria for the model were those related to geminate and repeated letters. BA is often able to spell words with geminates better than length matched words without. However, the model had difficulty in reproducing this pattern. This might reflect the fact that for an *n* letter geminate word (e.g. *hello*), the model must still activate *n* units at the letter layer (h+e+l+geminate marker+o) in a similar way to *n* letter words with all-different letters. It is also conceivable that in BA the geminate marker may have been selectively spared, hence explaining why she is better with geminates but the lesioned model isn't (Miceli et al., 1995, report a patient who they suggest has a selectively impaired geminate marker).

It is also worth considering whether the geminate pattern can be explained without recourse to a geminate node. A geminate node that is associated to a single letter identity may predict that geminate substitutions (e.g. rabbit→*rannit*) should be as common as other letter substitutions. However, Romani and Calabrese (1996) noted that this was not the case in 2 graphemic buffer patients, and the same effect was noted in BA (although the number of errors on geminates is low). An alternative may be to represent geminate sequences identically to other letter sequences but to assume that a letter is primed (at some level) after production, so that the same letter is then easier to retrieve again. However, this has difficulties in accounting for geminate shifts (e.g. rabbit→*rabitt*). Another proposal is to have a single letter associated to two position encoding tokens (e.g. McCloskey et al., 1994). However, as noted below, it is hard to make specific predictions from this model without a description of how the units are activated and selected.

The difficulty with repeated letters was found even when a more extensive range of lesioning was carried. Although, one lesion conditon apparently did produce better performance for words with repeats than those with all-different letters (suggesting that poor performance is not a necessary consequence of damaging the sequencing nodes), even in this instance there was a greater tendency for only one letter of a repeated pair to be produced relative to the control pairs[10]. These problems are potentially serious because they bring into question the choice of representation used in the model (see Olson & Caramazza, 1994).

The problem of representing multiple occurrences is common to all psychological mechanisms involving sequences (such as serial recall, sentence production and comprehension, speaking and spelling). One possibility is to have multiple instantiations (or tokens) of each representational unit. For instance, repeated tokens of each letter may be represented at each position (following McClelland & Rumelhart, 1981) or represented in each possible letter context (as in trigram models such as Seidenberg & McClelland, 1989). Figure 11 shows how repeated tokens may be incorporated into a competitive queuing model of spelling. The next section will

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[10] The effect of repeated items in non-spelling tasks involving serial recall (e.g. immediate recall of a digit sequence) has been previously investigated (see Jahnke, 1969). The basic phenomenon has been termed the 'Ranschburg Effect' (Jahnke, 1969) and may be stated as follows: if the sequence contains a repeated item (e.g. 5295074) then recall will be worse than if the sequence contains all-different items (e.g. 5298074), and there will be a tendency for the second repeated item to be omitted or substituted. Thus, BA does not show evidence of a Ranschburg effect in spelling repeated letters although the model does.

discuss how such a model may be set-up.

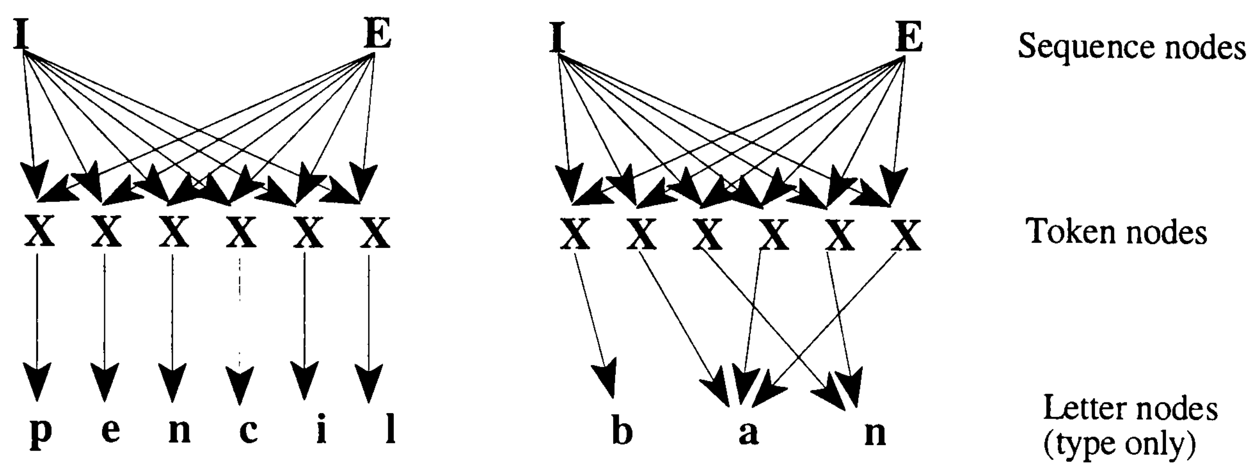

Figure 11 : A repeated token model of competitive queuing illustrating how the words pencil *and* banana *may be represented.*

<u>Modifications to the model</u>

Modifying the current model to a repeated token model may bring about certain benefits, other than the ability to model BA's data. For example, the model would be able to learn words with repeated letters as well as other words. The tokens themselves may also have the potential to encode information such as consonant-vowel status (e.g. Cubelli, 1991), or may be connected to units in an ortho-syllable frame. If such nodes were to represent actual positions in a word then the representation would begin to take on a spatial character, as implied by studies of neglect dysgraphia (e.g. Caramazza & Hillis, 1990a). However, the implementation of a token layer of representation would involve the modeller having to make many assumptions about the exact design with (as yet) very little empirical or theoretical guidance. For instance, why would this model require an E-node (see Page & Norris, submitted, for a model that does without)? Are the tokens specific to each word or are they a shared pool used by every word? Which layer does competition take place at? It is also not clear what role a geminate node would play in a repeated token model.

In conclusion, it is hoped that the lesioning enterprise has provided some more general insights into the computational difficulties associated with the spelling process, and has identified possible avenues for future research. The successes and difficulties faced by this model may have implications for the modelling of serial order in other domains. Indeed the notion that serial order can be encoded by an ordering of activation values has already been applied to connectionist models of short-term memory (Burgess & Hitch, 1992, 1996; Glasspool, 1995; Page & Norris, submitted), speech production (Houghton, 1990; Houghton, Hartley & Glasspool, 1996), typing (Rumelhart & Norman, 1982), and visual search (Houghton & Tipper, 1996).

5. THE RETRIEVAL OF PROPER NAMES

5.1 Introduction: Proper Name Processing in Reading and Writing Impairments

In previous studies of proper name retrieval the standard methodology has been to investigate the patients ability to produce a name to confrontation or definition. This literature was reviewed in Chapter 1 (Section 1.5). Naming in this way is generally assumed to involve access to a semantic description of the individual concerned (e.g. Bruce & Young, 1986). However, it is possible to study the importance of semantic memory on proper name processing by asking patients who have damage to phoneme-grapheme and/or grapheme-phoneme conversion to read or write names, since such patients are also assumed to be reliant on a semantic description for production. There have, however, been few studies of proper name processing in reading and writing impairments (but see Cipolotti et al., 1993; Saffran, Schwartz & Marin, 1976; Shallice & Saffran, 1986). This is in spite of the fact that there are certain advantages in using this methodology. For instance, it is hard to find suitable stimuli for a naming experiment for items such as *Nigeria* or *Beirut* unless, of course, the patient has a very high standard of map knowledge. It is, however, trivially easy to ask a patient to read or write such words. Also, the naming to confrontation/definition method is necessarily restricted to familiar proper names whereas reading and writing can use both familiar (e.g. *Jack Nicholson*, *Dean Martin*) and unfamiliar names (e.g. *Jack Martin, Dean Nicholson*) as stimuli. For example, Young, McWeeny, Ellis and Hay (1986) showed that normal subjects were faster at reading the former type of name relative to the latter, suggesting some person-specific facilitation in normal name reading, over and above factors such as first name and surname frequency.

Shallice and Saffran (1986) provide one of the first studies of proper name processing in a dyslexic patient. The patient was a 'pure alexic' (or letter-by-letter reader) who had difficulties in recognising and reading words aloud. Despite this, the patient was able to classify many words into semantic categories and showed some evidence for sparing of proper name knowledge. The patient could classify 93% of proper names which she could not read as author/politician but only 30% of common nouns were successfully categorised in a 5-category choice (animals, plants, food, body parts, objects). This suggests that written comprehension of proper names may be selectively spared.

Other reading studies have suggested that in some instances, proper name retrieval may be relatively spared. Saffran et al. (1976) studied proper name reading in deep dyslexia. They found that lexical substitutions occurred when reading isolated words (e.g. *May*→June) but were significantly reduced when presented for reading in an unfamiliar proper name context (e.g. *May Johnson*). Saffran et al. (1976) suggest that proper name context may restrict the spread of activation from a common lexical locus. Reading words in an appropriate phrase (e.g. *a heart attack*) also reduced the rate of lexical substitutions, but to a lesser extent than the proper name context.

The only study of proper name production in a deep dysgraphic patient, that I am aware of, is that of Cipolotti et al. (1993; see Section 1.5.3) in which proper name retrieval for familiar people and places was selectively spared relative to common noun retrieval. More recently, however, Brédart et al. (1997) have suggested that apparent retrieval difficulties for common nouns relative to proper names may be secondary to common noun comprehension difficulties. For instance, in a follow up study of MED this patient was found to be impaired on word-picture matching for common nouns but not famous names (McNeil et al., 1994).

This Chapter investigates a deep dysgraphic patient's ability to retrieve proper names. She is able to retrieve proper names just as well, if not better, than common nouns and her ability to produce proper names is related to a number of factors including familiarity and context/cueing. In contrast, a deep dyslexic patient is reported with a selective difficulty in reading names. The work of Saffran et al. (1976) is extended by considering common first names, famous names and personally familiar names. The results are discussed in terms of the distinction between processing of proper names and common nouns.

5.2 Proper Name Processing in BA

In the deep dysgraphic patient, BA, the motivation for studying proper names was initially driven by the observation that proper names form a large part of her spontaneous written vocabulary. Names produced spontaneously include the names of personal acquaintances, famous people and country/city names. In fact, after one testing session she returned the next week with a list of 345 different common first names (e.g. *John, Anne*) which she had produced during the week at home unaided. When asked to produce a list of actors/actresses at home she wrote down 209 names. Many of the names were no longer common in the public domain (e.g. *Spencer Tracy*) which suggests that she had not copied them from newspapers or television. Her ability to generate the names of animals (147) and types of food (124) was also good, with many low frequency items being produced (e.g. *elk, vole, tapioca*). These initial observations are interesting because it suggests that given enough time her ability to produce single words is good. This is consistent with a lexical retrieval deficit (as suggested earlier) rather than a complete loss of information. Warrington and Shallice (1979) went as far as to speculate that their 'access dyslexic' patient could exhibit a normal reading vocabulary given enough time. On the basis of the evidence above, it is possible that BA too could exhibit a near-normal spelling vocabulary given enough time, at least for high imageability words for which there is little evidence of any confounding comprehension deficit.

This observation is also interesting because if BA does have a retrieval difficulty then the category of proper names may be expected to be particularly affected, since this pattern has been documented in the literature on normal word retrieval problems (e.g. Burke et al., 1991; Young et al., 1985). Therefore, her ability to recognise, comprehend and produce proper names was examined in more detail.

5.2.1 Recognition and Comprehension of Proper Names

BA's ability to recognise names was assessed in a lexical decision task and in a famous person decision task.

<u>Lexical Decision with Names</u>

This task contained 25 first names, 25 country names and 25 common nouns. The common nouns were all of high imageability and taken from a variety of semantic categories (living and nonliving). Words from each of the three lists were matched item-for-item for word frequency (Carroll et al., 1971) and word length. Nonwords were created by substituting a single letter in the word. The position of the substitution within the word was varied and orthotactic/phonotactic constraints were preserved. The test was administered in spoken form since the main paradigm used to test BA's spelling of names was writing to spoken dictation. BA scored 95% (143/150). Three age and education matched control subjects performed slightly better than BA (with scores of 98%, 99% and 100%).

Recognising Famous Names

Several models of name recognition incorporate name recognition units for familiar people (e.g. *Margaret Thatcher*) which are activated after the isolated first names and surnames (Burton & Bruce, 1993; Valentine, Brédart, Lawson & Ward, 1991). These units differ from person identity nodes (or PINs) in that they are pre-semantic in nature and modality specific (i.e. separate written and spoken name recognition units). The test consisted of 20 famous names (e.g. Tom Jones, Michael Jackson) and 20 unfamous names (e.g. Tom Jackson). The unfamous names were created by rearranging the first names and surnames used in the famous condition. When the names were presented orally to BA she scored 95% (38/40). In the written version she scored 93% (37/40). Three age and education matched controls scored 97%, 97% and 100% (in the written form).

Thus BA has little difficulty in recognising names. Her ability to comprehend names was first assessed in a matching task.

Written word - Spoken word Matching

A number of studies have reported category-specific deficits in global aphasia. For example, they may be poor at written word - spoken word matching with common first names (e.g. John) but not famous names (e.g. Picasso), (Forde & Humphreys, 1995; Warrington & McCarthy, 1987). Forde and Humphreys (1995) showed that their patient was impaired at deriving phonology from written words and so must presumably be performing the task semantically. They argued that common first names have impoverished semantic representations (perhaps restricted to gender) which are insufficient to distinguish between exemplars, whereas famous names are able to access a richer semantic-biographical information to enable correct matching.

BA's ability to derive phonology from written words is poor (e.g. written rhyming judgements) and her ability to match a spoken word to a written word has been shown to be good for high imageability nouns but impaired for low imageability function words. Therefore, if common first names do have impoverished semantic representations then BA might be expected to be impaired at this task.

Items were taken from a set of 30 common first names, 30 common surnames, 30 high imageability common nouns (mixed categories) and 20 famous surnames. The first names, surnames and nouns were matched for length and frequency (Carroll et al., 1971). BA was given 5 written words from the same set. She was then required to match a written word to each spoken word presented in turn, in a pseudo-random order. She made no errors with the first names (30/30), famous names (20/20) or common nouns (30/30), but four errors with the surnames (26/30, 87%). Thus BA shows no impairment in matching common first names even though she is impaired at comprehending other low imageability categories.

The next test examined her comprehension of proper names further and also tested comprehension of place names.

Odd One Out Tasks

BA was given three common first names consisting of either two boys names and a girls name (e.g. Charles, Susan, Robert) or two girls names and a boys name (e.g. Betty, Alice, Harry) and was required to point to the name which was the odd one out (i.e. different gender). She scored 20/20 on this task (the 3 controls also scored 20/20). On a similar task with 3 written country names (e.g. Russia, Spain, Portugal) in which she must decide which country is not part of the same region, she scored 18/20 (3 controls scored 18, 20 and 20). In a similar test with city names (e.g. Venice, Barcelona, Rome) she scored 17/20 (3 controls scored 18, 20 and 20).

Thus BA's knowledge of places and common first names is good. Her knowledge of famous people was assessed in the last test.

Famous people semantics

These tasks used the names of 15 famous people. The patient must decide whether an occupation goes with a given person (e.g. John Major - Politician) or whether a physical feature goes with a person (e.g. John Major - Glasses). Half of the items require a 'yes' response and half require a 'no' response. Items in the 'no' condition were formed by rearranging the people and attributes used in the 'yes' condition. The questions were spoken by the experimenter and BA indicated her response by pointing to the written words *yes* and *no*. BA scored 26/30 in the occupation decision task (3 controls scored 28, 30 and 30) and 27/30 in the appearance decision task (3 controls scored 25, 27 and 29).

In summary, BA has little difficulty in recognising or comprehending proper names and shows no dissociation between common nouns and proper names at these levels. The next section will examine her ability to retrieve proper names.

5.2.2 Written Production of Proper Names

Category Fluency

BA had previously been able to write down an impressive number of names and nouns in unconstrained circumstances (i.e. with no time limit and at home). An attempt was made to replicate this fluency in the laboratory by asking her to write down as many exemplars of a given category that she could. The results are displayed in Table 21. For comparison, data from a deep dyslexic patient (KBP, Section 5.3). The number correct was noted after each minute, stopping after 5 minutes. When asked to generate words beginning with a given letter then any type of word was permissible (including proper names) but were instructed to avoid words derived from the same stem (e.g. walk, walked, walking). BA made 11 misspellings in which the intended target was clear (e.g. *Switzland* [Switzerland]). These were scored as correct, since they demonstrate appropriate selection of a lexical item (even though letter retrieval was deficient).

BA was better at generating first names relative to any other category. The other patient reported in this Chapter (KBP) was also impaired at category fluency but did not show any evidence of preservation of first names. The only other noticeable 'category' effect in BA was a difficulty with generating abstract words. This is not surprising given her difficulty in comprehending these words (Section 2.2).

Table 21: Category fluency in BA (written) and KBP (spoken). Total number of words produced after 5 minutes (number after first minute shown in brackets).

	BA	KBP
PROPER NAMES		
Girls names	25 (10)	5 (2)
Boys names	24 (11)	6 (5)
Country names	14 (8)	10 (3)
Surnames	12 (4)	4 (0)
City Names	10 (6)	7 (2)
Actors/actresses	10 (4)	2 (0)
Total	**95**	**34**
CONCRETE CATEGORIES		
Food	19 (8)	24 (7)
Clothes	14 (6)	7 (3)
Animals	11 (7)	15 (8)
Colours	11 (5)	8 (3)
Body Parts	9 (1)	11 (6)
Drink	8 (5)	13 (5)
Total	**72**	**78**
WORDS BEGINNING WITH...		
T words	16 (3)	8 (1)
W words	11 (6)	8 (4)
P words	9 (4)	8 (5)
B words	8 (3)	7 (2)
S words	8 (3)	11 (4)
ABSTRACT CATEGORIES		
Moods and emotions	0 (0)	NT
Action words / _ing words	1 (0)	NT

NT = not tested.

Given BA's good ability to generate first names, her ability to write first names to dictation relative to other categories was assessed.

First Names, Surnames and Nouns

This list comprised of 30 common first names (e.g. Martin, Rebecca), 30 common surnames (e.g. Baxter, Watson) and 30 high imageability nouns (e.g. berry, ostrich). Words which can function as either proper names or nouns were avoided (e.g. carpenter), as were names which are almost exclusively associated with a single person (e.g. Thatcher, Jagger). The words were matched individually for word frequency (Carroll et al., 1971) and word length, and were presented in a random order for BA to write to dictation.

BA scored 73% (22/30) with the first names, 13% (4/30) with the surnames and 37% (11/30) with the nouns. All these differences are significant (first name v. surname, $\chi^2(1)= 22.0$, $p<.001$; first name v. noun, $\chi^2(1)= 8.2$, $p<.005$; surname v. noun, $\chi^2(1)= 4.4$, $p<.05$).

Although this result suggests that BA is better with some categories than others, the familiarity of words was not matched. Consequently, BA may have been better with first names because the words were more familiar to her. The effect of personal familiarity was assessed more carefully in the next experiment.

Effect of first name familiarity

Although personal familiarity is likely to be an important consideration in all single case studies, it may be particularly important in studies using proper names since there is likely to be wider variation in exposure to words/concepts such as *Victor* and *Edward* as opposed to, say. *table* and *lettuce*. BA's husband was asked to rate a large corpus (N=500) of first and surnames according to the patient's own personal familiarity (amount of contact) with these names. A six point scale was used (5=highly familiar, 0=very unfamiliar). The rater was also asked to highlight any words which he didn't recognise as being a real name, although none were noted. A matched list of items was prepared consisting of high-familiarity first names (mean rating=4.5, sd=0.7), low-familiarity first names (mean rating=0.4, sd=0.5), high imageability nouns and low imageability nouns. Each word was matched closely to another word in each of the four lists according to tabulated word frequency (Carroll et al., 1971) and word length.

The words were presented in random order for BA to write to dictation. She scored 78% (47/60) on the high familiarity names, 33% (20/60) on the low familiarity names, 33% (20/60) on the high imageability nouns and 17% (10/60) on the low imageability nouns. Overall, BA was significantly better at spelling the proper names relative to the common nouns ($\chi^2(1)=23.69$, $p<.001$), thus replicating the original finding. However, this effect is largely due to the influence of the high familiarity names which were spelled significantly better than low familiarity names ($\chi^2(1)=24.63$, $p<.001$). Within the common noun category, high imageability nouns were spelled significantly better than low imageability nouns ($\chi^2(1)=4.44$, $p<.05$) as has been documented before.

Although this study shows that proper name processing is influenced by familiarity it does not weaken the contrast between common nouns and proper names, since many of the common nouns are also highly familiar. BA's husband was asked to re-rate the words for familiarity a second time (defined according to the same scale), this time taking ratings for the common nouns as well as proper names. Indeed the mean familiarity ratings for the proper names were not significantly greater than for the common nouns (mean rating: names=1.22, nouns=1.00; $t(238)=1.15$, *ns*).

It has been demonstrated so far that BA's ability to produce common first names is good, and at least as good as high imageability common nouns. The next test will examine whether this effect is also found for famous proper names.

Famous Names

BA was able to write to dictation 115 famous name pairs (e.g. *Mel Gibson*, *Vincent Price*). The famous names consisted of figures famous during the last 50 years (mainly film and television celebrities). She scored 57% (66/115) correct . Items were scored as correct only if both the first and surname were correctly spelled. If responses are scored according to the number of 'parts' correct then her score on these words was 73% (168/230; 94 first names and 74 surnames correctly produced). The errors produced are discussed below, but typically consisted of failures to respond. By comparison, for high imageability nouns (extracted from the total corpus) she scored 53% correct (546/1034). Thus BA is at least as good at writing down the names of famous people compared to high imageability nouns, if not better if one considers first and surnames as distinct.

BA was also asked to write to dictation 25 names of non-contemporary figures which may be denoted only by a single name (e.g. *Columbus*). These names were matched to 25 high imageability nouns for word frequency (Carroll et al., 1971) and word length. BA was able to write only 12% (3/25) of the famous names to dictation but 28% (7/25) of the nouns to dictation. The 3 names which she was able to produce had all been famous during her own lifetime (*Churchill*, *Hitler*, *Kennedy*). If one considers only the more historical names (e.g. *Columbus*, *Mozart*) then she was unable to write any of these names (0%, 0/18) but was still able to write 33% (6/18) of the matched nouns. Her errors consisted of visually related responses (N=10; e.g.

Mozart→*Mozit*), failures to respond (N=9), unrelated responses (N=2; e.g. Beethoven→*Twin*) and a semantic approximation (N=1; Napoleon→*Bonl*). It is possible that her difficulty with historic names (as opposed to famous contemporary names) could reflect differences in imageability or familiarity between these two categories.

BA's difficulty in producing historical names is unlikely to reflect a comprehension deficit. She was given a written forced choice test involving a subset of the names used above in which she must choose the correct occupation (e.g. *Columbus* - actor, scientist, painter, explorer) or nationality (e.g. *Einstein* - German, French, Spanish, Italian). She scored 30/32 on this test (her errors were incorrectly classifying Columbus and Picasso as Portuguese and French respectively).

Effect of other Semantic Categories

It has been demonstrated that BA is often able to produce proper names better than even high imageability nouns. In order to assess whether BA's ability to write to dictation is influenced by other category effects a list of 161 words were prepared drawn from 10 semantic categories. There were seven common noun categories which were all considered to be high in imageability. There were two proper name categories (common first names and countries) and one adjectival category (colours). The groups of words did not differ in word frequency (Carroll et al., 1971) or length, although words were not matched on an item-for-item basis. Words were presented in random order.

The results are displayed in Table 22. BA showed no overall effect of semantic category. The observation that proper names were not spelled any better is interesting, although it is not necessarily inconsistent with the existing pattern. This is because her ability to produce proper names is not fixed but is related to a number of other factors, including familiarity, context and possibly frequency and imageability. However, the most important point to note is that on none of these tests was performance worse for proper names relative to common nouns, despite the fact that she has been classed as having a deficit of lexical retrieval.

In order to eliminate factors such as frequency and familiarity a comparison of her ability to produce the same word in different contexts may be informative.

Table 22 : Effects of semantic category on BA's writing to dictation.

Category	%	**N**
Food	86.7	(13/15)
Furniture	82.4	(14/17)
Body Parts	72.2	(13/18)
First names	69.2	(18/26)
Family (e.g. *sister*)	69.2	(9/13)
Colours	63.3	(7/11)
Animals	63.2	(12/19)
Plants	61.5	(8/13)
Transport	61.5	(8/13)
Countries	56.3	(9/16)

Can Proper Name Context aid Retrieval?

Writing Isolated Surnames given Disambiguating Information

It was noted above that BA is often poor at writing isolated surnames to dictation (13%). BA was given a further 29 surnames to write to dictation but this time presented in two different conditions: as an isolated word (e.g. Jones) or in the context of a specific person (e.g. "Jones - as in the singer Tom Jones"). Surnames which are already strongly associated with a specific person (e.g. Thatcher, Jagger) were avoided. The two conditions were given in an AB-BA design over two sessions to minimise effects of repetition. BA scored 24% (7/29) with the isolated surnames and 66% (19/29) with the surnames in context ($\chi^2(1)=10.04$, $p<.005$). This effect cannot be attributed to lexical variables (e.g. frequency) since the same word was used in both conditions. The next experiment assessed whether similar effects are found for first names and names which can also function as other English words..

Writing Names which are also other Words

The names of 36 famous people whose surname is also another English word, mainly common nouns, were collected (e.g. Vincent Price, Noel Coward). BA was asked to write to dictation either the whole name, the first name only, or the surname only (the non-name condition). The words were presented over two sessions. She was not asked to produce the same item more than once in a given session and items were given in an AB-BA design (A=whole name, B=parts). BA was able to spell 65% (20/31) of first names when presented in isolation and 89% (32/36) when presented in the context of a whole name ($\chi^2(1)=5.69$, $p<.05$). There were only 31 names in the isolated names condition because some names were repeated in the famous names (e.g. John Hurt, John Thaw). All 4 of her errors for the first names in context were synonym errors (e.g. Jimmy→*Jim*, Nick→*Nicky*) and could, arguably, be classified as correct. Her errors for the isolated first names consisted of failures to give a response (N=3), nonwords/fragments (N=3), a synonymous name (N=1) and other names (N=4, e.g. Lucille→*Audrey*). She was able to spell 61% (22/36) of surnames/non-names when presented in isolation and 86% (31/36) when presented in the context of a whole name ($\chi^2(1)=5.79$, $p<.05$). Her errors for the surname in context were 3 misspellings and 2 failures to respond. Her errors for the isolated surname/noun consisted of 4 failures to respond, 4 semantic errors, 2 visual lexical substitutions, 3 nonword/fragment responses and 1 morphological error. Although, the number of errors is small it is interesting to note that 4 semantic errors were found for the isolated surnames/nouns (e.g. day→*Thursday*), but no such errors were found when the same words were in a proper name context (i.e. *Doris Day* not *Doris Thursday*).

This study, together with the one on surnames, suggests that BA's ability to produce proper names can benefit from a person-specific context, and not solely on factors such as frequency and familiarity.

Analysis of Error Types

In total, BA was given 276 isolated first names to write to dictation and she wrote 61.2% (169/276) correctly. In all cases the names were not presented in blocks but were interspersed with common nouns to discourage the use of strategies. Her 107 errors consisted of 44 (41%) failures to produce a response, 28 (26%) lexical substitutions, 22 (21%) fragments (12 correct fragments, 7 related fragments, 3 unrelated) and 13 (12%) nonword responses (12 visually related, 1 semantically related). Although the error types are similar to those reported before (e.g. Table 1), one interesting feature is that of the 28 lexical substitutions 27 were between name-name pairs (e.g. Brenda→*Barbara*; see Appendix 6) and only one was between a name-noun pair (Beth→*bath*). Not only did lexical substitutions preserve proper name status they also preserved gender in 89% (24/27) of instances. Furthermore, name substitutions are influenced by orthographic/phonological similarity as well as by semantic similarity. 74% (20/27) of responses shared at least half of the letters/phonemes (e.g. Kevin→*Keith*) whereas only 26% (7/27) were visually unrelated (e.g. Victor→*James*).

In the total corpus of responses from writing to dictation famous name pairs (e.g. Elizabeth Taylor) she scored 57% correct (49/115). Of the 49 errors, only one of these (2%, 1/49) could be classified as semantic in nature (Bette Davis → *Betty Grable*). By comparison, she scored 53% correct with the total corpus of high imageability nouns, and 12.1% (59/488) of her errors were semantically related. Thus, she is less likely to produce semantic errors for famous proper names ($\chi^2(1)=4.53$, $p<.05$).

Of the remaining errors, one error (2%) transposed the first name and surname (Charlton Heston → *Heston Charlton*). Twelve errors (24%) affected both the first and surname (e.g. Boris Karloff → *Borif Kof*), 7 errors (14%) affected the first name alone (e.g. Nick Berry → *Nicky Berry*) and 28 errors (57%) affected the surname alone (e.g. Anthony Hopkins → *Anthony Hopwink*). It is interesting to note that 82% (94/115) of first names were spelled correctly when given as part of a famous name but that only 61% (169/276) were spelled correctly when presented in isolation ($\chi^2(1)=15.50$, $p<.001$). This is consistent with the previous finding that semantic/person-specific context can aid proper name retrieval.

Summary

BA is better at writing names (e.g. Jones, Tom) when they are presented in the context of a famous person (Tom Jones) than when they are not, even though the orthographic form is the same in both instances. It has also been shown that performance may be better for the same orthographic form when it is in the context of a famous person (e.g. Doris Day) compared to when it is processed as a non-name. Saffran et al. (1976) suggested that these effects may be due to reduced spread of activation to competitor items. Other possibilities include a beneficial effect of uniqueness and/or an increase in imageability. This will be returned to in the Discussion.

5.3 Proper Name Production in Deep Dyslexia : A Comparative Study

The previous study documented the ability of a patient to write proper names via a semantic route and identified a number of factors which influence her performance. This section documents a similar patient (KBP) who reads via a semantic route, but has a particular difficulty in reading people's names.

5.3.1 Case Background

KBP is a 46 year old, left-handed man who had a left cerebro-vascular accident in April 1991. He was walking within 10 days of hospital admission although he has still not regained the full use of his right arm. At onset, he was unable to converse in sentences but could produce some single words. He was often able to write down at least the initial letter of most words. This pattern was also found when KBP began testing for this study, some 4 years post onset, and has remained throughout testing. KBP is well oriented in space and time.

KBP had few medical problems prior to stroke, except for a hearing difficulty as a young child which was corrected by operation. He received 10 years of education and left school without formal qualifications. However, his wife reports that he had no particular reading or spelling difficulties prior to his stroke. He had previously worked as a factory foreman in a plastics company. When tested in our lab, he obtained a score corresponding to the 34th percentile on

Raven's Standard Progressive Matrices. This score is probably in line with his pre-morbid ability given his educational/occupational background.

KBP's spontaneous speech is hesitant and non-fluent with many word finding difficulties. His general speech production difficulties fit the pattern of so-called Broca's aphasia or agrammatism. When asked to describe the Boston Cookie Theft picture (Goodglass & Kaplan, 1972) his response was :

KBP : Chair... some, uh, cake, water ...

JW : What's happening here?

KBP : Kids, cake, crash ...

JW : What's happening here?

KBP : Water, woman here - stupid!, plate, stupid!

When asked to repeat single words and nonwords he was also impaired (words=20/24, 83%; nonwords=13/30, 43%). His errors consisted of phonological paraphasias and/or articulatory 'slurring', but semantic errors and other lexical errors were noticeably absent. His performance on a range of other cognitive tasks was assessed.

Phonological discrimination

KBP's ability to discriminate phonemes is good. In a same/different judgement with single phonemes which differ by one distinctive feature (e.g. /f/, /v/) he scored 12/12. In a same/different judgement with nonsense syllables (e.g. "prin", "drin") he scored 11/12. In a task taken from PALPA (test 4), the subject must match a spoken word to one of three similar sounding pictures (e.g. fan, van, can) which differ by one phoneme and/or feature. KBP scored 40/42 on this task.

Phonological short-term memory

KBP has a digit repetition span of 2 (2 digits = 8/10; 3 digits = 4/10 correct). KBP's ability to point to named objects following a spoken sequence of words was also assessed. There was an array of 8 objects and the experimenter spoke a series of monosyllabic and phonologically dissimilar words (e.g. cup-hat-horse) to which KBP was then required to point to in the correct order. His performance was similar to the repetition task (2 objects=8/10; 3 objects=5/10; 4 objects=4/10 correct). He was able to identify each object individually (8/8).

Lexical decision

KBP was given a lexical decision task in which words were grouped according to frequency and imageability. In the auditory version (PALPA, test 5), 160 words and nonwords were presented and KBP scored 150/160 (93.8%; 7 false positives, 3 false negatives) putting him within the normal range. In the written version (PALPA, test 25), 120 words were presented and KBP scored 96/120 (80.0%; 13 false positives, 11 false negatives) putting him well outside the normal range. His errors in rejecting words were influenced by imageability (2 high imageability, 9 low imageability) but not frequency (5 high frequency, 6 low frequency). The words in this lexical decision task were printed in lower case. Since KBP prefers to write in upper case, the possibility that lexical decision may be improved by using upper case letters was assessed. However, similar results were found. He scored 93/120 (77.5%; 14 false positives, 13 false negatives). Again, his performance was influenced by imageability (2 high imageability, 11 low imageability) but not frequency (6 high frequency, 7 low frequency).

Picture Naming

KBP was asked to name 40 pictures from PALPA (test 53). He scored 23/40 (57.5%). His ability to repeat the same items was good (37/40, 92.5%) suggesting that there is some anomia over and above his mild articulatory/phonological deficit. His errors in the naming test consisted of semantic errors (47%, 8/17), no responses (35%, 6/17), phonological/articulatory errors (12%, 2/17) and a morphological error (6%, 1/17). KBP was given a further 100 pictures to name. After each naming attempt, he was asked four questions about the item (2 requiring a 'yes' response and 2 requiring a 'no' response). For example, "does it live underground?". Of the 67 items correctly named he was able to correctly answer 92.5% (248/268) of the probe questions. Of the 33 items that he could not name, he was able to answer 94.7% (125/132) of the probe questions. KBP's good understanding of items which he cannot name suggests that his anomia may be characterised primarily as one of lexical retrieval (see Kay & Ellis, 1987).

Semantics

KBP was given three tests involving matching of words and pictures. In the first test, KBP was required to match a high imageability noun to one of five pictures (PALPA tests 47 & 48). Distractors include semantically similar, visually similar and unrelated objects. He was unimpaired when spoken words were presented (40/40) but made 3 errors when written words were presented (37/40), all to semantically related targets. The second test consisted of the long-form British Picture Vocabulary Scale in both spoken and modified written formats. KBP had a spoken vocabulary age of 15 years 9 months (raw score = 128). I consider this to be an acceptable adult vocabulary. However, he had a vocabulary age of only 6 years 5 months (raw score = 60) on the written version. Finally, KBP's ability to match a spoken word to one of four written words was assessed. Three types of words were used: function words, nouns and verbs. There were 34 words in each group. The words in each group were matched for word frequency (Kucera & Francis, 1967) and consisted of some of the most common words in usage (F > 428). The distractors consisted of other items from the 34 word set of the same grammatical category. The position of the target was varied between the four positions. KBP scored 97.1% (33/34) on the nouns, 73.5% (25/34) on the verbs and 52.9% (18/34) on the function words. This suggests that his ability to comprehend written words (like his lexical decision) may be influenced by imageability and/or grammatical class.

KBP's knowledge of semantic associations was tested using the Pyramids and Palm Trees test (Howard & Patterson, 1992). He made only one error (51/52) when three pictures were used. When three written words were used he made 7 errors (45/52). No control subject (reported by Howard and Patterson, 1992) made more than 3 errors. Therefore, KBP is impaired at deriving semantic associations from written words but not from pictures.

Summary

KBP has difficulties in retrieving spoken words spontaneously and to confrontation. This suggests damage to the phonological lexicon used in speaking. He also has difficulties in recognising and comprehending written words. This may reflect damage to the orthographic lexicon used in reading. It should be noted, however, that there is little evidence of damage to the semantic system when performance is assessed using only intact input routes (i.e. using spoken words and pictures). This pattern of poor comprehension of written words and poor production of spoken words may be expected to give rise to difficulties in reading aloud.

5.3.2 General Reading Assessment

KBP's reading follows a 'deep dyslexic' pattern in that he is unable to read aloud nonwords and he produces semantic errors when reading words. Given that his semantic knowledge is generally good when assessed by other means, it is possible that this pattern reflects damage to an input component (e.g. Shallice & Coughlan, 1980), an output component (e.g. Caramazza & Hillis, 1990c) or both. He was unable to read any of the 3-5 letter nonwords on the PALPA list (0/18; test 36) and he showed no effect of spelling-sound regularity (exception words=50% (25/50), regular words=32% (16/50) correct; PALPA, tests 35 and 53). This suggests use of a lexical route for reading.

He shows a strong effect of imageability matching for length and frequency (HI=50% (20/40), LI=5% (2/40) correct; $\chi^2(1) = 20.31, p < .001$). However, an effect of frequency did not reach significance, matching for imageability and length (HF=35% (14/40), LF=20% (8/40) correct). There was a significant effect of grammatical category, controlling for frequency and letter length (nouns=29/59 (49%), adjectives=17/59 (29%), verbs=12/59 (20%); $\chi^2(2) = 11.75$, $p < .001$). He was also impaired at reading aloud function words (3%; 1/32). Effects of imageability and grammatical class are consistent with use of a lexical-semantic route and damage to one or more central components (i.e. the semantic system, phonological lexicon, and/or orthographic lexicon). There is some effect of letter length and syllable length on his reading ability controlling for frequency and imageability (PALPA test 29: 3-4 letters=58% (7/12), 5-6 letters=25% (3/12); PALPA test 30: 1 syllable=63% (5/8), 2 syllables=13%(1/8), 3 syllables=0% (0/8)).

KBP read 38.7% (209/540) of words correctly in the preliminary assessment of his reading (which excluded proper names). Table 23 shows the distribution of his errors. Errors were classed as visually/phonologically related if they shared at least half of the letters/phonemes with the target. Errors were classified as circumlocutions if KBP produced a describing phrase (e.g. "it flies"), or a set of semantically similar words (e.g. "film, act, cinema").

Table 23 : Analysis of KBP's errors in reading aloud (excluding proper names).

	%	N		Example
No Response	**48.6**	161		
Lexical Substitution	**35.6**	118		
Semantic			49	*elbow* → leg
Semantic + visual/phon			5	*smoke* → smog
Visual then semantic			2	*proud* → money [pound?]
Visual/phonological			44	*pint* → paint
Unrelated			18	*petal* → pills
Circumlocution	**6.0**	20		
Pure circumlocution			18	*giraffe* → like elephant, taller
Visual then circumlocution			2	*move* → film and act [movie?]
Nonword	**5.1**	17		
Single phoneme error			7	*elephant* → "enephant"
2+ phoneme errors			6	*vase* → "vess"
First phoneme produced			4	*fox* → /f/
Morphological	**4.5**	15		
Inflectional			11	*flower* → flowers
Derivational			4	*teach* → teacher
	100%	331		

5.3.3 Recognition and Comprehension of Proper Names

KBP was given the written version of the lexical decision task with names described in Section 5.2.1. Proper names were written with the initial letter capitalised. The same proportion of nonword distractors were also written with the initial letter capitalised. He scored 82.0% (123/150) correct. He correctly recognised 100% (25/25) of the countries, 92% (23/25) of the first names and 72% (18/25) of the nouns, but incorrectly classed 24% (18/75) of the nonwords as real words. Although KBP is impaired at this task he has no difficulty in recognising proper names relative to nouns and, if anything, is somewhat worse with the common nouns.

On the same spoken word - written word matching task that had been given to BA he scored 97% (29/30) on the first names, 97% (29/30) on the surnames, 97% (29/30) on the high imageability nouns and 100% (20/20) on the famous names. When asked to categorise written first names as boy/girl he scored 90% (27/30).

KBP's knowledge of famous people was assessed in a matching task. He was required to match a first name (e.g. Bill) or surname (e.g. Clinton) to a photograph in an array of 12. There were 4 conditions (first name/surname *x* written/spoken) which were administered over 2 sessions. Words were given to KBP one at a time, in blocks of 6, and in pseudo-random order. No word was presented more than once in a given session. The test was also repeated using a different set of 12 photographs. For spoken first names and surnames, he scored 92% (22/24) and 96% (23/24). For written first names and surnames, he scored 96% (23/24) and 83% (20/24).

KBP's knowledge of biographical (e.g. "Is John Major a politician?") and appearance information (e.g. "Does John Major wear glasses?") was also good. He scored 97% (29/30) and 93% (28/30) respectively when presented with oral questions requiring a yes/no response.

When asked to match a written country name to one of 2 animals (e.g. matching *China* to a panda and not a bear) he scored 100% (9/9). KBP was required to match a city name (e.g. Paris) or a country name (e.g. France) to a photograph of a famous landmark (e.g. the Eiffel Tower). There were 16 photographs in total, which were presented in 4 conditions (country/city *x* written/spoken word) over two sessions. Words were given to KBP one at a time, in blocks of 8, and in pseudo-random order. No word was presented more than once in a given session. For spoken city names and country names he scored 81% (13/16) and 88% (14/16). For written city names and country names he scored 88% (14/16) and 94% (15/16). His errors were due to a failure to recognise three of the places (Athens, Bangkok and Jerusalem).

In summary, KBP's ability to recognise and comprehend proper names is good, and is often at least as good as for common nouns. Therefore, any difficulty in retrieving proper names versus common nouns is unlikely to reflect a semantic deficit.

5.3.4 Reading Proper Names

The task of category fluency involves many of the components which are also used in reading semantically (e.g. the semantic system and phonological (output) lexicon) but does not involve analysis of a written word form. Thus the task may be useful for disentangling effects arising from input from those arising at an output level.

Category Fluency

KBP's ability to orally generate exemplars of a category is shown in Table 21 (above). His performance across categories was generally quite variable. However, it should be noted that his four worst categories were all types of proper name: boys and girls names, actors/actresses and surnames. The fact that KBP was poor at producing proper names in spoken fluency suggests that any difficulty he has in reading these words is unlikely to solely reflect a difficulty in recognising written proper names, since there was no written input in this task.

Effect of Familiarity

KBP's wife was asked to rate over 300 first names for familiarity according to the same six point scale that had been used previously for BA (5=highly familiar, 0=very unfamiliar). Using these ratings, two groups of first names were selected , high familiarity (mean rating=4.8, sd=0.4) and low familiarity (mean rating=0.1, sd=0.4). Matched groups of high and low imageability common nouns were also selected. Words were matched item-for-item for tabulated frequency (Carroll et al., 1971) and word length.

The words were presented in random order for KBP to read. The results are shown in Figure 12. The effect of name familiarity was significant ($\chi^2(1)=11.4$, $p<.001$) as, again, was the effect of imageability ($\chi^2(1)=25.2$, $p<.001$). Although KBP shows an effect of familiarity in name processing (like BA) his ability to process familiar names is no better than nouns (unlike BA). This suggests that the relevant contrast between the two patients is indeed proper name status and not factors such as imageability, familiarity or frequency.

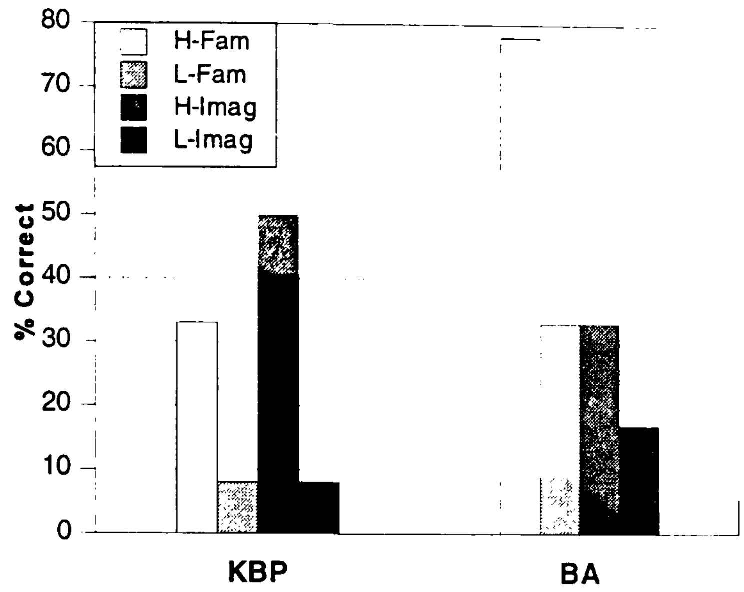

Figure 12: Comparison of KBP's and BA's performance in producing first names (high v. low familiarity) and common nouns (high v. low imageability) matched for length and tabulated frequency.

Reading Famous Names

KBP was able to read only 18% (16/88) of names of famous contemporary people correctly (e.g. *Frank Sinatra*), scoring as correct if both first name and surname were correctly produced. If each 'part' of the famous name is considered, then his performance is somewhat better (36%, 64/176 parts correct; 31 first names, 33 surnames). In most instances (77%, 68/88) he was able to provide some disambiguating information (excluding gender which can usually be derived from the first name alone). For instance, he was able to point out that *Harold Wilson* was a Labour Prime Minister who was famous for smoking a pipe, although he was unable to read *Harold Wilson* aloud. This is suggestive of a lexical retrieval deficit. The types of errors made are discussed below but consisted, mainly, of failures to respond.

On the list of historical names (e.g. *Columbus*) and length and frequency matched nouns he scored 28% (7/25) with the nouns and 12% (3/25) with the names. His errors to the names consisted of 10 failures to respond, 5 visual lexical substitutions, 3 nonword responses, 2 circumlocutions and 2 semantic errors.

Effect of other Semantic Categories

KBP was asked to read 161 words drawn from 10 semantic categories. The groups did not differ in terms of frequency and word length, and generally consisted of high frequency items (mean group frequency > 42; Carroll et al., 1971). A second list of words were given drawn from 5 semantic categories, containing more words in each group and with closer matching of words (item-for-item matching on frequency and word length). These words tended to be somewhat less frequent (mean group frequency < 7; Carroll et al., 1971). The results are displayed in Table 24. On the high frequency list, KBP was significantly impaired at reading first names relative to animals, foods and countries ($\chi^2(1)$= 9.25, 7.60 and 6.53 respectively, $p<.05$). On the low frequency list, KBP was significantly impaired at reading first names relative to foods and countries ($\chi^2(1)$= 6.24 and 5.08 respectively, $p<.05$). No other differences reached significance. Better performance with country names relative to first names suggests that 'proper names' do not behave as a unitary category. In one testing session, for example, he was able to read the words *Peru* and *Morocco* but not *Henry* or *Edward*. It should be noted that peoples names are not the only category which KBP is particularly impaired at reading. He is also impaired at reading number names (e.g. *four* or *4*; the numbers given were 'core' numbers (1..10, 20, 30, etc.) rather than numbers which may be named by 'rule' (24, 67, etc.)).

Table 24: KBP's reading of words from different semantic categories.

High frequency list			**Low frequency list**		
Animals	68%	(13/19)	Food	47%	(14/30)
Food	67%	(10/15)	Countries	43%	(13/30)
Countries	63%	(10/16)	Animals	37%	(11/30)
Vehicles	54%	(7/13)	Objects	33%	(10/30)
Body parts	44%	(8/18)	First names	17%	(5/30)
Furniture	41%	(7/17)			
Plants	38%	(5/13)			
Family (e.g. *sister*)	38%	(5/13)			
Colours	36%	(4/11)			
First names	23%	(6/26)			
Arabic numbers	15%	(3/20)			
Written numbers	15%	(3/20)			

Effect of Proper Name Context

KBP's ability to benefit from a person specific context was assessed. He was given 36 famous names (e.g. Vincent Price) and the corresponding first names (e.g. Vincent) and non-name (e.g. price) to read aloud. Words were presented over two sessions and the same item was not given twice in the same session. He read 39% (14/36) of first names when presented in the context of a famous person and 23% (7/31) when presented in isolation ($\chi^2(1)$= 2.85, *ns* (but p <.1)). He read 50% (18/36) of the surnames when presented in the context of a famous person and 36% (13/36) when presented as a non-name ($\chi^2(1)$= 1.42, *ns*). Although KBP does not show any significant advantage of having names presented in a famous context in this test he shows some trend . This trend does in fact reach significance if a larger corpus of responses is taken into consideration. Comparing all the responses to reading a first name in context (e.g. Michael *Jackson*) to reading a first name in isolation (e.g. Michael), it was found that KBP was significantly better in the context condition (35%, 31/88) than in the isolated condition (21%, 43/207), ($\chi^2(1) = 6.87$, $p < .01$). This effect was noted earlier in BA.

Error Types

In total KBP was presented with 207 common first names, of which only 21% (43/207) were read correctly. His errors consisted of 52% (89) failures to give a response, 43% (70) lexical substitutions and 3% (8) nonword responses. Thus, he makes similar types of errors in reading first names as common nouns (see Table 23). As with BA, however, one notable feature of his errors is a tendency for names to substitute for names. Of the lexical substitutions, 74% (52) were first name substitutions (e.g. *Doris*→Dorothy), 14% (10) were phonologically/visually related name-noun substitutions (e.g. *Kate*→kite) and 11% (8) were unrelated name-noun substitutions (e.g. *Danny*→doctor). The name substitutions are given in Appendix 6. Not only did names tend to substitute for names but the errors also tended to preserve gender. This occurred in 89% (46/52) of instances. Furthermore, 79% (41/52) of the name substitutions preserved at least the first letter. This suggests that name substitutions are influenced by both semantic and orthographic/phonological (form-related) effects.

For the famous name pairs (e.g. *Frank Sinatra*) KBP made 72 errors (82%, 72/88). Four of these (5.6%, 4/72) were classed as semantic errors. He read *Ginger Rogers* as "Gene Kelly", *Boris Yeltsin* as "Mikhail Gor...", *Gary Glitter* as "David Essex" (both 70's pop stars), and *Jimmy Hill* (a football commentator) as "James Hunt" (a racing driver). By comparison, for high imageability nouns, KBP read 47% (141/298) of words incorrectly, and of these errors 31.9% (45/141) were semantically related. Thus, semantic errors were more likely to occur on high imageability nouns than on famous names ($\chi^2(1)= 18.70$, $p<.001$), even though KBP was worse overall at reading famous names relative to high imageability nouns.

Summary

The data from KBP is interesting because in some respects he shows similar performance to BA with regards to proper names, whereas in other respects his performance is quite different. As for the similarities, both patients :-

a) have deficits which may be characterised as ones of lexical retrieval (albeit phonological in KBP and orthographic in BA)

b) show an effect of familiarity in producing first names

c) show an effect of person-specific context in producing first names

d) produce name substitution errors which tend to preserve gender and be form-related

e) produce less semantic errors in producing famous names than high imageability nouns

The main difference between the patients, however, lies in their different performance levels for proper names relative to common nouns. This is illustrated in Figure 13. Whilst BA is as good at producing proper names relative to common nouns (if not better in some instances), KBP is poor at producing proper names relative to common nouns. Importantly, both patients show the same level of difficulty in retrieving high imageability common nouns. This suggests that the differences in the processing of proper names between the patients reflects the nature of the impairments rather than the degree of the impairment.

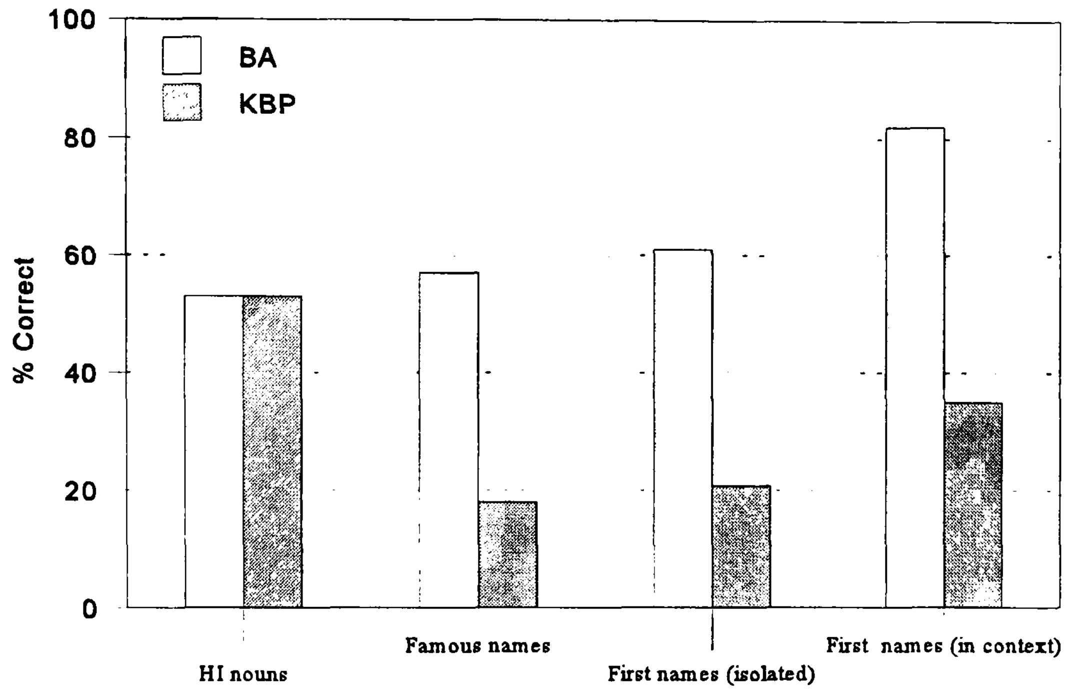

Figure 13: A comparison between BA and KBP's performance on high imageability nouns and various types of proper names.

5.4 Discussion

The Discussion will be divided, broadly, into three parts which will consider (1) why one patient was apparently good at producing proper names whilst the other was poor, (2) the similarities that existed between the patients in their processing of proper names, for instance the benefit of person-specific context, and (3) the relationship to previous studies in the literature.

<u>The Proper Name - Common Noun Distinction</u>

There are, at least, two possibilities as to why BA may be good at producing proper names (relative to common nouns) and KBP may be poor. Firstly, the damage may reflect a selective impairment/preservation of the 'category' of proper names. If we assume that there are different representational properties associated with proper names and common nouns then it may be possible to selectively impair/spare the sub-region which contains the proper name features (e.g. McNeil et al., 1994). However, the differences are unlikely to reflect a loss of information from the semantic representations of proper name and common noun items because both patients performed well on comprehension tasks. One possibility is that proper names and common nouns form specialised subregions in the (output) lexicon which may be selectively spared/impaired, as has been suggested for nouns and verbs (e.g. Caramazza & Hillis, 1991). However, one difficulty with this idea is the observation that KBP shows a dissociation between people's names and country names (both types of proper name) which implies a deficit to a level of representation that is semantically organised rather than grammatically organised.

Secondly, the difference in proper name processing between the patients may emerge because the patients have sustained damage to different levels within the system which do not directly correspond to an underlying distinction between proper names and common nouns. Although both patients may be classified as having deficits of lexical retrieval, KBP appears to have particular difficulty in selecting a target at the lexical level (hence a high rate of lexical substitutions) whereas BA appears to have particular difficulty in retrieving the letters making-up the word (hence a high rate of nonword/fragment responses). If KBP has a lesion to the semantic-lexical connections then this could well give rise to a difficulty in producing peoples names if these connections are organised by semantic category (e.g. Garrett, 1992) or if there is indeed a unique connection from a PIN (e.g. Burton & Bruce, 1993) or name node (e.g. Burke et al., 1991) to the lexical items. In the case of BA, the damage might best be characterised by a reduction in activation at the lexical level itself (having knock-on effects at a letter level) which, it is assumed, is not organised along semantic dimensions. However, under some circumstances this might lead to a proper name advantage. For instance, the semantic representations of unique items may have a higher imageability than generic items and so receive a greater input from the semantic system (it seems intrinsically easier to conjure up an image of 'my dog' relative to 'a dog'). BA has already been shown to show a large effect of imageability in production. An effect of imageability may also be important in KBP (for instance he was better at producing unique names relative to isolated first names- e.g. *Michael Jackson* versus *Michael*). However, in his case imageability may be boosting a level of performance which is already strongly impaired relative to common nouns, whereas in BA it is boosting a level of performance which is in other respects comparable to common nouns (see Figure 13 above).

Thus at least part of the difference in performance levels for proper names between BA and KBP can be accommodated by suggesting damage at different levels, without necessarily postulating an output system which is divided along proper name and common noun lines. Nevertheless, it may be possible to make inferences about proper name processing in general by considering some of the similarities that exist between the patients.

The Effect of Person-specific Context

In order to explain the similarities that exist between the patients one needs to develop a framework which describes how proper names may be processed in reading and writing. First of all, it is important to consider how patients can read/write common first names (e.g. Tom) semantically.

Some researchers have suggested that the semantic representation for common first names sauch as *Tom* may consist of little more than the features <male> and <English-speaking> (e.g.

Forde & Humphreys, 1995). If this were the case, then common first names would be very hard to read/write semantically since *Tom* would be indistinguishable at the semantic level from other names with these features (e.g. *Charles, James*). However, both patients were able to read/write some first names even those not referring to acquaintances. Reading/writing a word such as *Tom* may involve the retrieval of some person specific information, although this might correspond to activation of a cluster of individuals (e.g. *Tom Sawyer, Tom Jones, Tom Cruise*), (following Burton & Bruce, 1993). This is illustrated in Figure 14 for a common first name (*Tom*) a unique proper name (*Tom Cruise*) and a common noun (*cruise*)[11].

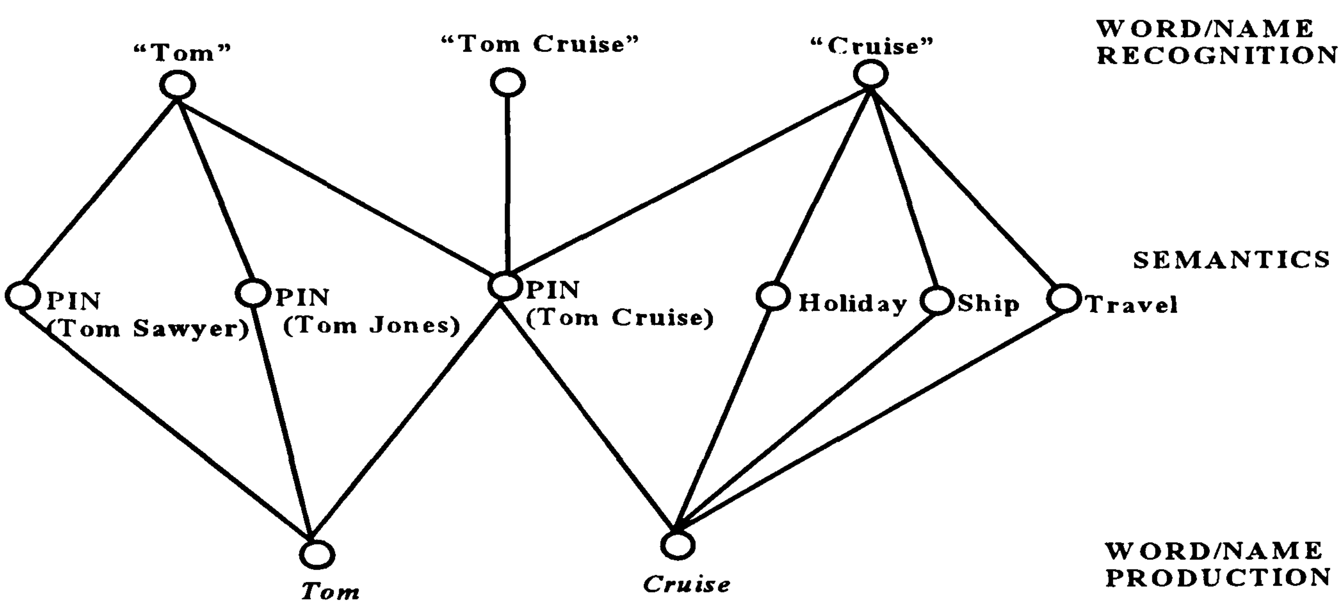

Figure 14: The production of common first names, unique names and common nouns in tasks such as reading and writing (via semantics).

Several hypotheses can be considered as to how/why presenting a name in a person-specific context should increase the chances of retrieval; for instance, it might be related to

[11] There is some evidence to suggest that names which can also function as nouns share the same representation at the lexical level (as shown in the diagram) since effects of repetition priming have been observed between nouns (e.g. *baker*) and names (e.g. *Kenneth Baker* [a politician]) and vice versa (Valentine, Moore, Flude, Young & Ellis, 1993).

'uniqueness', it might reduce the spread of activation to competitors, it might be associated with an increase in imageability.

Although uniqueness may well be an important aspect of proper name processing (indeed it is the defining property of a proper name), it may not always be the case that unique items are retrieved poorly. In the case of BA and KBP, words are produced better when processed as a unique name relative to as a generic name which may denote several individuals. At a computational level, uniqueness is often seen as detrimental because items do not receive summed activation from several sources and may therefore be more susceptible to fluctuations/reductions in the supply of activation (e.g. Burke et al., 1991). However, it is not clear how unique proper names could sometimes be at an advantage given this explanation alone.

Another idea is that processing a word as a proper name may reduce the spread of activation to lexical competitors, assuming that "when a word is used as a proper name or in an otherwise restricted context it presumably elicits fewer semantic associations than when it appears in isolation" (Saffran et al., 1976, p.262). Thus, the uniqueness of proper names may in some circumstances be advantageous in that it enables the lexical item to 'stand out from the crowd' during the selection process. In general, a lexical item may be harder to retrieve if it contains a high number of semantic features which overlap with other lexical items and may be easier to retrieve if it contains a high number of features which are shared by few other lexical items. It has been suggested that although the semantic representations of proper names may be composed of some very commonly shared features (e.g. male, Welsh, actor) they will also contain a higher proportion of uniquely specifying features (e.g. 'starred in the Silence of the Lambs') than common nouns (e.g. Ellis et al., 1989; Kartsounis & Shallice, 1996). This account not only offers an explanation for the benefit of person-specific context it may also explain the benefit of familiarity (since more uniquely-specifying facts will be known about highly familiar people) and the reduced semantic error rate for famous name production (since there may be less overlap between the semantic fields of famous people relative to high imageability nouns)[12]. However, the reduced spreading activation account may also generate other predictions which are apparently not borne out. For instance it would appear to predict that the 'normal' pattern should be better retrieval for proper names which is generally accepted not to be the case (e.g. Valentine et al., 1996). One could perhaps get around this objection if it were claimed that spreading activation only exerted this effect because of the nature of the brain damage which was sustained by patients such as KBP, BA and those reported by Saffran et al. (1976). However, such an account is not entirely satisfactory since it does not make clear predictions about normal performance.

One other possibility is that BA and KBP benefit from a person-specific context because it is associated with increased imageability relative to a name presented in isolation, as was suggested before with regards to differences between proper name and common noun processing. Both patients have been shown to be strongly influenced by imageability in reading/writing nouns, and it was suggested that a discrepancy between contemporary and historical figures may be accounted for in terms of imageability. An explanation based on imageability may also account for the advantage for familiar names which both patients showed. However, it does not offer an obvious explanation for the relatively rare occurrence of semantic errors in famous name production. An imageability explanation also has the disadvantage of being less computationally

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[12] The deep dysgraphic patient reported by Cipolotti et al. (1993) apparently produced more semantic errors in written naming of proper names than common nouns. However, the semantic similarity was not always strong (e.g. King Harold -> Robin Hood), and this pattern was not found in writing to dictation. This might reflect the fact pictures may provide more semantic information (e.g. wears medieval clothes) than can be obtained from words.

explicit than some of the other explanations considered.

Other patients/studies in the literature

Forde and Humphreys (1995) found that their patient was poor at spoken word - written word matching when common first names or unfamiliar names were used (e.g. *Tom* or *Tom Jackson*) but performed significantly better when famous names were used (e.g. *Tom Jones*). This is similar to the observation that a person-specific context is beneficial to production in reading/writing. This might arise because it may activate a source of biographical knowledge which is unique to that individual thereby increasing the chances of selection and reducing the likelihood that activation will spread to a competitor, and/or because it is more imageable.

A number of previous studies have reported an impaired ability to produce people's names relative to country names (e.g. Lucchelli & De Renzi, 1992; Carney & Temple, 1993). The deep dyslexic patient, KBP, was also impaired at producing first names relative to country names even matching for frequency and word length. It is unlikely that this could reflect differences in imageability alone since country names were still read at a higher level than even famous contemporary names, and countries cannot be considered as 'concrete' by standard definitions (e.g. Paivio et al., 1968). Although, it may be possible to explain the dissociation in terms of task difficulty (since the reverse dissociation has not been documented) it is not clear what property of people's names would make them so difficult relative to place names. A more plausible explanation is that the representation of people versus places may indeed be served by different (and dissociable) systems at the semantic (and semantic-to-lexical) level. This hypothesis, if borne out, would have important theoretical implications since it would imply that the relevant contrast is not between proper names and common nouns, but between semantic categories in the broader sense.

Several studies have attempted to model proper name retrieval (Brédart et al., 1995; Burton & Bruce, 1992, 1993; McClelland, 1981). For example, the Jets and Sharks model of McClelland (1981) consists of pools of nodes encoding information such as occupation, marital status, and name. The pools of nodes connect, bidirectionally, to a central set of nodes, each of which represents a single person (analogous to the PINs of Bruce & Young, 1986). Having bidirectional links means that nodes can be activated in cascade: that is, activation may be spread to other levels before processing is complete at any given level. Some of the data from BA and KBP is certainly in the spirit of a cascaded approach. If name substitution errors (e.g. Brenda->Barbara) were arising solely from a semantic level then it might be expected that errors should preserve gender and proper name status but there is no reason to assume that they should be form-related. If substitutions were arising solely from an orthographic level then the errors may well be expected to be form-related but there is no reason to assume that gender or proper name status should be preserved. In fact there was a strong tendency for substitutions to preserve gender and proper name status <u>and</u> be form-related. This suggests that selection of a lexical candidate is influenced by activity in several levels of representation and that selection is not encapsulated within each individual level. Similar results have been reported in aphasic and normal object naming (e.g. Martin, Gagnon, Schwartz, Dell & Saffran, 1996) and normal face naming (Brédart & Valentine, 1992), although the effects are considerably weaker than those reported here.

The emphasis in this chapter has been to apply a cognitive neuropsychological approach to understanding proper name processing. It has been suggested that proper names may indeed have different representational properties (e.g. fewer semantic associations), although this may not necessarily reflect an explicit encoding of a proper name-common noun category structure. The challenge for future research may be to integrate this approach with studies of connectionist models and laboratory findings with normal subjects.

6. GENERAL DISCUSSION

6.1 Summary and Synthesis of Main Findings

The general aim of this thesis has been to build upon the more traditional description of the spelling system in terms of 'boxes and arrows' (see Section 1.1), by investigating the mechanism of operation of the underlying components and the nature of the representations involved in lexical retrieval. The main methodology used in this thesis, has been the detailed analysis of the performance of a brain-damaged patient. The idea being that the nature of the impairments may be used to infer the nature of the processes which existed prior to brain-damage, i.e. in the skilled speller (e.g. Caramazza, 1986; Ellis, 1987; Shallice, 1988).

Chapter 1 presented a single case study of an acquired dysgraphic patient (BA). BA was unable to spell nonwords and produced some semantic errors. She showed effects of word frequency and imageability. These are suggestive of an impairment to lexical and semantic levels of representation. The characteristic of her spelling which was investigated in detail was the fact that her spelling errors were not uniformly distributed throughout the word and that the initial letters of a word appeared to be easier to retrieve than other letters. Perhaps the most interesting aspect of her spelling performance was that although the same pattern was found in a wide range of spelling tasks it was not found in them all. Notably, those spelling tasks not requiring access of an orthographic representation via the semantic system (e.g. delayed copying, filling in a missing-letter). This suggests that her predominant 'linear' serial position effect can be linked to one specific mechanism within the functional architecture for spelling which is involved in some tasks but not others. It was suggested that her deficit could be described as a failure to activate the letters making-up a word as a result of a reduction in the propagation of activation from semantic and lexical levels to a letter level of representation. It was suggested that the serial position effect may reflect an activation gradient over letter nodes such that letters to be produced first are the most active. This gradient is assumed to be present in the skilled speller and may enable letters to be produced in the correct serial order.

A strong claim might be that there is no explicit encoding of letter position within orthographic representations, but that encoding of position arises solely out of the activation gradient which emerges during lexical retrieval. Data from other patients, however, may be more consistent with a weaker interpretation. Morton (1980) described a patient who would often write down at least the first letter of a word when trying to recall the spoken name. What is unusual about this patient, however, is that the fragments that the patient wrote down often contained letters from different parts of the word. When asked to write down a list of countries her responses included:

In a

N Z

Tur y

J p n

C na

(presumably India, New Zealand, Turkey, Japan and China). Patients reported by Katz (1991) and Hatfield (1985) produced similar errors, although these patients also often wrote down letters in a 'non-linear' order typically writing down initial letters, then final letters and then filling-in the medial letters or leaving gaps. The patient reported by Cubelli (1991) also produced gaps (e.g. Bologna→*B l gn*), although these gaps were associated exclusively with vowels. The existence of 'gap' errors in these patients implies that knowledge of letter position (either relative or absolute) can be available without knowledge of the corresponding letter identity. These errors are hard to explain if it is assumed that letter position is only a by-product of how active letters are. In this case, if a letter(s) is not active enough then information relating to position will also be lost (i.e. India→*Ina*, not *In a*). In short, although activation gradients may be necessary to explain the encoding of position/order they might not be sufficient.

Other evidence presented in this thesis is consistent with this. A connectionist model which encodes serial order solely be means of a time-varying activation gradient was lesioned in Chapter 4. However, this model was found to have a particular difficulty in spelling words with repeated letters which BA did not show. One way in which this could be explained would be to assume that the activation gradient is not established over a fixed set of 26 letter nodes but over a conceptually more abstract set of nodes, which themselves may be able to encode information related to position (see Figure 11). Thus it may be possible to retrieve position-specific information without retrieving letter identity.

There is also some evidence to suggest that orthographic representations contain units larger than the single letter and/or other than the single letter (Chapter 3). BA had a tendency to produce fragments at certain boundaries within the word. For example, she was more likely to produce the response *b* for *bench* than *b* for *brick* (perhaps reflecting the influence of an ortho-syllabic onset unit). Having units larger than the single letter involved in lexical retrieval may enable the lexical-semantic route to interact with phoneme-grapheme conversion during output, since the latter will tend to produce multi-letter units as well (see Section 6.3.1).

Semantic effects on lexical retrieval were examined in two patients with regards to the distinction between proper names and common nouns. Although proper names may often be particularly affected in patients with word retrieval difficulties, in some instances they are not. This may depend on the nature of the damage that has been sustained and the nature of the task. In BA, it was suggested that increases in imageability or reductions in spread of activation might be able to reduce the magnitude of her retrieval deficit more for proper names. However, in KBP a retrieval component specific for proper names (peoples names in particular) may be impaired.

6.2 Comparisons and Implications for other Areas of Research

The task of spelling has many similarities with other areas of language processing, notably reading and speaking. The following sections will consider the implications from the findings in this thesis for wider aspects of language processing and also for rehabilitation.

6.2.1 Reading

Under normal circumstances, reading a word involves analysing and recognising the letter string, retrieving a meaning, and generating a phonological code (e.g. Ellis & Young, 1988). The latter aspect of the reading process is considered in the discussion of speaking (Section 6.2.2). This section is concerned with comparing the similarities between the orthographic codes in reading and spelling, and how they interact with the semantic system.

The question of whether ortho-syllables exist in reading is controversial (e.g Seidenberg, 1987). Nevertheless, there is strong evidence for some form of 'letter grouping' during orthographic input (Prinzmetal, 1990; Prinzmetal, Treiman & Rho, 1986; Prinzmetal et al., 1991; Seidenberg, 1987; Taft, 1979). For instance, Prinzmetal et al. (1986) presented words which were written in two different colours (e.g. *BANjo*, where upper and lower case letters represent different colours). Subjects were more likely to mis-report the colour of the letter 'N' when the colour boundary does not coincide with the word's ortho-syllabification (e.g. *BAnjo*) compared to when it does (e.g. *BANjo*), suggesting that certain letter combinations behave as a coherent functional unit whereas others do not. Badecker (1996) suggests that similar representational units exist for orthography and phonology not because orthography is learned primarily from phonology but because the cognitive system exploits the same set of domain-independent principles in both instances.

6.2.2 Speaking

BA's written production difficulty resembles, in some respects, the word-finding difficulties experienced by normal and aphasic subjects in a tip-of-the-tongue, or TOT, state (Brown & McNeill, 1966; Goodglass, Kaplan, Weintraub & Ackerman, 1976; see Brown, 1991, for a review). Firstly, the difficulty appears to be primarily lexical rather than semantic in origin. This may give rise to a strong 'feeling-of-knowing' the target word. BA too reports a strong feeling-of-knowing and intense frustration at not being able to fully retrieve the word. She frequently demonstrates understanding of the word for which she can produce no response. Secondly, partial information about the word form is often available when in a TOT state, particularly for the first letter/phoneme. Thirdly, her retrieval difficulty is related to factors such as word frequency and cueing which have often been associated with word retrieval difficulties (e.g. Brown, 1991).

Some researchers have even suggested that the TOT phenomenon may reflect incomplete activation of lexical-phonological representations (e.g. Meyer & Bock, 1992). Thus, BA resembles the TOT state both observationally and in terms of the explanation offered. However, there may also be some significant differences. BA's ability to retrieve letters appears to decrease smoothly across serial positions whereas letter report in the TOT state seems to be restricted to the first letter. This could reflect the fact that the first letter has a 'special' status. For example, as part of the address code for the lexicon (e.g. Butterworth, 1992). It is also conceivable that other letters are in fact partially available in a TOT state but that most experiments don't ask subjects to attempt to report them. Rubin (1975) studied the availability of letters other than the first letter in a group of subjects in a TOT state. Subjects were asked to write down any letters they thought might be in the word and, in a second experiment, to produce a word with a similar form. Letters were scored as correct starting from both the beginning and end of a word. Letters were scored as correct only if the preceding letter was scored as correct. Two such scorings are shown below for the words *Ebenezer* (the letter 'guessing' test) and *mistral* (the form-related word test).

	E	***b***	***e***	***n***	***e***	***z***	***e***	***r***	***m***	***I***	***s***	***t***	***r***	***a***	***l***
beginning	10	4	1	1	0	0	0	0	10	5	2	1	0	0	0
end	0	0	0	0	0	0	4	4	0	0	0	0	0	1	2

There are a number of methodological difficulties with this procedure including the use of words with repeated letters (e.g. Ebenezer), the method of scoring (which biases against the middle of a word) and a failure to report the number of incorrect guesses that were made (subjects were explicitly encouraged to guess if not sure). Nevertheless, the study suggests that there is an orthographic as well as phonological component to the TOT state and raises the possibility that subjects in a TOT state have access to orthographic information other than the first letter. Indeed, Rubin's (1975) conclusion to this experiment was remarkably similar to the one presented in this thesis: "clusters of letters tend to be retrieved together,...the aspects of a word-name that are needed earliest in production will be the easiest to retrieve" (p. 396-397). This latter principle would also account for the observation that supra-segmental phonological structures (e.g. stress, syllables) are often available in a TOT state, since these are likely to be needed before assignment of the segmental structure (e.g. Levelt, 1989; Shattuck-Hufnagel, 1979).

There are a number of other apparent anomalies between BA and subjects in a TOT state. Subjects in a TOT state tend to produce lexical approximations rather than fragments and cueing tends to facilitate retrieval of the whole word form rather than just a few phonemes/letters which is often found in BA. BA's deficit may be best described more in terms of a failure to retrieve the letters making up the word, whereas the TOT state may be best described as reduced activation of a lexical/word level of representation. This could explain why TOT subjects produce lexical approximations and BA produces fragments, why cueing has a more all-or-nothing effect in TOT subjects and why several letters are often available in BA but (perhaps) not in TOT subjects.

KBP also shows similarities to subjects in a TOT state in that he is often able to produce semantic information despite being able to produce the word form. Like normal subjects, he often produces a form-related or semantically related lexical item instead. Although not reported here, it has been observed that lexical retrieval is aided by presenting him with the first phoneme or in the case of famous names, a first name may be used as a cue to facilitate retrieval of a surname. For example, he was uable to read the name *Tony Blair* but was able to retrieve "Blair" following the cue "Tony".

There is some evidence to suggest that phonological representations are structured in a similar way to that proposed for orthographic representations in Chapter 2. Evidence for the existence of syllable-sized units of representation in phonology is extensive (see Levelt, 1989; Romani, 1992). There is also some evidence for dissociability between consonants and vowels in phonology. Romani, Grana and Semenza (1996) reported a double dissociation between two patients in terms of the number of phonemic paraphasias made on consonants and vowels, implying that different representational properties are associated with each or that there is indeed an explicit category structure for phonological consonants and vowels.

However, in other repects phonological and orthographic representations may differ. For instance, geminates in phonology may be represented differently from those in orthography (Romani & Calabrese, 1996). This might reflect the different output characteristics of speaking and writing: in writing a geminate the output consists of the production of the same letter twice but in producing a spoken geminate, the same phoneme is not produced twice but a single phoneme is lengthened. Other differences which may give rise to qualitatively different types of errors in speaking and spelling are the fact that units of representation may exist in one modality which have no obvious analogue in the other modality (e.g. articulatory features, stress) and the fact that the physical output mechanisms are very different (it is not physically possible for certain phoneme sequences to be articulated although there is no physical constraint on the letter sequences that may be produced).

6.2.3 Rehabilitation

A detailed knowledge of the underlying causes of a patient's difficulty may hopefully have implications for rehabilitation. In a dysgraphic patient such as BA, training strategies may involve rehabilitation of either the lexical-semantic spelling route (e.g. Hatfield, 1983) or the sublexical spelling route (e.g. Hillis & Caramazza, 1994) or both (e.g. Carlomagno, Iavorone & Colombo, 1994). It has already been shown that giving feedback on incorrect items improves performance on subsequent recall attempts (see Section 2.6.3). One rehabilitation strategy may be to train BA on a restricted set of vocabulary which is important to her everyday activities. However, this strategy would be limited in scope by the fact that training is unlikely to generalise to untrained items. Training of common phoneme-grapheme correspondences may have a more general benefit. However, the benefit may be restricted to tasks such as writing to dictation rather than spontaneous writing; since the latter would be dependent on BA being able to generate a phonological code for herself which she is currently very poor at doing.

For the deep dyslexic patient, KBP, the most appropriate strategy may centre on rehabilitating grapheme-phoneme correspondences (e.g. Berndt & Mitchum, 1994; De Partz, 1986). This is because (a) the lexical-semantic reading route appears to be damaged in several places (the orthographic [input] lexicon and phonological [output] lexicon), (b) his ability to understand spoken words is good (hence he can understand what he has read), and © he is often able to write down words which he cannot produce orally (hence he can generate a graphemic code suitable for grapheme-phoneme conversion). Practice at reading words aloud may also enable him to set-up more stable phonological representations thereby reducing the degree of his spoken word anomia (e.g. Nickels, 1992). One strategy which KBP uses spontaneously to help him read, is to search for embedded words within the letter string. For example, when attempting to read *ginger* he covered up the letters *ger* and said "gin". Thus, rehabilitation of spelling-to-sound could be aided by using a set of familiar monosyllables as well as using grapheme/letter sized units.

In short, a detailed knowledge of a patients functional deficit may be helpful for devising treatment programmes. Whether the converse is true (i.e. rehabilitation can shed light on the functional deficit) remains an area of debate (e.g. see papers in Riddoch & Humphreys, 1994; Wilson & Patterson 1990).

6.3 Directions and Implications for Future Spelling Research

This thesis has considered in detail only aspects of the spelling process relating to lexical retrieval. The remaining sections will describe how the framework proposed in this thesis may relate to other aspects of the spelling process.

6.3.1 The Role of Phonology

One important aspect of spelling which has not been considered in any detail in this thesis is the role of phonology. There is neuropsychological evidence to suggest that spelling is not necessarily dependent on phonological mediation (e.g. Patterson & Shewell, 1987; Shallice, 1981). However, this does not mean that under normal circumstances phonology does not have any role in the spelling process. Phonological effects in normal spelling are suggested by homophone confusion errors, such as writing *scene* for *seen* (Ellis, 1988), and phonologically related lexical substitutions which have minimal orthographic overlap, such as writing *surge* for *search* (Hotopf, 1983). There is also some evidence to suggest that the two spelling routes may blend together regular and irregular portions, such as spelling *rhythm* as *rhythum* (Baron, Treiman, Wilf & Kellman, 1980). Dual-route spelling models must converge at a common locus at some point. This implies that the routes may be able to facilitate or suppress each other. There is some evidence to suggest that the lexical-semantic route can influence the functioning of the sublexical route. Campbell (1983) found that after hearing "fright" subjects were more likely to spell the nonword /kraIt/ as *kright* than *krite*. However, after hearing "white" the opposite was found. This could reflect lexical effects on nonword spelling (Barry & Seymour, 1988).

Conversely, other researchers have suggested that the sublexical route plays an important role in the functioning of the lexical-semantic route (e.g. Hillis & Caramazza, 1991; 1995; Miceli et al., 1994). The 'summation hypothesis' states that lexical candidates receive activation both from the semantic system (the degree of activation is proportional to the degree of semantic overlap) and phoneme-grapheme conversion (the degree of activation is proportional to the degree of orthographic overlap). These activations are summed together to select the winning lexical item. Hillis and Caramazza (1991) cited evidence from patient JJ who was able to spell some irregular words that he couldn't fully understand. However, he was only ably to spell those irregular words for which he could demonstrate some understanding (e.g. superordinate category), whereas those words for which there was no apparent understanding were misspelled/regularised. Hillis and Caramazza (1991) suggest that the sublexical route is able to facilitate selection from amongst the set of lexical candidates generated by the semantic system, but only in cases where the semantic system can generate a set of candidates. When no lexical candidates are available then the sublexical route is used by itself.

The exact mechanism whereby the two routes converge is not specified in this 'summation' model. In particular, it is not clear how the product of the sublexical route (which will often not be a real word) can be matched directly to a word level of representation. The framework proposed in this thesis may be particularly suited to explaining how this convergence may take place. Phoneme-grapheme conversion could influence the activation of the lexical/word level indirectly via feedback from the letter or letter-cluster level. It is generally assumed that the process of phoneme-grapheme conversion is strictly left-to-right and generates single letters or letter clusters. If it is also assumed, as suggested in this thesis, that retrieval from the lexicon is left-to-right and operates on similar sized units (including units larger than the single letter) then it is possible for the operation of the two routes to become synchronised with one another.

In the future, two lines of research may be particularly suited for understanding how the routes converge: connectionist modelling and chronometric analyses of spelling. Although connectionist models of phoneme-grapheme conversion have been developed (e.g. Olson & Caramazza, 1994) there are, apparently, no implemented models which attempt to combine both routes. Glasspool, Houghton & Shallice (1995) discussed the computational difficulties of appending a phoneme-grapheme conversion mechanism to their competitive queuing model of spelling. They suggested that a level of representation corresponding to letter clusters may be needed. They also suggested that differences in the temporal characteristics of the routes may be a source of difficulty. For example, phoneme-grapheme spelling of *bite* may generate the units *b*, *i_e*, and *t*; thus the *e* may become available before the *t*.

As for chronometric analyses, one way of measuring the time-course of spelling generation may be to use the picture-letter matching task described in Section 2.5. For example, if shown a picture of a loaf of bread, the lexical-semantic spelling route will generate the spelling *bread* whereas phoneme-grapheme conversion will generate the regular spelling *bred*. If the two routes interact with each other then it might be expected that there will be a cost in processing speed in matching the picture bread to the letter 'A', compared to a suitably matched word which has a regular spelling. A related method may be to use a spoken word - letter matching task (e.g. Kreiner, 1992), which has the advantage over the picture method of being able to use nonwords and low imageability words. Alternatively, oral spelling latencies may be used to measure production times (e.g. Glover & Brown, 1994). For instance, Glover and Brown (1994) found that response initiation times were faster for spelling regular words with many orthographic neighbours (e.g. *pill*, *hill*, *till*) compared with regular words with fewer neighbours (e.g. *bulb*).

6.3.2 Spelling Development

There is some evidence to suggest that effects of serial position may be a characteristic of normal spelling development. Early researchers attempted to identify 'hard spots' in words which gave rise to the most spelling errors during normal acquisition (Conklin, 1924; Hollingworth, 1918; Tireman, 1920; all cited by Mendenhall, 1930). For example, Mendenhall (1930) observed different spellings of the word *trouble* and their relative frequencies: *troble* (38%), *trobel* (10%), *truble* (10%), *troulbe* (3%), etc. The positional distribution for spelling errors on the word *trouble* is given below, suggesting a difficulty in acquiring the *u* segment.

T	R	O	U	B	L	E
0	5	8	24	7	12	11

Averaging over a large number of words, Mendenhall (1930) found a serial position curve in which the greatest number of errors was at the word centre or directly to the right of word centre.

However, it is not clear from this type of analysis whether 'hard spots' really do reflect serial position or whether they reflect some other factor, such as a tendency for irregular segments to be found in certain positions. More recently though, Treiman, Berch and Weatherston (1993) found that children produced more errors in medial positions when spelling nonwords, suggesting that spelling regularity is not sufficient to account for this phenomenon. These findings are interesting because they suggest that medial sequences may be harder to learn in the first place and are not arising solely at retrieval (since nonwords are not 'retrieved').

A difficulty in encoding serial order may impede the acquisition of orthographic representations resulting in a pattern of developmental surface dysgraphia. Romani, Ward and Olson (submitted) documented a developmental surface dysgraphic patient (AW). AW was found to be unimpaired on a range of tasks requiring phonological segmentation, phonological short-term memory and visual figurative memory. However, AW was found to be impaired on a range of tasks which required the retention of serial order, such as remembering the order of a sequence of abstract visual characters (but not recognising which characters he had seen before) and string matching tasks in which the order of letters had been transposed (but not matching tasks where the identity of letters had been changed). Romani et al. (submitted) suggested that a difficulty in encoding order may result in difficulties in laying down long-term orthographic representations in the lexicon, so the speller relies on sublexical phoneme-grapheme conversion by default.

6.3.3 Other Orthographic Systems

Although the studies reported in this thesis provide important insights into the mechanisms which underlie lexical retrieval in the spelling of English words, it is important to consider whether these mechanisms are a 'universal' aspect of written word production. For instance, would similar mechanisms be found for completely different orthographic systems such as Arabic or Chinese. In the absence of knowledge of the empirical evidence (if any) that exists for acquired spelling disorders in other orthographic systems, these discussions will necessarily be speculative. However, it is hoped that future research into spelling might consider studying different scripts.

Link and Caramazza (1994) suggested that Mandarin Chinese poses a particular difficulty for dual-route models of spelling because many components would be absent (sublexical sound-to-spelling, allographic conversion, letter name conversion) and it is not clear what the basic unit of spelling would be given the absence of letters. Although Chinese characters (or logographs) typically do not consist of a string of elements they do have an internal structure. Many words are represented by a compound of characters. Within each character there may be several other elements, which may themselves function as characters. Given this type of orthographic code it is not clear whether one needs to posit a serial ordering mechanism for spelling at all. However, one possibility, is that serial ordering may be needed at the level of pen strokes. The pen strokes which compose each Chinese logograph are produced in a learned and conventional serial order (basically, left-to-right and top-to-bottom). It is this principle which forms the basis of Chinese dictionaries. Thus the meaning of a character can be looked-up by considering the first pen stroke, then the second and so on, in an analogous way to which letters are used in alphabetic dictionaries. Whether this ordering pattern is represented in the mental spelling lexicon or generated *de novo* on each spelling attempt is a question for future research.

Japanese is perhaps even more complicated in that different orthographic systems exist within the same language. Kanji characters are based on their Chinese counterparts and are used to represent Chinese-derived open class words and peoples names. Kana letters are phonologically transparent and are used to represent morphological endings, most closed class words, and open class words derived from Japanese and Western words. There is some evidence, however, that similar mechanisms of lexical retrieval may exist in Japanese spelling. Murakami (1980) studied the report of Kanji characters and Kana letters of subjects in a tip-of-the-tongue state using the method of Rubin (1975), described above (Section 6.2.2). Subjects are typically able to report the first Kanji character and Kana letter and show some knowledge of the second and third Kana letters.

Although serial ordering mechanisms may be needed to produce the spelling units of other scripts, the fine-level structure of orthographic representations in scripts such as Chinese and Japanese Kana, is likely to differ significantly from that outlined in Chapter 3 for English orthography. This may have the consequence that mechanisms found in the dual-route architecture for spelling English words may be completely absent or may take on a very different role (for instance 'allographic conversion' may be used to switch between the two different Japanese Kana scripts - Hiragana and Katakana). It is also likely that mechanisms specific to particular scripts may develop which have no counterpart in the standard dual-route model described for English spelling. For instance, orthographies which rely heavily on 'accents' as well as letters (e.g. classical Arabic) may contain a specialised mechanism dedicated to this. For the retrieval of proper names, it is hypothesized that similar effects would be found for different languages/scripts since semantic-level representations are assumed to be pre-linguistic in nature.

To conclude, it is hoped that the studies presented in this thesis further our understanding of lexical retrieval mechanisms in spelling and that they provide a basis from which to conduct future research using not only evidence from neurological patients but also from skilled spellers and computational models.

APPENDIX 1

Calculation Procedure for 'Normalising' Serial Positions

Letters were assigned to the five normalised positions according to the Wing and Baddeley (1980) formula, below. The letter k represents the integer values 0,1,2,3...n. For example, if a seven letter word contained an error on the third letter, reference to the second row shows this error would be counted in position 2.

	Position				
No. of Letters	*1*	*2*	*3*	*4*	*5*
k x 5 + 1	k	k	k+1	k	k
k x 5 + 2	k+1	k	k	k	k+1
k x 5 + 3	k+1	k	k+1	k	k+1
k x 5 + 4	k+1	k+1	k	k+1	k+1
(k +1) * 5	k+1	k+1	k+1	k+1	k+1

APPENDIX 2

Stimuli for Lexical Decision Experiment

Words	*Nonwords*		
	Left	*Middle*	*Right*
alphabet	elphabet	alphibet	alphaben
bachelor	fachelor	bachulor	bachelon
bacteria	lacteria	basteria	bacterid
bankrupt	pankrupt	bandrupt	bankrupe
birthday	nirthday	birchday	birthdas
business	tusiness	busaness	businest
calendar	halendar	calemdar	calendam
carnival	darnival	carnoval	carnivay
catholic	satholic	catrolic	catholin
chemical	shemical	chemocal	chemicat
computer	homputer	combuter	computem
elephant	ilephant	eleprant	elephand
european	duropean	eurogean	europeat
february	mebruary	febluary	februard
guardian	buardian	guandian	guardiad
hydrogen	sydrogen	hydrigen	hydroger
industry	andustry	induntry	industre
language	fanguage	landuage	languagh
lemonade	remonade	lemobade	lemonady
luncheon	runcheon	lunsheon	luncheor
magazine	bagazine	magadine	magazint
mahogany	pahogany	mahorany	mahogand
medieval	pedieval	medeeval	medievar
mortgage	dortgage	morthage	mortgagh
orthodox	arthodox	orthidox	orthodot
princess	brincess	printess	princesk
purchase	furchase	purshase	purchash
question	wuestion	quention	questior
religion	seligion	relagion	religiot
remember	demember	remerber	remembew
republic	gepublic	repablic	republin
sandwich	fandwich	santwich	sandwick
sergeant	dergeant	sergoant	sergeank
skeleton	okeleton	skedeton	skeletoy
symphony	bymphony	symprony	symphone
thursday	chursday	thunsday	thursdan

tomorrow	lommorow	tomonrow	tomorrot
tortoise	dortoise	torteise	tortoisy
triangle	priangle	triungle	triangla
umbrella	ambrella	umbralla	umbrelle

APPENDIX 3

Letter Frequency Values

Letter	#	%	*Rank*
a	5892	8.41	3
b	1241	1.77	18
c	3263	4.66	10
d	2120	3.03	14
e	8224	11.74	1
f	1004	1.43	19
g	1443	2.06	16
h	1617	2.31	15
I	5933	8.47	2
j	148	0.21	25
k	542	0.77	22
l	3406	4.86	9
m	2232	3.19	12
n	5253	7.50	6
o	4813	6.87	7
p	2223	3.17	13
q	135	0.19	26
r	5535	7.90	5
s	4046	5.77	8
t	5591	7.98	4
u	2266	3.23	11
v	844	1.20	20
w	614	0.88	21
x	225	0.32	23
y	1304	1.86	17
z	152	0.22	24
		100.00	
C	42938	61.28	
V	27128	38.72	

APPENDIX 4

Words Eliminated from the Connectionist Model Training Corpus

Words which the model failed to learn

Geminate letters (N=21) : asleep, cherry, cliff, cross, dress, giraffe, glass, grass, gross, guess, igloo, pretty, saloon, school, screen, scroll, skull, squirrel, staff, stuff, spell.

Repeated letters (N=25) : autumn, caramel, caravan, colour, damage, economy, facility, frequent, future, geology, honour, magazine, malaria, opinion, palace, position, receipt, reject, revenge, salary, statue, status, suicide, surprise, vision.

Geminate and repeated letters (N=8) : degree, million, scissors, tattoo, excess, mirror, sleeve, sneeze.

Words for which the model did not produce correct stopping

Repeated letters (N=25) : alcohol, asbestos, banana, crisis, evidence, fantasy, gondola, homework, instinct, language, limerick, monument, mortgage, mountain, pamphlet, percent, potato, prefer, pregnant, pursuit, pyjamas, queue, schedule, scorpion, junction.

Geminate and repeated letters (N=2) : horror, steeple.

APPENDIX 5

Results of Further Lesioning of the Connectionist Model

A : Word length effect (% words correct) for total corpus

B : Performance on words with geminates and all-different letters at various word lengths

C : Number of occasions (/200) in which a response contains both, none, or one letter of a geminate or matched pair

D : Performance on words with repeated letters and all-different letters at various word lengths

E : Number of occasions (/200) in which a response contains both, none, or one letter of a repeated or matched pair

A: LENGTH EFFECT (% WORDS CORRECT) FOR TOTAL CORPUS							
Lesion level		Word Length					
I	E	3	4	5	6	7	8
1	1	100.0	77.2	79.8	56.9	51.6	9.0
1	0.75	100.0	87.7	84.1	66.4	41.2	5.5
1	0.5	85.5	90.3	77.5	59.2	16.8	0.0
1	0.25	40.3	47.1	34.8	23.2	2.5	0.0
1	0	2.5	3.8	0.3	0.0	0.0	0.0
0.75	1	90.4	44.5	44.7	31.0	25.4	4.1
0.75	0.75	95.9	69.8	61.0	44.9	21.2	1.4
0.75	0.5	72.9	69.4	59.5	43.6	10.1	0.0
0.75	0.25	25.5	30.3	23.2	11.3	1.7	0.0
0.75	0	1.6	0.9	0.1	0.0	0.0	0.0
0.5	1	41.1	7.8	5.8	1.8	0.2	0.0
0.5	0.75	56.7	26.9	19.2	12.8	1.2	0.0
0.5	0.5	47.4	27.1	20.3	13.8	1.7	0.0
0.5	0.25	14.8	8.0	5.4	1.5	0.0	0.0
0.5	0	0.0	0.0	0.0	0.0	0.0	0.0
0.25	1	1.4	0.7	0.2	0.0	0.0	0.0
0.25	0.75	9.9	1.3	0.5	0.0	0.0	0.0
0.25	0.5	7.4	1.6	0.3	0.0	0.0	0.0
0.25	0.25	1.6	0.1	0.0	0.0	0.0	0.0
0.25	0	0.0	0.0	0.0	0.0	0.0	0.0
0	1	0.0	0.0	0.0	0.0	0.0	0.0
0	0.75	0.0	0.0	0.0	0.0	0.0	0.0
0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
0	0.25	0.0	0.0	0.0	0.0	0.0	0.0
0	0	0.0	0.0	0.0	0.0	0.0	0.0

B: PERFORMANCE ON WORDS WITH GEMINATES AND ALL-DIFFERENT LETTERS AT VARIOUS WORD LENGTHS

ALL-DIFFERENT CORPUS - % WORDS CORRECT

Lesion level		Word Length				
I	E	3	4	5	6	7
1	1	100.0	76.0	82.9	64.4	58.6
1	0.75	100.0	87.0	92.4	82.7	39.0
1	0.5	82.6	94.2	85.3	73.3	11.0
1	0.25	38.2	59.2	49.3	29.7	0.0
1	0	0.0	4.9	0.0	0.0	0.0
0.75	1	94.7	43.1	44.5	34.9	31.0
0.75	0.75	97.9	68.1	68.6	54.1	21.0
0.75	0.5	75.6	77.6	72.8	60.4	9.0
0.75	0.25	22.1	34.8	28.8	16.4	0.0
0.75	0	0.0	1.6	0.0	0.0	0.0
0.5	1	47.4	4.8	5.0	1.3	0.0
0.5	0.75	60.0	23.2	21.1	13.9	0.0
0.5	0.5	54.1	32.1	28.3	17.9	0.0
0.5	0.25	12.1	7.1	4.3	0.4	0.0
0.5	0	0.0	0.0	0.0	0.0	0.0
0.25	1	2.6	0.0	0.0	0.0	0.0
0.25	0.75	10.6	1.3	0.0	0.0	0.0
0.25	0.5	11.2	0.4	0.5	0.0	0.0
0.25	0.25	1.2	0.0	0.0	0.0	0.0
0.25	0	0.0	0.0	0.0	0.0	0.0
0	1	0.0	0.0	0.0	0.0	0.0
0	0.75	0.0	0.0	0.0	0.0	0.0
0	0.5	0.0	0.0	0.0	0.0	0.0
0	0.25	0.0	0.0	0.0	0.0	0.0
0	0	0.0	0.0	0.0	0.0	0.0

GEMINATE CORPUS - % WORDS CORRECT

Lesion level		Word Length				
I	E	3	4	5	6	7
1	1	90.0	86.1	76.6	84.8	67.5
1	0.75	95.0	94.5	85.1	93.8	72.5
1	0.5	100.0	83.0	88.0	86.9	67.5
1	0.25	60.0	36.4	45.1	36.6	25.0
1	0	45.0	0.0	3.4	0.0	0.0
0.75	1	60.0	61.2	44.0	48.3	35.0
0.75	0.75	75.0	73.9	69.7	62.8	52.5
0.75	0.5	95.0	69.7	68.0	68.3	52.5
0.75	0.25	50.0	22.4	32.0	26.9	5.0
0.75	0	5.0	0.0	0.6	0.0	0.0
0.5	1	0.0	25.5	4.6	4.1	0.0
0.5	0.75	45.0	40.6	22.9	17.9	12.5
0.5	0.5	35.0	38.2	31.4	24.1	15.0
0.5	0.25	20.0	9.7	10.3	5.5	2.5
0.5	0	0.0	0.0	0.0	0.0	0.0
0.25	1	0.0	0.6	0.0	0.0	0.0
0.25	0.75	0.0	3.6	0.0	0.0	0.0
0.25	0.5	0.0	4.2	1.7	0.0	0.0
0.25	0.25	5.0	0.6	0.0	0.0	0.0
0.25	0	0.0	0.0	0.0	0.0	0.0
0	1	0.0	0.0	0.0	0.0	0.0
0	0.75	0.0	0.0	0.0	0.0	0.0
0	0.5	0.0	0.0	0.0	0.0	0.0
0	0.25	0.0	0.0	0.0	0.0	0.0
0	0	0.0	0.0	0.0	0.0	0.0

C: NUMBER OF OCCASIONS (/200) IN WHICH A RESPONSE CONTAINS BOTH, NONE OR ONE LETTER OF A GEMINATE OR MATCHED PAIR										
Lesion level		GEMINATE			ALL-DIFFERENT			DIFFERENCE		
I	E	NONE	ONE	BOTH	NONE	ONE	BOTH	NONE	ONE	BOTH
1	1	0	13	187	0	0	200	0	-13	13
1	0.75	0	9	191	2	6	192	2	-3	1
1	0.5	9	15	176	1	21	178	-8	6	2
1	0.25	29	53	118	19	72	109	-10	19	-9
1	0	54	81	65	29	114	57	-25	33	-8
0.75	1	4	38	158	0	5	195	-4	-33	37
0.75	0.75	3	31	166	7	10	183	4	-21	17
0.75	0.5	14	9	177	21	35	144	7	26	-33
0.75	0.25	54	29	117	47	80	73	-7	51	-44
0.75	0	80	57	63	70	102	28	-10	45	-35
0.5	1	23	70	107	24	25	151	1	-45	44
0.5	0.75	33	39	128	26	47	127	-7	8	-1
0.5	0.5	55	7	138	60	69	71	5	62	-67
0.5	0.25	104	3	93	103	66	31	-1	63	-62
0.5	0	134	6	60	134	64	2	0	58	-58
0.25	1	101	39	55	114	26	56	13	-13	1
0.25	0.75	117	21	61	143	26	29	26	5	-32
0.25	0.5	145	7	48	141	43	16	-4	36	-32
0.25	0.25	179	0	21	179	19	2	0	19	-19
0.25	0	189	0	11	183	17	0	-6	17	-11
0	1	147	16	30	174	8	12	27	-8	-18
0	0.75	165	9	23	178	8	11	13	-1	-12
0	0.5	182	4	14	189	10	1	7	6	-13
0	0.25	197	0	3	199	1	0	2	1	-3
0	0	200	0	0	200	0	0	0	0	0

D: PERFORMANCE ON WORDS WITH REPEATS AND ALL-DIFFERENT LETTERS AT VARIOUS WORD LENGTHS

ALL-DIFFERENT CORPUS - % WORDS CORRECT

Lesion level		Word Length				
I	E	4	5	6	7	8
1	1	76.0	82.9	64.4	58.6	3.2
1	0.75	87.0	92.4	82.7	39.0	2.1
1	0.5	94.2	85.3	73.3	11.0	0.0
1	0.25	59.2	49.3	29.7	0.0	0.0
1	0	4.9	0.0	0.0	0.0	0.0
0.75	1	43.1	44.5	34.9	31.0	3.2
0.75	0.75	68.1	68.6	54.1	21.0	0.0
0.75	0.5	77.6	72.8	60.4	9.0	0.0
0.75	0.25	34.8	28.8	16.4	0.0	0.0
0.75	0	1.6	0.0	0.0	0.0	0.0
0.5	1	4.8	5.0	1.3	0.0	0.0
0.5	0.75	23.2	21.1	13.9	0.0	0.0
0.5	0.5	32.1	28.3	17.9	0.0	0.0
0.5	0.25	7.1	4.3	0.4	0.0	0.0
0.5	0	0.0	0.0	0.0	0.0	0.0
0.25	1	0.0	0.0	0.0	0.0	0.0
0.25	0.75	1.3	0.0	0.0	0.0	0.0
0.25	0.5	0.4	0.5	0.0	0.0	0.0
0.25	0.25	0.0	0.0	0.0	0.0	0.0
0.25	0	0.0	0.0	0.0	0.0	0.0
0	1	0.0	0.0	0.0	0.0	0.0
0	0.75	0.0	0.0	0.0	0.0	0.0
0	0.5	0.0	0.0	0.0	0.0	0.0
0	0.25	0.0	0.0	0.0	0.0	0.0
0	0	0.0	0.0	0.0	0.0	0.0

REPEATED CORPUS - % WORDS CORRECT

Lesion level		Word Length				
I	E	4	5	6	7	8
1	1	72.7	60.0	36.7	38.5	15.6
1	0.75	72.7	42.5	23.3	17.8	4.4
1	0.5	49.1	20.4	14.0	2.2	0.0
1	0.25	14.5	0.8	0.9	0.0	0.0
1	0	0.0	0.0	0.0	0.0	0.0
0.75	1	67.3	38.8	14.0	24.4	4.4
0.75	0.75	61.8	28.3	14.0	10.4	0.0
0.75	0.5	36.4	12.5	6.0	2.2	0.0
0.75	0.25	0.0	1.7	0.5	0.0	0.0
0.75	0	0.0	0.0	0.0	0.0	0.0
0.5	1	50.9	14.6	0.9	0.0	0.0
0.5	0.75	38.2	6.3	0.9	0.0	0.0
0.5	0.5	23.6	1.7	0.0	0.0	0.0
0.5	0.25	0.0	0.0	0.0	0.0	0.0
0.5	0	0.0	0.0	0.0	0.0	0.0
0.25	1	10.9	0.4	0.0	0.0	0.0
0.25	0.75	7.3	0.0	0.0	0.0	0.0
0.25	0.5	0.0	0.0	0.0	0.0	0.0
0.25	0.25	0.0	0.0	0.0	0.0	0.0
0.25	0	0.0	0.0	0.0	0.0	0.0
0	1	0.0	0.0	0.0	0.0	0.0
0	0.75	0.0	0.0	0.0	0.0	0.0
0	0.5	0.0	0.0	0.0	0.0	0.0
0	0.25	0.0	0.0	0.0	0.0	0.0
0	0	0.0	0.0	0.0	0.0	0.0

E: NUMBER OF OCCASIONS (/200) IN WHICH A RESPONSE CONTAINS BOTH, NONE OR ONE LETTER OF A REPEATED OR MATCHED PAIR										
Lesion level		REPEATED			ALL-DIFFERENT			DIFFERENCE		
I	E	NONE	ONE	BOTH	NONE	ONE	BOTH	NONE	ONE	BOTH
1	1	0	14	186	0	0	200	0	-14	14
1	0.75	2	41	157	0	7	190	-2	-34	33
1	0.5	1	101	98	0	41	152	-1	-60	54
1	0.25	5	169	26	0	103	96	-5	-66	70
1	0	9	189	2	3	178	19	-6	-11	17
0.75	1	1	42	157	0	5	194	-1	-37	37
0.75	0.75	1	77	122	2	18	179	1	-59	57
0.75	0.5	4	147	49	1	59	138	-3	-88	89
0.75	0.25	9	174	17	10	132	57	1	-42	40
0.75	0	15	183	2	10	178	12	-5	-5	10
0.5	1	5	103	92	5	24	167	0	-79	75
0.5	0.75	7	134	59	8	48	143	1	-86	84
0.5	0.5	10	178	12	12	108	80	2	-70	68
0.5	0.25	21	179	0	23	153	24	2	-26	24
0.5	0	30	170	0	32	168	0	2	-2	0
0.25	1	89	84	27	90	29	75	1	-55	48
0.25	0.75	105	83	12	101	37	62	-4	-46	50
0.25	0.5	106	92	2	113	53	34	7	-39	32
0.25	0.25	131	69	0	125	71	4	-6	2	4
0.25	0	133	67	0	136	64	0	3	-3	0
0	1	145	55	0	154	10	32	9	-45	32
0	0.75	147	53	0	155	17	25	8	-36	25
0	0.5	172	28	0	168	23	9	-4	-5	9
0	0.25	185	15	0	174	24	2	-11	9	2
0	0	180	20	0	179	21	0	-1	1	0

APPENDIX 6

Name Substitution Errors

BA

Target	*Response*
Brenda	Barbara
Charles	Charlie
Clarence	Clarice
Danny	Daniel
Derek	Eric
Diana	Diane
Eve	Ena
Gracie	Gary
Gregory	Greg
Irene	Eileen
Irene	Ivy
James	Jamie
Janet	Jan
Jimmy	James
Joseph	Josephine
Julian	Julie
Kevin	Keith
Lucille	Audrey
Mark	Martin
Molly	Olive
Phillip	Phillipe
Robert	Robin
Rodney	Rod
Roy	Royston
Sidney	Eric
Victor	James
Vincent	Victor

KBP

Target	*Response*
Alan	Damon
Albert	Arthur
Ben	Benny
Cary	Gary
Clare	Carol
Colin	Carl
Deborah	Rita
Diana	Doris
Donald	Doug
Dora	Dorothy
Doris	Dorothy
Edward	Charles
Edward	Evan
Edward	Edwin
Emily	Vera
Frederick	Alfred
Gail	Graham
George	James
Gerry	Gary
Gordon	Gary
Graham	Gary
Henry	Harry
Jack	John
James	Jamie
Jane	Joan
Jane	John
Jason	John
Jennifer	Jeremy
Jenny	Julie
Joanne	Anne
Jonathan	John
Joseph	Joe
Joseph	John
Judy	June
Judy	Jack
Julie	Judy
Kenneth	Keith
Kevin	Vince
Lee	Les
Mae	Mavis

Meryl	Mavis
Nick	Dick
Patrick	Paul
Peter	Pat
Ralph	Rita
Robert	John
Roger	Robin
Rupert	Robert
Russ	Roz
Shirley	Sarah
Sophie	Samantha
Thomas	Terence

APPENDIX 7

BA's errors in writing to dictation (from 2000 word corpus)

FRAGMENTS

accident	accid
accordian	accorda
acrobat	ae
acrobat	ae
aeroplane	areopa
aeroplane	areop
aeroplane	aroplan
alice	al
alligator	aig
alligator	agg
alphabet	alp
ambulance	amb
angle	ang
arrest	arra
baby	ba
bagpipe	b
bagpipe	pip
bamboo	ba
basis	bac
bayonet	b
beaker	b
beam	b
beard	bea
beer	po
beggar	b
bell	t
bench	be
bench	ba
blister	blist
bodice	bod
body	b
border	cor
Brazil	b
brazil	braz
bribe	br
brick	bri
bronte	bro
bruce	bru
budget	bud
bullet	b
bullet	bult
bump	b
cactus	ca
camera	ca
canoe	c
canoe	can
caravan	caval
caravan	caval
cemetery	cemete
centre	cu
century	centun
champagne	chamkan
character	cha
cheap	cro
chemist	chim
chin	ch
christina	christa
cider	c
columbus	col
coral	co
corridor	c
corridor	corro
courage	caro
cousin	cou
crescent	cre
crocus	crom
croquet	co
cupboard	cupbo
Darren	d
day	ni
debt	id
denmark	den
denmark	dem
deputy	dupt
detail	deti
detective	det
disease	dis
doctor	doco

dough	do
drama	dra
ebony	i
egypt	egp
elephant	elepha
Esther	est
exectutive	exe t
fact	fa
factory	f
factory	f
faith	hy
falcon	fe
fantasy	fan
fantasy	fanta
fence	fe
fingerprint	fingure
fireworks	fi
fluid	flu
flute	flu
fortune	forto
fraud	fr
frederick	ge
frequent	qu
fumble	t
future	fut
future	fag
gentle	gent
gentle	g
geraldine	gerad
germany	ger
giraffe	griff
grapes	gr
gregory	greg
Hamilton	ha
harbour	harb
Harris	harr
helicopter	hel
hold	ha
holiday	ho
holland	ho
honest	ho
honour	hono
hound	hou
human	hum
idea	I'd

idiot	dide
ignore	ech
ignore	th
ingrid	g
israel	ist
jacket	jumj
Jackson	jas
janet	jan
joke	jo
Judy	j
kangaroo	k
knuckle	knu
knuckle	knuck
lady	el
ladybird	b
late	l
laugh	lad
leopard	leop
liar	li
lilac	lic
lobster	lobor
louise	l
Lucy	l
magazine	mage
malaria	m
marble	ma
maze	ma
medicine	m
medicine	mech
memory	meme
mermaid	mer
meryl	mem
miracle	mittle
missile	mi
Morocco	mo
moth	bu
moustache	marchiw
mutiny	mudd
muzzle	mu
myth	mi
napoleon	bonl
nerve	ne
nest	ne
network	net
Nicholas	nichal

object	ob
obtain	obt
orbit	or
ornament	orma
ostrich	o
otter	o
palace	th
Palmer	p
pan	pa
paradise	para
paradise	parrid
parent	pai
pattern	pa
pedal	p
pelican	poqu
pencil	per
pendulum	p
penguin	pe
period	per
phantom	phan
phantom	phat
pharmacy	pha
photograph	photo
photograph	phograph
pigeon	pig
planet	pl
pocket	pa
pocket	pop
poison	p
policy	p
Portugal	p
poster	post
pouch	pou
pressure	p
province	provi
province	pro
psychology	psyos
puppet	pupp
puree	pur
purple	purl
purple	ma
pyramid	py
pyramid	py
question	quin
racoon	ric
reagan	re
Rebecca	re
replica	rear
rifle	rif
riot	r
rooster	rooth
rough	r
salary	sal
salute	s
scarf	sc
scissors	scal
sea	s
sea	s
secret	sel
shadow	sh
shake	sha
shakespeare	shakespar
shame	sh
Sheila	shi
sledge	sl
sledge	slog
slice	sli
smile	s
snake	s
sophie	so
soprano	sop
spain	mex
sparrow	sp
spatula	spit
spinach	spet
spoon	sp
stable	stap
statue	stu
submarine	sub
suicide	sua
sulphur	sulp
sulphur	so
swallow	w
task	piz
text	t
thermometer	th
title	ti
tobacco	tobb
tortoise	tortoe
tractor	trac

tractor	trank
tribe	r
tsar	tu
tube	tu
tube	tu
tube	tu
turquoise	tuquise
umbrella	umbrel
upward	up
velvet	vel
vernon	ver
violet	vial
volcano	vol
wench	w
willow	w
wire	s
wrist	wri
zack	z

NONWORD RESPONSES

accident	accidult
accordian	accordan
anchor	anchorge
anchor	anchrge
apricot	aprocit
argue	argu
arm	arb
article	artice
author	autho
autumn	auntum
bag	hanb
banana	nanane
basket	basken
bat	tennet
beige	beigus
bike	bycle
bit	br
blister	bistle
blueberry	blackberraw
bride	brig
bump	bum
bungalow	bunglow
bungalow	bunglow
butcher	butchon
cabinet	cupbroad
calm	com
canada	canam
canal	cannal
carriage	cairrage
castle	castlen
castle	castl
cave	cavan
century	centery
chimney	chiminy
city	citon
climb	climi
clip	clipt
coach	coacher
colonel	colone
contract	contactor
control	contable
costume	coster
cradle	crddle
crocodile	cocodile
custom	custam
daisy	daisye

daisy	daisey
damp	daip
danger	deang
dean	deas
dentist	dentant
deposit	desposit
disease	disceace
dough	dodg
dress	drad
effort	effent
egypt	egyt
elbow	elbor
enid	enida
ethel	ethol
fabric	fabic
fear	fae
fever	feve
find	fila
fireman	firebro
forest	forsty
frog	frop
funnel	tunner
future	futher
garden	garder
gentle	genlti
geography	geogu y
georgina	sussan
germ	geam
ghost	chour
ghost	gnil
ghost	ghosp
giraffe	gifarre
giraffe	giffif
golf	gof
gospel	gospthy
graph	graf
half	hatf
hand	wram
harbour	habour
hero	heo
holiday	holiway
horror	horrib
horse	houres
hospital	hosipal
hotel	hotal
house	homse
hungry	hungrian
hurricane	hurrican
infant	infante
jacket	jackage
jelly	chiver
jesus	jesu
jury	triaf
kangaroo	kanakoo
ketchup	ketchum
Laura	laure
lawnmower	lawnmowre
legend	histir
lesson	leason
Lloyd	loyl
lump	bumk
marble	marley
medal	melat
media	mete
medicine	mechine
melon	mellon
Mexico	mesce
michelle	michele
Miller	Millard
minute	minuit
mirror	mirrog
mixture	mixfune
moses	mose
mouse	mousey
mouse	mour
move	minl
napkin	napin
nephew	newphe
palace	palance
paper	paperd
piano	pion
pigeon	piggey
planet	palet
plus	pam
poetry	poety
poppy	popple
potato	potatoe
potato	potatoe
power	powa
pretty	pretter

prison	pisoner
proud	prou
pudding	desset
pumpkin	pumper
ribbon	ribben
rifle	tria
robin	robbin
saddle	sandler
salad	sal d
Samuel	susamel
satire	sattre
satire	sappi
secret	senial
seven	sever
Sheila	sharle
shepherd	sheppord
slope	stord
sofa	sop
soft	smoo
speak	speaf
spire	spick
squirrel	squerral
stuff	suf
stuff	stuffold
swim	swimp
table	tida
tally	targen
teeth	toothe
text	exe
thatcher	hillard
thorn	thar
tobacco	tobbise
tobacco	tobicco
tomato	tomatoe
tone	toa
umbrella	umberla
umbrella	umbrello
upward	upstand
valley	vettl
valley	valle
valour	vatle
vein	vie
village	villieger
village	villige
vodka	voldu
watch	minition
who	wha
widow	withow
widow	windfe
window	winglass
wrist	writch
yacht	yarg

LEXICAL SUBSTITUTIONS

above	another
adult	add
almost	none
also	which
also	what
america	USA
and	the
answer	and
answer	any
apron	pink
armchair	firechair
ashtray	tray
at	they
aunt	niece
aunt	auntie
bat	tennis
battery	batter
because	become
behind	beside
belief	belong
beth	bath
bone	knee
breath	breeze
brenda	barbara
brooch	bracelet
broom	book
bud	bus
budget	bugie
budget	bugie
bullet	pistol
but	with
cable	cabin
camel	camper
carry	cash
cattle	cow
celery	lettuce
chunk	chocolate
city	build
clarence	clarice
clue	clothes
coin	coil
colour	calendar
Cooper	cooker
cowboy	cow
cradle	cry
crime	cry
crisis	cried
crisis	christ
crocus	crow
cup	cap
cut	knives
danny	daniel
Diana	diane
doubt	due
duck	duke
either	there
Evans	mary
every	arrive
eyebrow	eyebrush
face	hair
famous	fall
finger	figure
fire	fine
frog	flog
fruit	sultana
funnel	tunnel
grapefruit	grow
gravy	soup
greenhouse	house
ham	heart
hang	half
hawk	eagles
head	hand
hedgehog	hog
hell	help
hide	hard
high	hill
him	us
hinge	screw
hold	hand
hotdog	hot
human	humid
husband	man
icecream	ice
icicle	ice
in	be

instinct	give
Irene	ivy
irene	eileen
it	if
itself	her
jewelry	gold
Jones	joe
julian	julie
justice	justine
keel	killing
kevin	keith
knock	knot
knock	knot
knock	knob
latch	lack
latter	latin
latter	ladder
leg	knee
length	leather
lens	lent
less	last
letter	post
license	drive
life	lift
lighthouse	lighterhouse
lobster	lobe
lump	jump
magazine	maze
malt	malta
mermaid	maid
million	money
molly	olive
moment	mine-up
moment	away
money	monet
neither	no
odour	oat
often	we
on	or
opinion	open
opposite	odd
ornament	vase
our	hour
oyster	escape
peach	beech

pedal	bike
penny	half
pest	pet
phase	face
phillip	phillipe
policy	polished
prey	hymn
quiet	yes
risk	reach
rubble	rubber
salary	salad
saucer	saucepan
save	money
scout	camp
scramble	scrap
seat	settee
sheep	lamb
shelf	sleeves
ship	sail
sidney	eric
siege	castle
sister	daughter
sledge	joinery
slime	slimy
smoke	chimney/sweep
sock	ankle
sofa	suet
solid	stool
sound	loud
sour	sod
special	spelling
squirrel	mouse
stick	stroke
suede	swear
sweater	waist
sword	saw
taste	take
then	they
there	were
thing	together
thou	book
tongue	tissue
track	train
train	station
train	railway

truck	lorry
truth	true
unless	list
upward	wall
valour	valet
vision	spill
voyage	ship
Ward	nurse
wasp	bee
week	weeks
what	with
wheel	vehicle
when	where
where	want
while	would
wide	way
windmill	wind
without	out
word	writing
world	would
wrath	ratty
wrench	screw
wrong	written
yard	length

MORPHOLOGICAL ERRORS

actor	act
arms	arm
arrive	arrival
atom	atomic
aunt	auntie
bake	baker
bridge	bridges
build	building
burn	burnt
car	cars
cherry	cherries
child	children
copy	copying
cry	crying
cube	cubic
elephant	elephants
england	english
eye	eyes
eyes	eye
farm	farmer
gate	gated
grow	grown
hedge	hedgerow
history	historian
knit	knitting
month	monthly
mountain	mountains
mouth	mouthful
party	parties
poem	poet
scotland	scottish
smoke	smoking
square	squares
stone	stony

teach	teacher
vase	vases
vote	voting

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