A cognitive neuropsychological approach to the assessment and remediation of acquired dysgraphia

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This study used a cognitive neuropsychological approach to investigate a case of acquired dysgraphia in an adult who had sustained focal brain damage. The interpretation and remediation of her dysgraphia were guided by reference to a detailed model describing the functional architecture of the normal language processing system. The aims of the study were to investigate the usefulness of model-based assessment

1) in identifying the precise nature of the underlying mechanisms responsible for the dysgraphia; and
2) in designing an efficacious treatment programme that was informed by theories of normal language processing.

Interpretation of detailed pre-therapy testing using tasks derived from current psycholinguistic models suggested that the subject's dysgraphia arose from deficits with processing low-imageability semantic information as well as from a breakdown at the level of the graphemic assembly buffer. Two treatment phases which targeted the identified deficit areas were implemented using a multiple baseline (across behaviours) methodology. The first treatment consisted of semantic therapy targeting the writing of low-imageability words, and the second treatment involved a segmentation hierarchy for treating the writing of non-words. The results indicated positive and selective treatment effects as well as strong generalization effects to related items and functions. The results are discussed in the light of current psycholinguistic theories of model-based assessment and treatment.

I Introduction

The growth of the discipline of cognitive neuropsychology in the late 1980s and 1990s has heralded an alternative approach to the assessment and treatment of adults with aphasia, i.e., those individuals who have an acquired neurogenic language deficit. When a cognitive neuropsychological approach is taken, the assessment of a patient's language deficits and remaining abilities becomes a theoretically motivated

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and dynamic process that has as its foundation a detailed model of language processing. Issues relating to the assignment of a general diagnostic label to the language disorder consistent with the site of neurological lesion are secondary to detailed hypothesis-driven investigations designed to reveal the nature of the language deficit. The present research has used one such model-based assessment resource – the Psycholinguistic Assessment of Language Processing in Aphasia (PALPA) (Kay *et al.*, 1992) – to highlight the way in which the assessment process is specifically designed to determine the integrity or otherwise of the various language-processing components, and the way in which assessment in turn drives the theoretical application of model-based therapy.

A finding which both necessitates and reinforces the cognitive neuropsychological approach to the assessment of aphasia is that different processing mechanisms may underlie the same surface symptoms in different aphasic patients. For example, the misnaming of a pictured object may be due to:

1) disruption to the semantic specification of that concept;
2) a difficulty in retrieving the lexical label for that concept; or
3) an inability to produce the necessary phonological form of the word.

Ultimately, treatment can only be optimally effective if the precise nature of a particular patient's processing capacities and deficits is uncovered. Cognitive neuropsychology has, therefore, been able to begin to equip the aphasia therapist with a theoretical framework with which to address two critical issues: first, how best to assess a patient's language so as to reveal the precise nature of his or her disturbance and, second, how to design and monitor efficacious treatment.

Diagrammatic 'box-and-arrow' models of lexical processing, such as that depicted in Figure 1, have become commonplace in the cognitive neuropsychological literature, particularly for aphasic disorders. These maps for language mediation serve as a basic starting point for psycholinguistic investigations. The model in Figure 1 is a variant of Morton's (1980) logogen model, subsequently modified by Patterson and Shewell (1987), Kay *et al.* (1992) and Lesser and Milroy (1993). This model specifies the word-processing routines available for single-word processing and is used as the reference model for the present research.

Whilst many detailed descriptions of the processing routines shown in Figure 1 have been published (the reader is referred to Behrmann and Byng (1992) and Ellis *et al.* (1994) for excellent reviews), a brief summary of the basic framework of the model will be provided

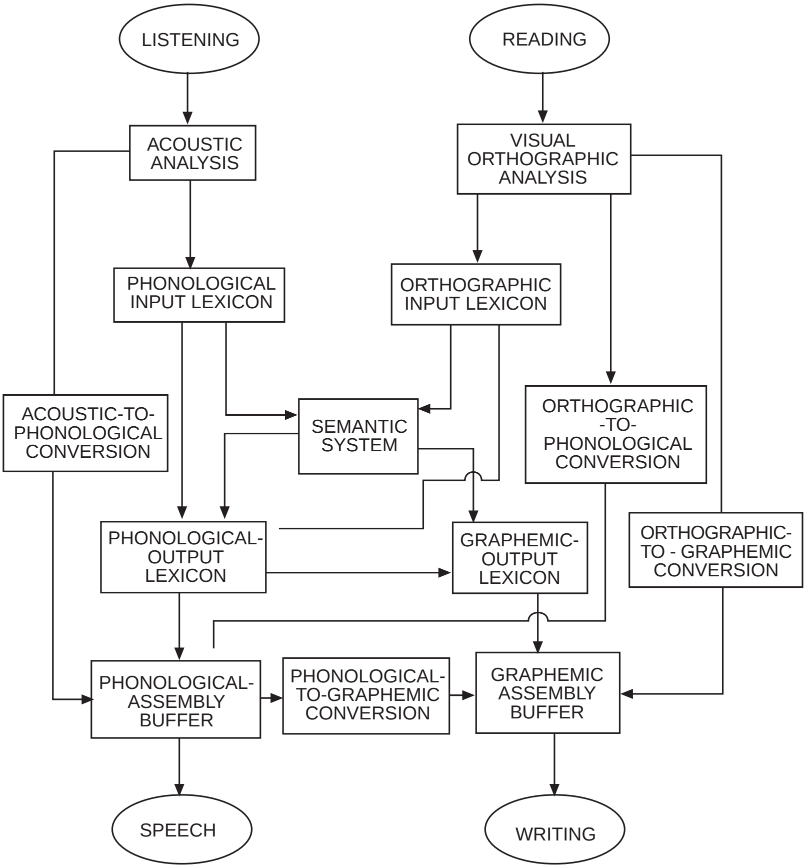

Figure 1 A process model for the recognition, comprehension and production of spoken and written words and non-words.
Source: adapted from Patterson and Shewell (1987)

here. In order to understand a spoken word, for example, acoustic analysis of the speech wave allows it to be decoded into an accurate string of sounds. Auditory discrimination is one aspect of this process. Next, the phonological input lexicon must identify these strings as familiar words. Therefore, at this level there must be a pool of stored representations of all words that the individual has ever heard. If the stimulus string registers as a familiar entity, then it passes to the central semantic system, where meaning correlates are assigned to the lexical item and comprehension is completed. Written word comprehension proceeds in a similar manner from orthographic analysis of the written stimulus, to identification of the item within the orthographic input lexicon and finally to the semantic system.

Output tasks require activation of the various semantic attributes that define the concept. Semantic information thus generated then addresses the phonological output lexicon for spoken word-form templates and the graphemic output lexicon for written word-form templates in order to find the appropriate lexical form which matches the meaning correlates. The output lexicons, like the input lexicons, contain representations of all spoken or written words known to the individual. The next level, the assembly buffer stages, represents working-memory systems which temporarily store abstract entities in the correctly assembled spatial sequences (phonological or graphemic representations in the phonological and graphemic assembly buffers, respectively) (Caramazza *et al.*, 1987). At this stage, overt production of the spoken or written word remains unrealized. Subsequently, phoneme strings are converted into speech movements and grapheme strings are converted into hand movements for writing.

The concepts of frequency and imageability appear frequently throughout the cognitive neuropsychological literature; some explanation of their significance is therefore warranted. For high frequency words, the amount of excitation necessary to activate the lexical entries in the input and output lexicons is generally lower than for words less frequently encountered. Traditionally, frequency effects (i.e., differential access to low- and high-frequency words) are thought to be indicative of processing at the level of the input and output lexicons. More recently, however, it has been suggested that frequency effects may reflect the nature of processes associated with the input and output lexicons and the semantic system (Ellis *et al.*, 1994; Ellis *et al.*, 1992). Imageability refers to the ease with which a particular word is capable of invoking a sensory image in the mind of a subject. For example, for most people, the noun *apple* activates a wide range of sensory representations (e.g., visual and olfactory), and such an item is generally rated as being highly imageable. The noun *irony*, on the other hand, possesses no direct visual semantic attributes, and is typically classified as an item with low imageability. Imageability effects (where performance on tasks requiring access to words with high imageability is better than on tasks with words of low imageability) are indicative of a central semantic system disturbance (Plaut and Shallice, 1994; Lesser, 1993).

Additional processing routines have been added in various revisions to this model (Patterson and Shewell, 1987; Caplan, 1992; Ellis *et al.*, 1994) to account for a person's ability to perform various non-word operations, such as the ability to read non-words, to write a non-word to dictation, or to copy or repeat non-words. Non-words do not pass through the lexical system; the ability to perform non-word operations must, therefore, be mediated by non-lexical conversion routines. For example, when a person is required to write to dictation the non-word *plink*, a process of phoneme-to-grapheme conversion is set in train, allowing that person to directly convert input signals into a different output form, effectively bypassing the internal lexicon.

In the literature, there have been some general criticisms of the box-and-arrow models (see Lesser (1993) for a summary). These criticisms have served to caution the aphasia therapist against the unquestioning acceptance of their veracity. Some researchers have suggested that the models are simplistic and do not do justice to the intricate complexity of language processing (Hillis and Caramazza, 1994; Riddoch and Humphreys, 1994). Indeed, more recent research has sought to expand on the nature of the processing mechanisms that are carried out within the 'boxes' or the language representations (Plaut and Shallice, 1994). A second criticism is that structural models give the impression that each language stage becomes activated sequentially; this is a view not held by the connectionist theorists, who suggest that language processing does not proceed in a linear manner but occurs interactively (Stemberger, 1985; Dell, 1986; Humphreys *et al*., 1988). Whilst due consideration must be given to the aforementioned concerns, and to the view that the models may understate the complexity of language processing at the neural level, they do provide a functional architecture of the single-word processing system that serves to define how language is comprehended, read, spoken and written. Predictions derived from these models can therefore be empirically tested.

Of particular interest to the present research are the numerous successful single-case remediation studies in the cognitive neuropsychological literature which describe how models, such as that depicted in Figure 1, can assist the aphasia therapist in devising, implementing and monitoring therapy which targets the specific underlying deficit; see, for example, Lesser and Milroy (1993) for a review of major efficacy studies. Coltheart *et al*. (1994) state that 'there can be no question about the major contributions that models have made to neuropsychological assessment techniques in the past decade' (p. 21). As a result of fine-grained assessment of the functioning of the various language-processing components, specific foci for treatment can be accurately established and treatment goals made more specific than in the traditional symptom-based approach.

Whilst a growing body of evidence attests to the utility of the cognitive neuropsychological approach in the remediation of a variety of language disorders, specific issues relating to the development of a theory of rehabilitation have been dealt with less comprehensively. For example, crucial components of a theory of rehabilitation – such as detailed information describing the therapy tasks, the stimuli used, the methods of teaching on error, the pacing of tasks and the interaction between the therapist and client – have been largely overlooked. However, even the most vocal critics of the use of cognitive neuropsychological models to define treatment techniques have conceded that fully fledged theories of rehabilitation are not essential at this stage. Four factors are important in the eventual development of a theory of rehabilitation and guidelines regarding specific treatment techniques:

1) that the clinician use an hypothesis-driven approach to assessment;
2) that these hypotheses are generated from detailed assessment which is underpinned by theoretical models of language processing;
3) that the cognitive neuropsychological assessment approach has, as its major goal, the identification of the underlying processing deficits which in turn are targeted by specific therapy techniques; and
4) that the subsequent responses to the treatment methods thought to address the deficient processes be carefully documented (Caramazza, 1989; Hillis and Caramazza, 1994).

In order to explore in greater detail the usefulness of model-based assessment in the remediation of acquired language disorders, a single-case study of an aphasic client with a significant dysgraphia (writing disorder) is presented in this article. The aims of the study are two-fold. First, the study determines whether an assessment procedure based on a cognitive neuropsychological model of language processing allows for a precise and accurate description of which components of the patient's language system are primarily impaired. A second goal of the study is to ascertain whether the treatment techniques generated from the findings of the assessment are effective in remediating the patient's language deficit.

II The subject

The subject (CV) is a 45-year-old monolingual, English-speaking female with left cerebral hemisphere dominance. She had qualified as a registered nurse, but was running a successful clothing business at the time of her admission to hospital. She was admitted to hospital in late 1992 following an acute subarachnoid haemorrhage, secondary to a voiding left-sided posterior communicating artery aneurysm, which had been induced by a blow to her head from a falling bookcase on the previous day. Two days later she underwent surgery to clip the aneurysm. There were no post-operative complications but seven days post-operatively an expressive dysphasia and right hemiparesis evolved. Following the emergence of the dysphasia, a computed tomographic (CT) scan was carried out. There was a small area of low density in the left basal ganglia region in keeping with an established infarct. In the left parietal region there was also a general area of low density involving grey and white matter and a loss of definition of the cortical sulci, both of which were consistent with an area of developing ischaemia/infarction. There was no evidence of a rebleed.

Initial assessment of language abilities in 1992, two weeks post-haemorrhage, revealed that CV's verbal expression, while fluent and grammatical, exhibited hesitations at content word boundaries as well as circumlocutory behaviour, and some semantic paraphasias (substitution of incorrect but semantically related words). Upon discharge from hospital, CV attended twice weekly for speech pathology with a continuing focus on semantic therapy as well as therapy for her other main deficits. These had been identified through model-based assessment and included:

1) moderately impaired auditory analysis skills;
2) moderately impaired access to lexical–phonological representations;
3) moderately impaired grapheme-to-phoneme links;
4) severely impaired phonological input-to-output conversion;
5) severely impaired post-semantic writing deficits; and
6) severely impaired phoneme-to-grapheme conversion routine.

Two years post-onset, CV continued to receive twice weekly speech pathology intervention, but the focus of treatment had shifted to improving her poor writing skills through therapy aimed at strengthening phoneme–grapheme links and graphemic segmentation therapy. At this stage, ability to segment and to write three-lettered non-words to dictation was 95% accurate. Verbal output continued to demonstrate occasional semantic paraphasias and circumlocutory behaviour. However, the most frustrating disability for CV was her poor writing skills. It was at this stage that CV came to the attention of the investigators, and the following assessment and remediation study spans a nine month period in 1995, a little over two years post-trauma.

III The assessment process and results

1 Procedure

Unlike many studies whose choice of tasks is confirmed in the initial design stages of the study, the subtests to be described in this study are selected as the test progresses on the basis of hypotheses formed or supported from results obtained. Consequently, the assessment process and interpretation of results form a joint, dynamic process and are therefore described together.

In order to gain a clear profile of CV's language abilities, and in particular to investigate the underlying deficits contributing to her persistent anomia and dysgraphia, an assessment battery using subtests from the PALPA (Kay *et al*., 1992) and clinician-devised testing was conducted in April 1995. The PALPA consists of 60 subtests based on a psycholinguistic approach to the interpretation of processes in the recognition, comprehension and production of spoken and written words and sentences. The PALPA is not designed to be given in its entirety to an individual; 'rather the assessments should be tailored to those that are appropriate to the hypothesis under investigation' (Kay *et al*., 1992: 2).

Issues relating to reliability and validity of the PALPA have been the subject of considerable debate in the literature; see Wertz (1996) and Kay, Lesser and Coltheart's (1996) response. It is fair to say, however, that traditional investigations of psychometric reliability and validity have not been conducted. The authors do report data from a limited normative sample of 32 non-brain-damaged subjects and 25 subjects with aphasia. For readers unfamiliar with the PALPA, a brief description of the content of the subtests discussed in this paper is given in Appendix 1.

2 Discussion of results

A summary of assessment results obtained from CV is presented in Table 1.

a Semantic input tests: For all semantic input tasks, CV demonstrated a marked superiority for high-imageability words as compared to low-imageability words. CV scored 100% on all high-imageability tasks (PALPA Subtests 47 and 48). Her response latencies were slower for the low-imageability words than for high-imageability words. Whilst she made only one error when tested with the PALPA Subtest 51 (Word Semantic Association; Low-Imageability Words) (see Appendix 1 for a description of this subtest), a significant feature of her performance was that three of her responses were delayed. It appeared that full access to low-imageability information was generally slower than for high-imageability information. This observation led us to the first hypothesis: that low-imageability information is less readily accessible to CV than high-imageability information.

Table 1 Summary of assessment results (April 1995)

Semantic Input Tests:	
Subtest 47: Spoken Word – Picture Matching	100% (one delayed response)
Subtest 48: Written Word – Picture Matching	100%
Subtest 51: Word Semantic Association	High imageability – 100% Low imageability – 14/15 (93%); Error – 1 semantic, 3 responses were delayed
Subtest 49: Auditory Synonym Judgements	57/60 (95%) Errors – all low imageability
Subtest 50: Written Synonym Judgements	100%
Lexical Decision:	
Subtest 5: Auditory Lexical Decision: Imageability × Frequency	100%
Subtest 25: Visual Lexical Decision: Imageability × Frequency	100%
Definitions for Abstract Words:	
Using PALPA words	3/12 (25%) Five errors bore some semantic relationship to the target
Oral Picture Naming:	
Subtest 54: Picture Naming × Frequency	92/100 (92%) Semantic errors – 4 Derivational errors – 1 Mixed semantic/phonemic error – 1 Phonemic errors – 2 10 responses were delayed, 4 of these responses were initially semantic errors and then were self-corrected.
Oral Reading:	
Subtest 31: Oral Reading: Imageability × Frequency	72/80 (90%) Low-imageability words – 80%; High-imageability words – 100% Errors: Low-imageability Low-frequency – 7/8 Low-imageability High-frequency – 1/8
Subtest 30: Oral Reading: Syllable Length	17/18 (94%) Error – derivational
Subtest 36: Oral Reading: Non-words	13/24 (54%) Errors – lexicalizations 6, phonemic 5
Repetition:	
Subtest 9: Repetition: Imageability × Frequency	100%
Subtest 8: Repetition: Non-words	20/24 (83%) Errors – all lexicalizations

Table 1 Continued

Writing:	
Written Naming (using Snodgrass and Vanderwart (1980) picture set)	66/100 (66%) Semantic errors – 16 Derivational errors – 3 Literal paragraphias – 17 (there were eight assembly errors and nine addition/substitution errors)
Writing Errors to Dictation (using Snodgrass and Vanderwart (1980) stimuli)	13/34 (38%)
Subtest 40: Spelling to Dictation: Imageability × Frequency	24/40 (60%) Errors – Low-Imageability Low-Frequency 5/16 Low-Imageability High-Frequency 7/16 High-Imageability Low-Frequency 3/16 High-Imageability High-Frequency 1/16 Literal paragraphias 8 Incomplete 2 Unrelated 2 No response 2
Subtest 45: Spelling to Dictation: Non-words	2/24 (8%) Errors – Lexicalizations 5 Errors showing partial graphemic form 13
Copying Non-words using PALPA items	100%
Delayed Copying of Non-words	8/24 (33%)
Delayed Copying using Multisyllabic words	6/13 (46%)
Arranging Non-word Grapheme Segments to Dictation:	
PALPA non-words	9/24 (38%) three segments – 5/6 correct four segments – 1/6 correct five segments – 2/6 correct six segments – 1/6 correct

To test this hypothesis, CV was administered further semantic processing tasks. She made three errors on Subtest 49 (Auditory Synonym Judgement). All errors were low-imageability word pairs, consistent with our first hypothesis. Her perfect score for the matched written version of Subtest 50 (Written Synonym Judgement) contrasted with her earlier results from the written semantics test. At this stage, however, we hypothesized that the imageability deficit was to be found across both auditory and visual modalities. Such a deficit may be due to:

1) a disturbance in the phonological and/or orthographic input lexicons;

2) compromise to the semantic system itself; or
3) a disconnection to the route linking the phonological and/or orthographic input lexicons to the semantic system.

To test these hypotheses, CV was administered a lexical-decision task followed by other tasks designed to test for the coexistence of distinct imageability effects. If imageability effects were observed in other tasks, such as defining words, then the hypothesis of a central semantic problem with low-imageability words would tend to be supported (Warrington and Shallice, 1979; Coltheart, 1987; Howard and Franklin, 1988; Franklin, 1989; Lesser, 1993; Plaut and Shallice, 1994).

b Lexical decision: CV was administered Subtest 5 (Auditory Lexical Decision) and Subtest 25 (Visual Lexical Decision) from the PALPA, which ask the patient for a decision as to whether a particular item is a real word or a non-word. In these subtests, both imageability and frequency variables were manipulated. The respective roles of the input lexicons are to identify strings of sounds or letters as familiar units; therefore real words known to the individual are matched by a stored representation within the lexicon and are therefore more likely to be accepted as real words in a lexical decision task, whereas non-words have no such representation and are more likely to be rejected. CV scored 100% correct on both the auditory and written lexical-decision tasks, suggesting that any problems with the transmission of auditory and written information cannot be explained by breakdowns in the input lexicons.

c Providing definitions for abstract words: In the light of her performance in the semantic input tasks reported so far, it was hypothesized that CV had greater difficulty with the comprehension of low-imageability (LI) words than of high-imageability (HI) words. As imageability effects are indicative of a central semantic-level breakdown, it was predicted that these effects would compromise not only input but also output tasks, as both types of task rely on the same semantic store. Although it is not possible to name pictures of LI words as such, Howard and Franklin (1988) suggested that defining LI words might provide some comparison with HI words. CV gave accurate definitions for only three out of 12 LI items (e.g., *What is a lie?*) as compared to a near perfect performance with HI words (e.g., *What is an apple?*). Five of the LI word errors bore some semantic relatedness to the target words (e.g., Question: *What is luck?* Patient response: *Good. Like winning money*), thus supporting a central semantic component to her inability to manipulate LI items. These findings supported the hypothesis that a central semantic disruption of LI word processing formed at least part of the basis of CV's anomia.

d Oral naming: The tasks administered to probe CV's processing of high-imageability words were augmented by a comprehensive assessment of picture naming. In this assessment, CV was asked to name 100 randomly selected pictures from the Snodgrass and Vanderwart (1980) stimulus set, all highly imageable items. Her score of 92% indicated a mild anomia. However, error analysis yielded some interesting results which, when compared with other test behaviour, added to the interpretation of the underlying defective mechanisms in naming. There were four semantic errors (e.g., *gun* for *cannon*), one inflectional error (e.g., *shoes* for *shoe*), one mixed semantic and phonemic error (*peanapple* for *peanut*) as well as two phonemic errors (e.g., *capsicun* for *capsicum*). The basis of the semantic errors was unlikely to be failure of the picture recognition system to address semantic representations, or retrieval of an underspecified semantic representation, as CV's performance on all input tasks using HI items was unimpaired. The most likely explanation for her semantic errors in naming HI words is that she was capable of retrieving a full and correct semantic representation; however, due to some deficit in output from the semantic system, some information was lost, resulting in underspecification of phonological word forms in the phonological output lexicon (Butterworth *et al.*, 1984). From this perspective, the basis of the naming deficit for highly imageable words could be either in the connection between the semantic system and the phonological lexicon, or disturbance in the phonological output lexicon itself.

At this stage, we ruled out damage to the phonological output lexicon as a possible source of naming errors because there were more semantic naming errors than phonemic approximations. Ellis *et al.* (1992; 1994) argue that this pattern of naming errors more closely implicates the semantic system to output lexicon connection. Thus, we hypothesized that there were two disturbed processes at play with respect to CV's impaired naming. The first related to a central semantic disturbance for low-imageability words and the second to a disruption in the connection between the semantic system and the phonological output lexicon for high-imageability words. Subsequent investigations sought to further define the nature of CV's processing disruptions, specifically the operation of her sublexical conversion routines.

e Oral reading: There are three possible routines that can mediate oral reading:

1) a lexical–semantic routine linking the orthographic input lexicon, the semantic system and the phonological output lexicon;
2) a lexical non-semantic routine which maps the codes in the orthographic input lexicon directly onto their counterparts in the phonological output lexicon; and
3) a sublexical pathway which directly converts orthography to phonology (the so-called letter-to-sound rules pathway) (see Figure 1).

As predicted from CV's results on other semantically mediated tasks, her oral reading abilities overall revealed a mild but definite imageability effect. She scored 100% on the highly imageable items in Subtest 31 (Oral Reading: Imageability × Frequency) but was less successful when low-imageability items were introduced (80%). These results suggested that CV was using the lexical–semantic route for oral reading and that the previously identified deficits in abstract semantics were also impacting on this task.

CV's performance on PALPA Subtest 31 (Oral Reading: Imageability × Frequency) also revealed evidence of a frequency effect with 7 of the 8 errors being on the low-frequency and low-imageability items. It has been suggested by Lesser (1989) and Ellis *et al.* (1994) that such frequency effects may also be a product of a breakdown in the connection between the semantic system and the phonological output lexicon, which is consistent with our previous hypothesis (see section *d* above). To exclude a possible disruption in the phonological assembly buffer, Subtest 30 (Oral Reading: Syllable Length) of the PALPA was administered. Only one error was made on PALPA Subtest 30, thereby demonstrating that the phonological assembly buffer was essentially intact.

The reading of non-words was also assessed using Subtest 36 (Oral Reading: Non-words). Since only one route can be employed to read non-words (the orthographic-to-phonological conversion route), CV's difficulties with non-word reading (54%) must be due to problems within this conversion routine. Problems within visual orthographic analysis had been previously ruled out by CV's good performance on all other tasks which required this process.

The finding that CV's orthographic-to-phonological conversion route was disrupted reinforces our earlier suggestion that she uses either of the two lexical routines for reading. The presence of lexical errors in a non-word repetition task (e.g., when asked to repeat the non-word *dusp*, she responded with *dust*) in the absence of deficits in the orthographic input lexicon, also supports this proposal (see section *f* below).

f Repetition: Like reading, there are three routines available for repetition: two lexical routines and a sublexical routine. The lexical–semantic route proceeds via the phonological input lexicon, through the semantic system and to the phonological output lexicon, whereas the direct lexical route bypasses the semantic system. The sublexical pathway is concerned with acoustic-to-phonological conversion. CV scored 100% when repeating the 40 PALPA real word items in Subtest 9 (Repetition: Imageability × Frequency), supporting the integrity of the phonological input and output lexicons. However, on Subtest 8, the repetition of non-words, CV scored only 83%. All errors were lexicalizations. The only available route to repeat non-words is via the sublexical acoustic-to-phonological conversion route. CV's poor performance suggests that the sublexical repetition routine was less viable than the lexical routines.

At this stage we were able to confirm that CV's anomia was related to:

1) a mild impairment of the central semantic representations of low-imageability words;
2) a partial disconnection between the semantic system and the phonological output lexicon for high-imageability words; and
3) problems within both sublexical conversion routes, the orthographic-to-phonological and acoustic-to-phonological routes.

Having defined more precisely the nature of CV's impairment in spoken tasks, the next set of assessments sought to investigate further the nature of her persistent dysgraphia.

g Written naming: Comparison of written naming with oral naming performance on the 100 pictures from the Snodgrass and Vanderwart (1980) stimulus set revealed a marked superiority for oral naming (92%) over written naming (66%). CV's poorer performance on writing high-imageability object names immediately implicated the existence of post-central breakdowns, because previous assessment had demonstrated the integrity of the semantic system for concrete items. Errors were evenly distributed between 16 semantic paragraphias (e.g., *iceman* for *snowman*) and 17 literal paragraphias (e.g., *umberala* for *umbrella*). This pattern of errors contrasts with oral naming performance, where errors were predominately semantic and thus attributed to a disruption in the connection between the semantic system and the phonological output lexicon.

The presence of semantic errors in writing can be accounted for by proposing a similar breakdown between the semantic system and, in this case, the graphemic output lexicon, as input semantic processing for highly imageable items had been found to be intact. There remained 17 literal paragraphias whose origin could be explained with reference to the literature. That eight of the 17 graphemic errors were substitution and/or addition errors (e.g., *penquin* for *penguin*) suggested the involvement of the output lexicon itself, but the 7 assembly errors (e.g., *envepole* for *envelope*) additionally implicated the graphemic assembly buffer. In fact, Margolin and Goodman-Schulman's (1992) extended model of writing implies that addition and substitution errors can also arise at the level of the graphemic assembly buffer.

Two additional observations supported our conclusions. The presence of a moderate frequency effect in written naming related back to damage at the graphemic output lexicon level (see section *i* below) and length effects (see section *k* below) pointed to a disruption in the graphemic assembly buffer (Lesser, 1993). The absence of a regularity effect suggested that CV was utilizing the (defective) direct lexical routine.

h Writing picture names to dictation: Items from the 100 Snodgrass and Vanderwart (1980) pictures which were incorrectly written were presented for writing to dictation**.** This test served to support a number of hypotheses. When a word which has been incorrectly written is presented to a patient to write to dictation, the subject can effectively bypass the semantic system and its connection to the graphemic-output lexicon because both semantic and word form information are provided by the examiner. If CV's semantic system was intact and all her difficulties resided in the graphemic output lexicon and beyond, telling her the word should not have altered her performance (because the disruption in the graphemic output lexicon and graphemic assembly buffer would cause a similar problem on both tasks). This was not observed. CV was able to write correctly only 38% of her error words to dictation. This finding supported the hypothesized involvement of the semantic system and its connections. Persisting length effects (i.e., greater difficulty with longer items) suggested that the graphemic assembly buffer remained involved.

Incidentally, another possible route exists for performing a writing-to-dictation task and that is by the sublexical phonological-to-graphemic conversion route (see Figure 1). This route was not suggested as a possible alternative path for CV to use because subsequent testing of Non-word writing to dictation (see section *j* below) showed that this route was substantially disrupted.

i Investigations into the role of imageability with writing: A number of different written tasks were carried out to investigate the hypothesis that a central difficulty with low-imageability words was present. CV's results supported this hypothesis. Her reduced performance of 60% with PALPA Subtest 40 (Spelling to Dictation: Imageability × Frequency) also revealed strong imageability effects and moderate frequency effects. Hence, central semantics as well as access to the graphemic output lexicon were again implicated.

j Non-word writing to dictation: CV's ability to write non-words to dictation (Subtest 45) was severely impaired, with a score of 2/24. Both correct responses were three letters in length. The possibilities for impairment may have included the phoneme-to-grapheme conversion procedure or problems at the level of the graphemic assembly buffer. Previous results from CV's performance on non-word repetition tasks contraindicated significant involvement of auditory analysis. Previously identified disruption in the acoustic-to-phonological conversion procedure (see section *f* above) could account for some of her difficulty in writing non-words but cannot fully explain the severity of the difficulty encountered in writing non-words. Examination of written non-word errors showed 5 lexicalization errors, which demonstrated a preference for the more intact lexical routine for writing to dictation, and thereby circumventing the impaired non-lexical routine. The presence of partial graphemic form for 13 of the errors indicated that the sublexical routine was not completely disconnected, but that phoneme-to-grapheme correspondence was compromised.

The fact that CV successfully copied all PALPA non-words would suggest that the sublexical copying routine was operational. However, a delayed copying task similar to that employed by Howard and Franklin (1988), utilizing matched non-words, gave a score of 33%, which suggested that information being decoded in an (intact) visual orthographic-analysis level was being compromised at a later stage (i.e., the conversion procedure and/or the assembly buffer). Length effects were present which suggested graphemic assembly failure, bearing in mind that the graphemic assembly buffer is a working-memory system (Caramazza *et al.*, 1987; Caramazza, 1989; Margolin and Goodman-Schulman, 1992). Further evidence to support these findings was found in the form of a similar qualitative performance on delayed copying of multi-syllabic real words.

k Arranging grapheme segments to dictation to form non-words: On this informal task, CV was asked to arrange letter blocks to form non-words spoken by the examiner. CV performed poorly (38%) on this task, which requires intact phoneme-to-grapheme conversion, intact sound–symbol associations, intact acoustic and phonological segmentation skills and intact assembly buffer functioning. Five of the six three-letter words were correct whereas longer units were largely incorrect. This pattern of performance demonstrated a length effect that could originate from the assembly buffer level or that could indicate difficulties with auditory or phonological segmentation and sound–symbol disturbances.

3 Summary of findings

The use of a cognitive neuropsychological model to guide assessment revealed that CV presented with processing breakdowns at a number of different levels. The interpretation of each assessment result was considered in the light of converging evidence from other tests. Semantic errors in the spoken and written output of high-imageability words were attributed to a partial disconnection to the link between the semantic system and the respective output lexicons. While comprehension was essentially intact, there nevertheless existed slowness with processing low-imageability words as well as underspecification of their meaning. Difficulty with low imageability words was more evident in output tasks and seemed to be influencing written-output accuracy. Breakdowns at the level of the graphemic output lexicon and the graphemic assembly buffer further affected written output. Marked impairment of the sublexical phoneme-to-grapheme conversion routine meant that non-word writing was limited. An additional limitation imposed on non-word writing was the impairment at the level of the graphemic assembly buffer. Figure 2 presents a graphic summary of CV's processing impairments. Given the multi-level impairments contributing to her dysgraphia, it was felt that a remediation programme which initially targeted two unrelated and independent processes would be appropriate (i.e., treatment directed at the abstract semantic deficit and treatment for the graphemic assembly deficit). Selectivity of treatment effects, and hence efficacy, would then be easily ascertained.

IV Study of efficacy of therapy

1 Aims

The overall aim of this study was to explore whether information derived from model-based evaluation regarding loci of deficient functioning was sufficient to direct treatment in a considered, theoretically motivated manner which was ultimately efficacious. Assessment indicated that there was more than one factor contributing to CV's dysgraphia. Therefore, the goal of the remediation programme was to improve her written output at the single-word level through targeting

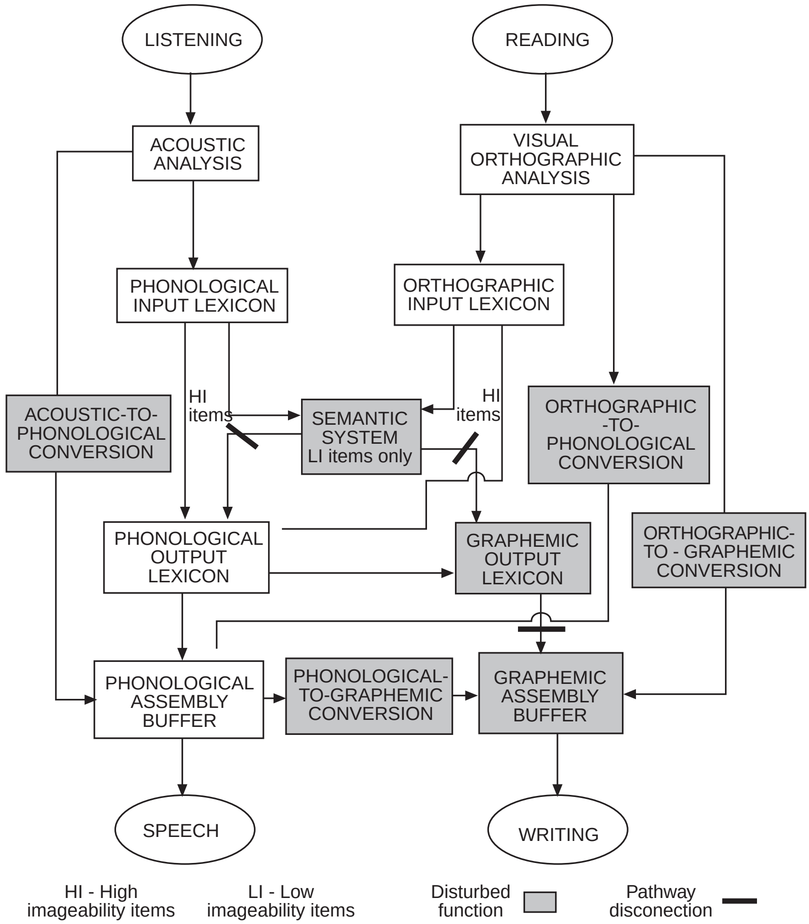

Figure 2 Hypothesized disruptions to CV's processing routines

both her abstract semantic deficit and her difficulties at the graphemic assembly buffer level.

A further aim of the remediation part of the study related to whether any gains made in therapy would be generalized to other situations and other tasks. This is obviously a desirable consequence of remediation. It is important to ensure that the study has in-built controls to measure possible generalization effects, so that demonstration of efficacy is not confounded by other variables (Howard, 1986). Willmes (1990) suggested that when generalization is a possible outcome of treatment, it is necessary to add control tasks which evaluate:

1) functions related to the target behaviour which were expected to improve as a result of treatment; and
2) functions unrelated to the target behaviour which were not expected to be influenced by treatment.

The measurement of generalization effects may also assist in clarifying 'what's in the boxes', thereby adding to existing theories regarding the composition of the language-processing components. For example, if the abstract semantic deficit was central in origin – as suggested by CV's assessment results – generalization to untreated related abstract entities would be expected, as well as some general improvement in all tasks which require abstract word mediation. Improvement in concrete words would not be anticipated if the theoretical statement of differing storage mechanisms for high- and low-imageability items is correct. Working on the second process of graphemic assembly would, it was hoped, result in some specific generalization to untreated items, as well as enhancement of other graphemic tasks requiring the graphemic assembly buffer, as discussed above.

2 Design of the study

A modified multiple baseline across behaviours design was selected for a three-phase study. An initial baseline measurement phase (Phase A) of five measurement points was established for each of the two dependent variables:

1) writing low-imageability nouns to dictation; and
2) writing four-letter non-words to dictation.

For each of the two dependent variables there were two matched sets of 15 items, representing items to be treated (during the B phases of the study) and untreated control items. The untreated control items for the low-imageability therapy consisted of synonyms of the treated items. The untreated control items for the non-word therapy were composed of items matched for graphemic consonant–vowel structure. The criterion level for ceasing treatment 1 (i.e., treatment aimed at improving the writing of low-imageability words to dictation) and beginning treatment 2 (i.e., writing non-words to dictation) and then for subsequently terminating treatment 2 was set at a minimum of 80% correct for treated items, maintained over two consecutive treatment-measurement points. Alternatively, termination of treatment followed a maximum of 20 treatment sessions. Once treatment was initiated, the first-therapy measurement was taken following two treatment sessions (but prior to the start of the third session). Subsequently, measurements were taken after three treatment sessions, but were carried out before the next treatment session started.

Following implementation of treatment targeting the first dependent variable – i.e., writing low-imageability words to dictation (Phase B) – performance continued to be measured for this behaviour while simultaneously measuring untreated behaviours in extended A phases. At the completion of treatment for low-imageability items, treatment of non-words began as a shifted Phase B. Measurements for all 60 items continued, with the previously treated low-imageability items and their controls assuming the role of an extended B phase.

In line with the suggestions by Willmes (1990), additional internal controls were added, and these were re-evaluated following each treatment phase. The controls consisted of functions both related to and unrelated to the target behaviour, which we predicted would show either positive effects of treatment (the related tasks) or no effects (the unrelated tasks). In the case of treatment 1, related controls were tasks involving the comprehension and production of low-imageability words. Unrelated control tasks assessed performance on various non-word operations. For treatment 2, the related controls selected were written naming, non-word writing, and segmentation tasks. The unrelated treatment-independent task assessed performance on all low-imageability items. In addition to these two control measures, a third control was included which examined functions unrelated to either target behaviour, and should not, therefore, be influenced by either treatment process (i.e., picture naming and the reading aloud of non-words).

3 Therapeutic program

The subject received treatment twice weekly, two to three days apart. Order of presentation in both treatment phases was randomized to eliminate order or sequence effects. Each treatment session lasted a maximum of one hour and consisted of the following phases.

Phase 1: Treatment was directed at a set of 15 low-imageability nouns and consisted of a hierarchy of five different semantic-discrimination tasks derived from the literature on the treatment of lexical–semantic deficits (Marshall *et al.*, 1990; LeDorze *et al.*, 1994; Nickels and Best, 1996). The words were always presented auditorily, never in the written form, in order to control for the learning of the graphemic structure of the treated words from repeated visual exposure in therapy. In order to measure pure semantic generalization effects, untreated matched synonyms were not presented in therapy. Details of the therapy carried out are given in Appendix 2.

Phase 2: The second treatment phase targeted graphemic segmentation skills. Fifteen four-lettered non-words were treated (see Appendix 2 for details). The phonological–graphemic segmentation hierarchy which was employed was developed on the basis of the subject's previous dysgraphia therapy and from the literature on the remediation of segmentation and sound–symbol letter-conversion deficits (Seron, Deloche, Moulard and Rouselle, 1980; Carlomagno and Parlato, 1989; Lesser, 1989; Luria, Naydin, Tsveskova and Virnarskaya, 1969, cited in Carlomagno and Parlato, 1989). The treated sets of non-words were always presented according to the same hierarchy. The untreated matched non-words were at no time presented in therapy.

4 *Results*

Figure 3 shows the changes in written performance during the treatment study i.e, the results for the initial baseline measurement (Phase A) and the behaviour of the dependent variables during each treatment phase (Phase B). The pre-treatment baseline-measurement points (i.e., points 1 to 5) demonstrated an acceptable degree of stability of the two dependent variables (i.e., writing low-imageability words to dictation and writing four-letter non-words to dictation). This stability indicated that no learning effects occurred as a consequence of the repeated exposure of CV to the probe items.

During Phase 1 (i.e., semantic therapy for low-imageability nouns), improvement in the naming of the treated items began to emerge from measurement point 8 (see Graph 1 on Figure 3). However, it was not until measurement point 12 that there was a further marked increase in writing the names of the treated items which resulted in the attainment of the 80% criterion level, (i.e., following 20 treatment sessions). Untreated semantically related low-imageability words (Graph 2 on Figure 3) demonstrated a degree of improvement which was also comparable to the improvement in the treated items, with noticeable improvement occurring from measurement point 8. These results suggest that generalization to semantically related items occurred. It would appear that the specific semantic treatment was having a generalized effect on enhancing the process of access to synonyms of the treated low-imageability words. Compelling evidence for selectivity of Phase 1 treatment effects was found when we examined written performance of non-words during this phase. The untreated unrelated function (i.e., writing non-words; see Graphs 3 and 4 on Figure 3) yielded absolutely no improvement during the semantic-treatment phase.

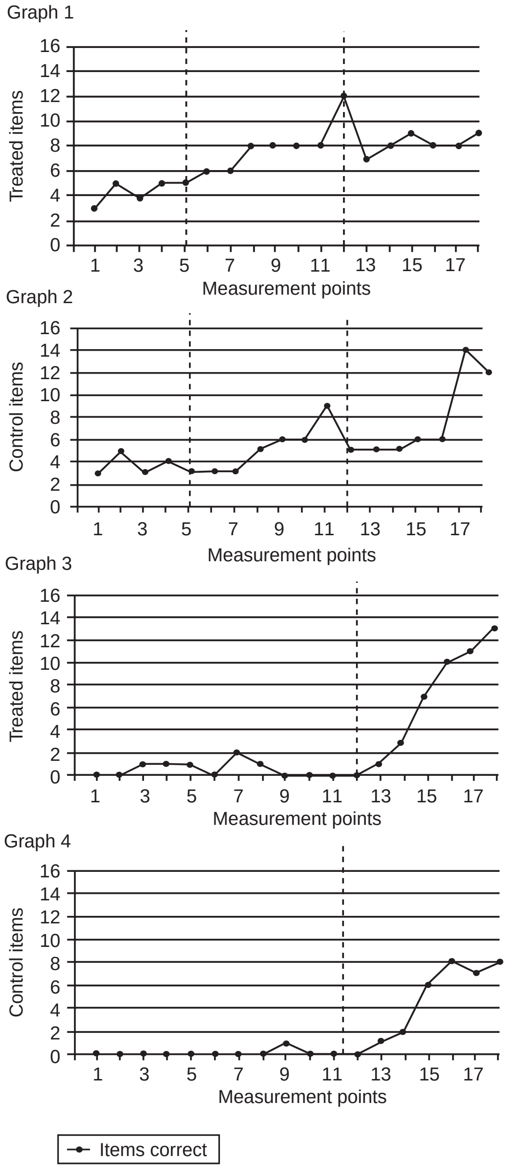

Figure 3 Number of items correctly written at each measurement point for both treated and control items for semantic low-imageability therapy (Graphs 1 and 2) and non-word segmentation therapy (Graphs 3 and 4)

With the implementation of Phase 2 treatment (i.e., graphemic-segmentation therapy), improvement in the treated items began to emerge at measurement point 14 on Graph 3 (following five treatment sessions). From this point, further improvement in treated items, along with improvement in untreated control items, occurred at each measurement point. It appeared, therefore, that generalization to untreated related items was occurring, but the extent of this was somewhat less than that for the treated items, indicating some selectivity in treatment effects. The positive results further suggested that therapy had targeted the disturbed language process, rather than targeting individual non-lexical items.

Evidence for the selectivity of graphemic-treatment effects during Phase 2 was revealed by examining total performance on written low-imageability items on Figure 4 (Graph 1) which, overall, showed similar performance at a level greater than in pre-treatment measurements but lower than during-treatment measurements. Hence the treatment effects from the low-imageability therapy were relatively

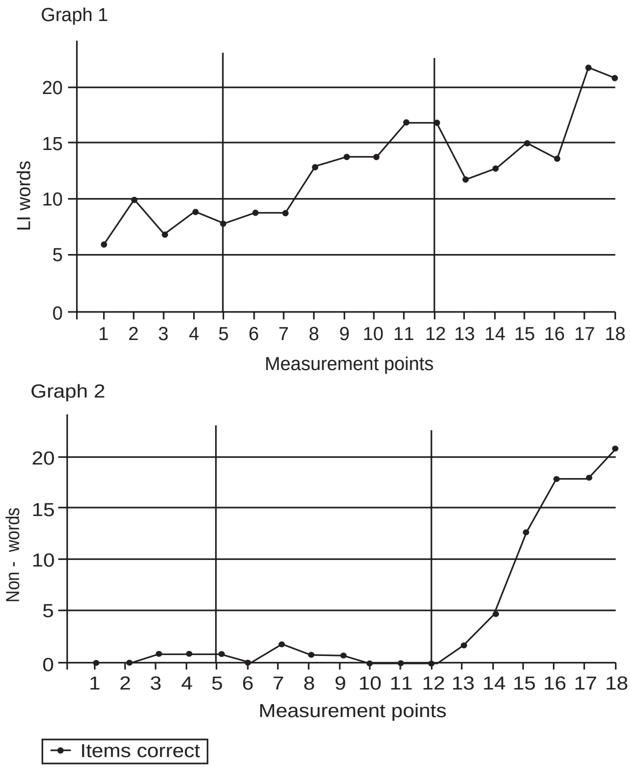

Figure 4 Total number of items correctly written (both treated and control words) for low-imageability words (Graph 1) and non-words (Graph 2)

robust and long lasting. The selectivity of the low-imageability semantic therapy is clearly shown in Graph 2 on Figure 4, where no change in the writing of non-words was noted until specific non-word segmentation therapy began at measurement point 12.

Further indications for the specificity of each treatment can be found by examining the results from the related and unrelated control tasks. Table 2 shows the results for semantically related tasks which were expected to improve as a result of the low-imageability semantic-treatment tasks. Examination of the percentage changes showed that all six semantically related control tasks improved following

Table 2 Results of related and unrelated control tasks pre- and post-therapy (per cent)

Test	A Phase	B Phase	
	Pre-treatment	Post-treatment 1	Post-treatment 2
Related function control tasks for low-imageability words:			
Subtest 51: Word Semantic Association (Abstract)	93	100	100
Subtest 49: Auditory Synonym Judgements	95	100	95
Subtest 40: Spelling to Dictation: Imageability × Frequency	60	75	75
Subtest 41: Spelling to Dictation: Grammatical Class	45	65	60
Subtest 31: Oral Reading: Imageability × Frequency (low-imageability only)	80	95	95
Abstract word definition	25	58	50
Related function control tasks for graphemic assembly:			
Written Naming (using Snodgrass and Vanderwart (1980) 100 stimuli)	66	69	81
Subtest 45: Spelling to Dictation: Non-words	8	8	33
Arranging grapheme segments (3–6 units)	38	33	67
Unrelated function control tasks for both treatments:			
Subtest 36: Oral Reading: Non-words	54	58	58
Subtest 54: Picture Naming × frequency (using Snodgrass and Vanderwart (1980) stimuli)	92	95	98

Treatment 1. McNemar tests were employed, where appropriate, to check for statistical significance on all tests for which it could be implemented. Only two subtests did not entail zero values on the contingency tables and were therefore submitted to statistical analysis. Improvements in Subtest 41 (Spelling to Dictation: Grammatical Class) did reach statistical significance ($\chi^2 = 5.6$, $p < .05$). Whilst performance on Subtest 31 (Oral Reading: Imageability × Frequency) improved from 80% to 95%, this difference was not statistically significant ($\chi^2 = 3.527$, $p > .05$). Following the second non-semantic treatment, three of the six related control tasks maintained their scores, whereas the other three tasks showed a slight reduction in performance. Overall, these results lend support to the efficacy of the low-imageability treatment.

Table 2 shows tasks for related function control tasks which were hypothesized to be sensitive to Treatment 2, the graphemic-segmentation therapy. Following the first treatment for low-imageability words, there were no significant increases in scores, which again demonstrated the selectivity of that particular treatment. Following Phase 2, however, obvious percentage improvements in all related function tasks occurred.

Finally, there were two tasks which, according to the cognitive model in use and to current psycholinguistic theory, should not yield any major improvement in performance (see Table 2). This expectation was confirmed:

1) from visual inspection of the non-word reading task; and
2) by no significant change in pre-treatment and post-treatment 2 measures on picture naming ($\chi^2 = .44$, $p > .05$).

V Discussion

The results from the present study demonstrated that using hypothesis-driven assessment to define treatment loci and to direct treatment methods, CV was able to improve her writing of low-imageability words and non-words, maintain these improvements when therapy ceased and generalize the effects of therapy to related (but not to unrelated) language tasks. In addition, the study highlighted the specificity of the therapy provided, in that improvement was limited to those tasks at which it was targeted, with little or no improvement found for tasks that were expected not to benefit from therapy. That treatment was efficacious, and that the positive effects of the therapy were specific to the functions being targeted, attests to the potential usefulness of employing a cognitive neuropsychological approach in the assessment and remediation of acquired dysgraphia.

The selection of the specific multiple-baseline design to demonstrate efficacy in the present study allowed us to disambiguate treatment effects and relate them to particular language-processing components. Unless there is particular attention to the design of the study (and in particular the inclusion of a number of in-built controls), it can be difficult to ascertain whether the treatments are indeed addressing the specific processes under scrutiny. For example, CV's positive response to the non-word segmentation therapy, and her subsequent improved performance on non-word writing tasks, might have been as much to do with improvement in her ability to compute phoneme–grapheme conversion (an integral and unavoidable component of the segmentation procedure) as with specific improvement in the operation of the graphemic assembly buffer. The fact that CV's marked improvements in the two non-word writing control tasks (Subtest 45 (Spelling to Dictation: Non-words) and Arranging Grapheme Segments) continued to show definite length effects suggests that assembly procedures still remained a significant component of her processing impairment. If phoneme–grapheme links had been the cause of the non-word writing difficulty, one might have expected a more general improvement on these two control tasks. Careful inclusion of the non-word writing and non-word reading tasks allowed us to be more precise in accounting for the specific effects of the therapy. The fact that the current study had a number of inbuilt controls (i.e., related items which were untreated and unseen in therapy, unrelated task controls, related task controls and the treatment of two unrelated areas) was an important means of documenting the selectivity of treatment effects.

Although any improvement for a language-disordered client is beneficial, the most desirable clinical outcome is for generalization effects and improvements in language function that extend beyond the effects of practice of specific items or rote learning (Howard, 1986; Hillis and Caramazza, 1994). The presence of strong function-specific generalization effects mitigates against a practice effect or rote learning of words as an explanation for CV's gains in writing. The stability of baseline measurements prior to treatment adds weight to the evidence against rote learning. The positive and specific generalization effects that were observed following the two treatment phases (as illustrated in Graphs 2 and 4 on Figure 3) indicate that the treatments were successful in reactivating certain processes within the defective language subroutines, rather than simply retraining or teaching individual items.

As well as addressing therapeutic issues, the findings from this study are informative from a psycholinguistic perspective, and shed light on some interesting theoretical standpoints that are current in the literature. The results also contribute to the literature with respect to the conceptualization of the representational structure and processing routines specific to the various components being treated. The absence of generalization (following the treatment of the central low-imageability deficit) to tasks which required the processing of high-imageability items supports Plaut and Shallice's (1994) contention that within the semantic system, the storage and representational mechanisms for low vs. high imageability items are separate and different. The 31 potential semantic features for low-imageability words that Plaut and Shallice (1994) identified has been shown by the current study to be clinically useful; these features formed the basis for some of the successful low-imageability treatment.

Further, the generalization from the low-imageability treatment to untreated, unseen synonym control items lends support to the Schreuder and Flores D'Arcais (1989) connectionist account of concept representation, which maintains that synonyms activate the same concept node and, consequently, identical pieces of semantic information (which includes both functional and perceptual information). Conversely, the activation of certain semantic and functional information directly addresses a concept from which various possible word forms, including synonyms, become available. Thus, it would appear that therapy aimed at developing the concept node via enhancement of semantic information, as in the current study, should result in improved word forms irrespective of their modality. In line with the interactive non-linear nature of Schreuder and Flores D'Arcais' (1989) account, one can hypothesize that the aforementioned therapy should result in greatest generalization effects to synonym word forms followed by closely related semantic entities, than more distantly related entries and so forth. Therefore, the representational structure of the semantic system proposed by Schreuder and Flores D'Arcais (1989) supports and explains the strong generalization effects to synonym word forms which were observed in the present study.

The results from this study are most easily interpreted with reference to an interactive model of language processing that proposes continuous bi-directional communication among the various language levels. As was hypothesized, written picture naming (dependent upon high-imageability processing) did not improve following the low-imageability treatment. Following the segmentation-therapy phase, as predicted, written picture naming improved markedly. Closer inspection of the actual changes in written naming performance, however, revealed an unexpected outcome.

A number of items which had been previously incorrect but had improved as a result of the segmentation treatment, had originally manifested as semantic rather than assembly errors. Using a graphemic variant of Dell's (1986) interactive production model, one can explain this phenomenon without condemning the segmentation therapy as being non-specific. In a number of instances, the initial semantic error was a word of three or four letters in length (e.g., *ski*) and the target word consisted of five or more letters (e.g., *sleigh*). It is likely that, for these items, the picture generated the correct semantic features and that the correct entry was also activated at the lexical-node level (i.e., the graphemic output lexicon). However, when the lexical entry passed to the graphemic-segment nodes (i.e., the graphemic assembly buffer), intrinsic difficulties associated with holding the entry in short-term storage in the correct ordinal sequence meant that reverberating lexical and semantic feedback overrode the weakened signal at the graphemic level. This resulted in the selection of a shorter lexical entry that was semantically related to the target and which could be successfully carried to the output system in the form of writing. Once processing at the graphemic level had been improved by the segmentation therapy, longer graphemic strings could be adequately accommodated, and hence reverberating feedback no longer impacted on the graphemic assembly buffer. That semantic errors in writing may arise as a result of influences at the level of the graphemic assembly buffer is a relatively novel concept, but is consistent with the predictions of interactive psycholinguistic models. For the present model, depicted in Figure 1, the results suggest that the arrows linking the various levels should be bi-directional. This minor modification would successfully account for the effects of therapy found here.

VI Conclusions

The efficacious results from this investigation demonstrate the usefulness of employing model-based assessment to expose the underlying mechanisms responsible for an individual's disordered language. The current study has indicated that informed and specific therapeutic strategies can be successfully generated within a cognitive neuropsychological framework, so that a patient with dysgraphia can improve in writing, can maintain that improvement once therapy stops and can generalize the positive effects of that therapy to other related language tasks. A careful choice of in-built control items and tasks and the selection of a multiple-baseline (across behaviours) methodology in the present study ensured that the effects of therapy were specific to the functions being treated.

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Appendix 1 Explanation of subtests from the Psycholinguistic Assessment of Language Processing in Aphasia (Kay *et al.*, 1992)

Subtest	Description	Example
Subtest 5: Auditory Lexical Decision: Imageability × Frequency	In this task, the effects of imageability and frequency (and their interaction) are evaluated by asking a patient to decide whether a spoken utterance is a word.	Subjects are presented with words (e.g., *episode*, *theory*, *elbow*) and non-words (e.g., *minner*, *wembow*) and asked to indicate whether they recognize the word or whether it is a made-up word.
Subtest 8: Repetition: Non-words	The purpose of this task is to test the integrity of sublexical acoustic–phonological conversion. All the materials are non-words.	The subject is asked to repeat one-syllable (e.g., *slurch*), two-syllable (e.g., *vater*) and three-syllable (e.g., *adio*) non-words.

Subtest	Description	Example
Subtest 9: Repetition: Imageability × Frequency	The effects of imageability and frequency (and their interaction) are evaluated in a repetition task.	Subjects are asked to repeat words that vary according to imageability and frequency.
Subtest 25: Visual Lexical Decision: Imageability × Frequency	The effects of imageability and frequency (and their interaction) are evaluated in a written task by asking a patient to decide whether a spoken utterance is a word.	Subjects are presented with written words and non-words and are asked to indicate whether they recognize the word or whether it is a made-up word.
Subtest 30: Oral Reading: Syllable Length	Whilst all the words in this task have five letters, they vary in syllable length from one to three syllables. Other parameters such as frequency, imageability and morphemic complexity are controlled for.	The patient is asked to read aloud words such as *blood*, *hotel* and *radio*.
Subtest 31: Oral Reading: Imageability × Frequency	Words to be read aloud by the patient are varied systematically in terms of imageability and frequency.	The patient is asked to read words that vary in terms of imageability and frequency (e.g., HI HF *night*, HI LF *alcohol*, LI HF *moment* and LI LF *mercy*)
Subtest 36: Oral Reading: Non-words	These non-words are monosyllabic and vary in letter length from 3 to 6 letters.	Non-words such as *ked*, *shid*, *snite* and *churse* are given to the patient to read aloud.

Subtest	Description	Example
Subtest 40: Spelling to Dictation: Imageability × Frequency	This task looks for effects of imageability and frequency (and their interaction) in written spelling to dictation.	The patient is asked to spell words to dictation.
Subtest 41: Spelling to Dictation: Grammatical Class	Grammatical class is manipulated in this spelling to dictation task where equal numbers of nouns, adjectives, verbs and functors are assessed.	The patient is asked to spell the word *hence* (functor) and *hang* (verb).
Subtest 45: Spelling to Dictation: Non-words	Patients are asked to spell non-words that are all monosyllabic and vary in letter length from 3 to 6 letters.	The examiner says the non-word *ked* or *dringe* and the patient is asked to think how it might be spelt and to write it down.
Subtest 47: Spoken Word–Picture Matching	This task requires the patient to point to a picture that is spoken by the examiner. Four distractor pictures are included: a close semantic distractor from the same superordinate category, a more distant semantic distractor, a visually similar distractor and an unrelated distractor.	The patient is asked verbally to point to the picture of the carrot from a five picture set consisting of carrot, cabbage, lemon, saw and chisel.
Subtest 48: Written Word – Picture Matching	As for Subtest 47 but this time the patient is instructed to read the word and point to the picture which it matches.	

Subtest	Description	Example
Subtest 49: Auditory Synonym Judgements	This task assesses a patient's ability to judge whether two spoken words are close in meaning.	The patient is asked to say 'yes' or 'no' depending on whether the two words such as *start – beginning* mean nearly the same thing.
Subtest 50: Written Synonym Judgements	This task is similar to Subtest 49 but uses written word pairs as stimuli.	
Subtest 51: Word Semantic Association	This task assesses a subject's ability to select a word that is closely semantically related to another word. Three distractors are provided: a word that is less closely semantically related and two unrelated words. All materials are written words.	The patient is asked to say which word is closest in meaning to the underlined word: comb *door* *brush* *gate* *tweezers*
Subtest 54: Picture Naming × Frequency	This is a picture naming test that investigates more specifically the influence of word frequency on naming performance using stimuli from Snodgrass and Vanderwart's (1980) original stimulus set.	The patient is asked to name 100 pictures, divided equally into high-, medium- and low-frequency items.

Appendix 2 Details of therapy provided

Phase 1 Therapy: Semantic Low-Imageability Therapy

1) Semantic relatedness judgements: For this task, the treated word was presented auditorily and systematically compared to each of nine to twelve written words which consisted of synonyms,

semantically related low-imageability words, unrelated low-imageability words and, where appropriate, antonyms. The subject then stated whether the written word was the ‘same as’, ‘different from’, ‘related to’ or ‘opposite to’ the heard word.

2) Semantic questions: This task was introduced in tandem with Task 1 once the subject was able to perform the initial task with 80% accuracy and no delays.

   There were three levels of questioning:

   Level 1. The initial questions were selected according to their relevance from a list of 31 possible semantic features for abstract words developed from a computer network by Plaut and Shallice (1994). Two types of question were asked. Forced choice questions were used for some of the semantic parameters, e.g., ‘Is a **bonus** a positive or negative thing?’ and yes/no questions were used for other parameters, e.g., ‘Is a **bonus** related to work?’.

   Level 2. An additional series of three yes/no questions was asked, pertaining to experiences associated with the particular item. The three questions asked were in the form ‘Is the experience of a **bonus** physical/mental/environmental?’

   Level 3. Following a ‘yes’ response to the level two question, a further question was posed: ‘In what way is it physical?’. The subject then attempted to provide a verbal description.

3) Semantic relatedness judgements without repeated input of the target: This task superseded task 1, once adequate mastery of task 1 had occurred. Task 3 was identical to task, with the exception that instead of the target word being said by the therapist prior to each written word, the target word was said just once. The subject therefore had to mentally hold the word form information and match it to each written word. Following the completion of judgements for each item, task 2 (Semantic questions) was implemented as described previously.

4) Matching auditory words to a choice of five written words – synonyms: This task was introduced simultaneously with task 3. In task 4, the subject was auditorily presented with a treated item word form and then was asked to select a synonym written word from a choice of five words. The five written words contained the target synonym plus four synonyms for other treated items. Once correct, a different treated target was presented and selection of the appropriate synonym for that word was attempted. In total, each group of five written words received eight presentations, i.e., one for each item and three repeated items, to reduce guessing behaviour as the available field narrowed.

5) Matching auditory words to a choice of five written words – antonyms: This task resembled the previous one in all aspects except that the subject had to make antonym judgements rather than synonym judgements. The task was introduced following several sessions with the synonym choice task and was shared within a session with task 3 (Semantic relatedness judgements without input of the target).

Phase 2 Therapy: Segmentation of Non-words

The treatment hierarchy consisted of:

1) Random presentation of the four letters which made up the non-word. The instruction was given by the therapist, 'Point to /b/' etc. The letters were spoken as phonemes.
2) The therapist asked, 'What sound does this one make?' The patient responded with the phoneme.
3) The therapist said the non-word slowly. The patient arranged the letters.
4) Once graphemes were correctly arranged, the therapist asked the patient to look at the word and when she felt that she could remember it, to close her eyes.
5) The therapist asked questions about the structure of the non-word, e.g., 'How many letters are there? Which sound comes first/last/after the /e/?'
6) While the patient kept her eyes closed, the therapist substituted a letter. The patient opened her eyes and the therapist said, 'I want BLET. Is this BLET?'
7) The patient responded, 'No', and identified (a) the incorrect grapheme, (b) removed the incorrect grapheme, and then (c) chose the correct grapheme from a group of written letter segments.
8) The therapist repeated the process from Step 5 to Step 7 four more times.