Model-Driven Remediation of Dysgraphia

Argye E. Hillis
Medical Rehabilitation Center of Maryland

Alfonso Caramazza
Cognitive Neuropsychology Laboratory, The Johns Hopkins University

The application of information processing models to guide or develop therapeutic intervention and, conversely, the application of clinical observation of behavior to inform and constrain information processing models have been controversial issues among clinical aphasiologists (Gigly and Duffy, 1982; Davis, 1982; 1986; Lemme, 1986; Trupe, 1986). In this paper we hope to demonstrate that both practices are possible and useful. We present a single case study of acquired dysgraphia which, along with converging evidence from other cases of selective impairments in spelling, serves to constrain a model of the cognitive process underlying spelling. Analysis of the patient's pattern of dysgraphic errors is explicable by proposing a functional "lesion" to one component of a model of the spelling process (see Caramazza, 1986 for discussion of drawing inferences about language processes from single case studies and Caramazza, Miceli, Villa, and Romani, 1986 for further discussion of the functional architecture of spelling processes). These results not only increase our confidence in the model, but also characterize the patient's deficit in such a way as to allow identification of suitable intervention strategies. In order to demonstrate that these strategies are effective for patients with the particular impairment identified, rather than general therapeutic endeavors that would benefit all dysgraphic patients, we briefly describe a second case of acquired dysgraphia. This subject's distinctly different pattern of errors suggests selective impairment to a different component of the spelling process, and indicates different remediation strategies.

<u>Case History</u>.

D.H., a 49-year-old, right-handed male with a high school education, is employed as a Quality Control Supervisor at a chemical plant. He suffered a thromboembolic stroke in May of 1986. His primary complaints at the time of hospital admission were acute memory loss and difficulty reading, writing, formulating sentences and word-finding. A neurological examination identified slight weakness of the right wrist flexors and extensors, impairments of recent memory, proverb interpretation, calculation, and writing. There was no evidence of cranial neuropathy, sensory or proprioceptive deficits, cerebellar, or extrapyramidal signs. Visual fields were normal. A CT scan 2 months post-onset revealed a left frontoparietal infarct.

An initial speech-language pathology evaluation indicated aphasia characterized by dyslexia, dysgraphia, and mild-to-moderate anomia. By three months post-onset, when this study was initiated, D.H.'s earlier semantic and phonemic paraphasias had resolved. His speech was grammatical and predominantly fluent, with occasional hesitations for word retrieval. His score of 55/60 on the <u>Revised Boston Naming Test</u> (Goodglass and Kaplan, 1983) was within the normal range for his age and education. He received full scores on sentence repetition and auditory - verbal comprehension subtests of the Boston Diagnostic Aphasia Examination (BDAE; Goodglass and Kaplan, 1983) and a score of 35/36 on the Modified Token Test (DeRenzi and Faglioni, 1978). D.H. was able to recall 6 digits forward and 4 digits backward. His total score on the Weschler Memory Scale (Weschler, 1972) had improved to within normal limits (56.6/93; mean for age = 58.8). His reading comprehension was very mildly impaired; performance on the BDAE and Reading Comprehension Battery for Aphasia (RCBA; LaPoint and Horner, 1979) was 100% accurate for words and 90% accurate for sentences and paragraphs. D.H.'s primary persisting impairment was in the area of written language. His narrative writing contained spelling errors in virtually every sentence. His dysgraphia impeded reemployment, because his job required writing daily reports.

Identification of Impaired Processes.

D.H. was administered the Johns Hopkins University Dysgraphia Battery (Goodman and Caramazza, 1985) to identify which writing processes were impaired. He wrote 326 words and 44 nonwords to dictation, spelled aloud 42 words and 20 nonwords, wrote the names of 51 pictured objects, and transcoded 62 words from upper to lower case or vice-versa after removal of the stimulus word. Since the types and rates of errors were essentially the same for all of these spelling tasks, damage to a common underlying process was implicated. Caramazza, Miceli, Villa, and Romani (1986) have proposed that all spelling tasks entail storage of a graphemic representation of a word, generated either by the graphemic output lexicon or by phoneme-grapheme conversion processes in the graphemic buffer while motor processes for oral or written spelling are implemented. Although information processing models differ with respect to procedures for computing the graphemic representation of novel or familiar words, all models may need to postulate a processing stage in which the graphemic representation is held while the word is being written (Miceli, Silveri, and Caramazza, 1985; Ellis, 1982; Newcombe and Marshall, 1980). We identified selective damage to the graphemic buffer as the source of D.H.'s errors first by eliminating other possible sources of errors, such as damage to other components of a model of spelling developed through converging evidence from numerous case studies of acquired dysgraphia (Figure 1, page 90).

We ruled out disruption of phoneme-grapheme conversion processes because there was no difference in spelling between words and nonwords. D.H. spelled correctly 50% (60/120) of the words and 48% (26/54) of the nonwords on a list controlled for length in letters. Disruption of motor writing processes was contraindicated because there was no difference between written and oral spelling; writing to dictation was 52% (61/118) accurate, and oral spelling to dictation was 54% (30/56) accurate. The homogeneity of his errors across dictation, delayed transcoding and written naming tasks also eliminated the possibility of a phonological input basis for his errors. Writing to dictation (auditory word input) and delayed copy transcoding (printed word input) were performed with the same level of accuracy--both 63% correct. Accuracy in written naming (picture input) was somewhat higher, but this finding can be explained by shorter word length in this task (mean word length of 4.8 letters in written naming, compared to mean word length of 5.3 and 5.6 for dictation and transcoding, respectively).

Damage to lexical processes was ruled out by comparing lexical parameters of stimuli and by analyzing error responses. There were no significant effects of grammatical word class on accuracy of written or oral spelling. D.H.'s written spelling was correct for 50% (14/28) of the nouns, and 53% (21/28) of the verbs and adjectives on a list counter-balanced for grammatical word class, frequency, letter length, and syllabicity. He also spelled correctly 42% (5/12) of the words in each open class in oral spelling of a similarly controlled list. D.H.'s spelling of closed class words was 95% (19/20) accurate in written spelling and 33% (2/6) accurate in oral spelling. This finding may be explained by his tendency to self-correct high frequency words (since all functors are high frequency) in written, but not oral, spelling. Concreteness was also not a significant factor in spelling accuracy; D.H. spelled correctly 57% (12/21) of the concrete words and 52% (11/21) of the abstract words on a list controlled for frequency and length in letters.

The only significant lexical factor on spelling accuracy was a demonstrated word frequency effect in written spelling. D.H. spelled correctly 75% (109/146) of the high frequency words and 49% (72/146) of the low frequency words on lists controlled for syllabicity, length in letters, and grammatical word class. The discrepancy between high and low frequency words could be explained by postulating an additional impairment at the level of the graphemic lexicon, resulting in poorer performance on low frequency words. A rival explanation, consistent with selective damage to the graphemic buffer, is that D.H. was more likely to self-correct high frequency words, when his initial attempt clearly did not "look right." Two findings support the latter explanation -- no frequency effect was demonstrated in oral spelling, and higher frequency words elicited a greater number of whole-word self-corrections (5 versus 0) in writing.

Furthermore, D.H. could not have relied on nonlexical spelling (phoneme to grapheme conversion processes), because there was no difference in accuracy between regular and irregular words. He spelled correctly 70% (21/30) of orthographically regular and 68% (54/80) of orthographically irregular words matched for frequency and word length in phonemes and letters.

Further evidence for the hypothesis that D.H. has selective damage to the graphemic buffer was obtained by comparing his pattern of errors against the pattern predicted by the hypothesized locus of damage, as follows:

1) Errors should be comparable for all output modalities, since motor processes required for oral and written spelling are expected to be intact.

2) Spelling errors should be similar for all input modalities, since the series of graphemes generated by the graphemic lexicon or by phoneme-grapheme conversion processes should be accurate.

3) We would not expect semantic, phonological, or morphological word errors, since the processes generating the lexical entry are assumed to be unimpaired.

4) Errors should reflect degradation of the graphemic representation of the target response, since errors must arise in the storage of an accurate series of graphemes. Deletions, substitutions, insertions and transpositions of letters are intuitively predicted. Both word and nonword error responses could result from degradation of the graphemic representation.

5) We would expect violations of English orthography among the errors, since degradation of the graphemic representation need not follow orthographic constraints.

6) Spelling errors should occur with increased frequency as a function of word length, since each grapheme to be stored introduces a potential error.

Each of the above predictions was borne out in our analysis of D.H.'s performance on the Dysgraphia Battery. Table 1 demonstrates the homogeneity of his errors across input (picture, dictation, copying) and output (oral and written) modalities. For example, in oral and written spelling of words and nonwords to dictation, single-letter errors predominated. Of these, the most common were letter substitutions (39% in writing; 39% in oral spelling) and deletions (42% in writing and 41% in oral spelling). Mixed errors (e.g., substitution + transposition) accounted for 16% (24/147) of the written spelling errors and 17% (6/36) of oral spelling errors. In both modalities, less than 10% of the responses contained multiple errors of the same type (e.g., two insertions). This pattern of predominantly single substitution and deletion errors, 15-20% mixed errors, and few multiple errors, also obtained for written naming and delayed transcoding.

Table 1. Distribution of errors in four spelling tasks -- Subject D.H.

	Writing to Dictation		Oral Spelling to Dictation		Written	Delayed
	Words	Nonwords	Words	Nonwords	Naming	Copying
Number of stimuli	326	34	42	20	51	124
Spelling errors						
Single letter	53%	52%	68%	60%	69%	67%
Substitutions	(39%)	(42%)	(44%)	(25%)	(44%)	(30%)
Insertions	(4%)	(8%)	(6%)	(13%)	(0%)	(0%)
Deletions	(43%)	(42%)	(39%)	(63%)	(56%)	(50%)
Transpositions	(15%)	(8%)	(11%)	(0%)	(0%)	(20%)
Multiple errors (of 1 type)	5%	9%	8%	10%	8%	0%
Mixed errors	1.7%	9%	16%	20%	15%	20%
Unclassifiable (partial responses & visual similar words)	25%	30%	8%	20%	8%	13%
Error rate	37.1%	53.0%	41.7%	50.0%	25.5%	37.1%
$\bar{x}$ word length (# letters)	5.34		5.68		4.80	5.62

D.H. Produced no semantic errors and only two morphological errors on the battery (Table 2). The majority (60%) of his spelling errors were phonemically implausible nonwords, compatible with degradation of an accurate lexical entry in the output buffer. A nonnegligible portion of these errors were orthographically illegal (e.g., length-->lentgh; brick-->brsst; scrubbed-- sbuced). His visually similar word responses (e.g., speak speck; starve-->stave) and phonemically plausible errors (e.g., thread-->thred; rinse-->rince) also consisted of deletions, substitutions, insertions, and transpositions of letters, and therefore could also be attributed to degradation of an accurate word. See Appendix A for examples of D.H.'s phonemically implausible nonword errors.

Table 2. Distribution of error types in four spelling tasks -- Subject D.H.

	Written Spelling		Oral Spelling		Written Naming		Delayed Transcoding	
Phonemically implausible nonwords (PIN)	98	(57.3)	16	(76.1)	6	(42.8)	15	(71.4)
Phonemically plausible errors (PPE)	22	(12.9)	3	(14.3)	6	(42.8)	1	(4.7)
Visually/phonologically similar words (VSW)	24	(14.0)	2	(9.5)	2	(14.3)	0	
Morphological errors	2	(1.1)	0		0		0	
Semantic errors	0		0		0		0	
Phonological errors (phonologically similar/ visually dissimilar)	0		0		0		0	
Partial responses	24	(14.0)	0		0		5	(23.8)
"Don't know" responses	1	(0.5)	0		0		0	
TOTAL	171		21		14		21	

Word length was the most striking determinant of spelling accuracy. D.H. exhibited steady decrements in spelling accuracy from 100% (14/14) for 4 letter words, to 14% (2/14) for 8-letter words in writing dictated words controlled for frequency and word class (Table 3). The proportion of error responses consistently increased as a function of word length in oral and written spelling and delayed copy of words and nonwords (Table 4). Letter deletions and mixed errors also increased as a function of word length, while single letter insertions and transpositions decreased (Table 5). Furthermore, the mean length of correctly spelled words (5.42 letters) was significantly shorter than the mean length of misspelled words (6.38 letters; $t = 6.9$; $p < .0001$). This consistent effect of stimulus length indicates an impairment of a working memory system. Normal performance on delayed repetition of words and sentences confined the deficit to the graphemic buffer.

In summary, D.H.'s performance is compatible with the hypothesis of damage to the graphemic buffer. The striking similarity of his errors

Table 3. Comparison of word lengths -- Subject D.H.

Stimuli	# Stimuli	# Correct	% Correct
4 letter words *	14	14	100.0
5 letter words	14	12	85.7
6 letter words	14	10	71.4
7 letter words	14	6	42.9
8 letter words	14	2	14.3

*bisyllabic; 1/2 high frequency & 1/2 low frequency; counterbalanced for frequency, number of phonemes per word, and word length

Table 4. Spelling errors as a function of length in 3 writing tasks. Misspelled words/Totalwords (% errors) -- Subject D.H.

Number of Letters	Written Naming	Writing to Dictation	Delayed Copy Transcoding
3	0/2 (0%)	---	---
4	1/15 (6.7%)	16/75 (21.3%)	1/4 (25.0%)
5	9/21 (42.9%)	30/110 (27.3%)	11/30 (36.7%)
6	6/11 (54.5%)	33/84 (39.3%)	15/42 (35.7%)
7-8	---	27/40 (67.5%)	3/6 (50.0%)

Table 5. Distribution of errors as a function of word length -- Subject D.H. (Percentages are in parentheses.)

Letter length	4	5	6	7-8	Total
Single errors	8 (50.0)	16 (53.3)	19 (57.6)	13 (48.1)	56 (52.8)
Substitutions	6 (75.0)	8 (50.0)	6 (31.6)	3 (23.1)	21 (38.5)
Insertions	0	1 (6.3)	1 (5.3)	0	2 (3.6)
Deletions	0	4 (25.0)	10 (52.6)	9 (69.2)	23 (41.1)
Transpositions	2 (25.0)	3 (18.8)	2 (10.5)	1 (7.7)	8 (14.3)
Multiple errors	1 (6.3)	2 (6.7)	1 (3.0)	1 (3.7)	5 (4.7)
Mixed errors	0 (0)	4 (13.3)	6 (18.1)	8 (29.6)	18 (17.0)
Unclassifiable	7 (43.8)	8 (26.7)	7 (21.2)	5 (18.5)	27 (25.5)
TOTAL	16	30	33	27	106

across all input and output modalities for all types of words and nonwords can only be explicated by a defect in a process common to all spelling tasks. The graphemic buffer is the only such process in the type of functional architectures that have been proposed for the spelling process.

The only evidence contrary to selective damage to the graphemic buffer is that D.H. produced suffix (but never prefix) substitutions, deletions, and insertions in written narratives. These errors could result from a separate morphological processing deficit, or they could represent spelling errors (grapheme deletions, substitutions, and/or insertions) at the end of words. The absence of morphological errors in spontaneous speech and repetition and the preponderance of spelling errors at the end of words (Figures 2 and 3) are consistent with the latter explanation.

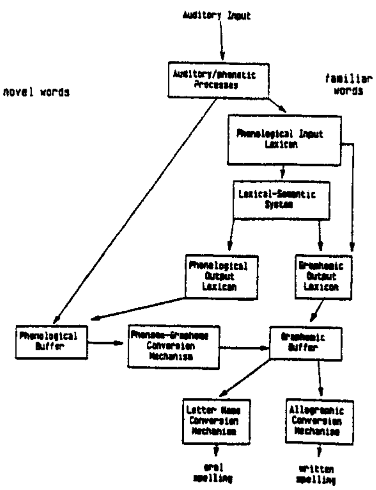

Figure 1. Schematic representation of a model of the spelling process.

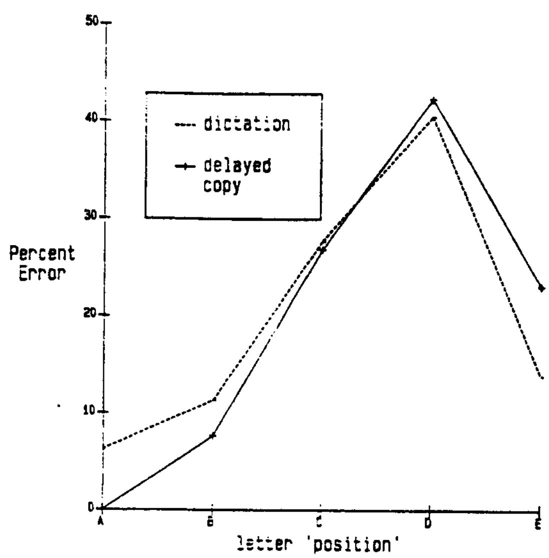

Figure 2. Distribution of D.H.'s errors as a function of letter position in words.

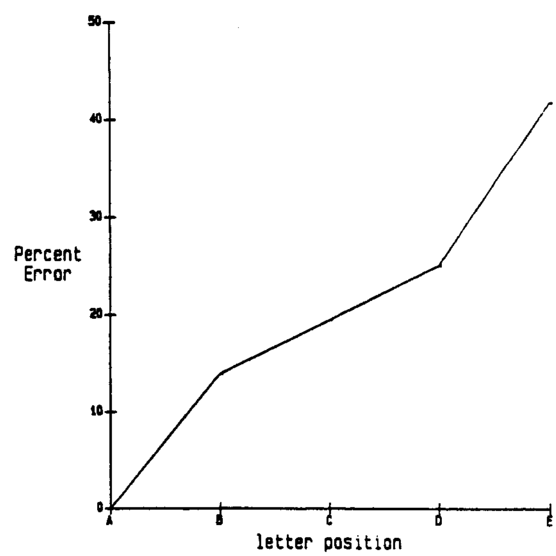

Figure 3. Distribution of D.H.'s errors as a function of letter position in nonwords.

Remediation Strategies.

Identification of the source of D.H.'s errors through the above analyses allows us to choose possible intervention strategies to help D.H. improve his writing. Since his spelling errors and perhaps his suffix errors result from selective damage to the graphemic buffer, strategies for teaching specific spelling of words or specific morphological rules would be futile. In fact, D.H. already performed flawlessly on tasks frequently used for these purposes, such as selecting accurate spellings or appropriate morphological forms of words for sentence frames (see Appendix B). Given his intact graphemic lexicon, strategies that exploit his ability to recognize correct spellings, such as enhancing self-correction by teaching the types of words likely to be in error, would be suitable. He also should be able to exploit his intact ability to use phoneme-grapheme correspondence rules.

A multiple baseline experiment was conducted to determine the effectiveness and generalization of training specific spellings of words vs. training self-correction strategies. There was one unpredicted finding: a positive response to "teaching" spellings of certain words. D.H. wrote 3 sets of 25 words, matched for frequency and length, to dictation. Baseline data were collected for 3 consecutive sessions. D.H. produced spelling errors on the longer words (+/- 2) each day, although his error responses varied (e.g., language--> "language," "languge" and "langague"), consistent with his hypothesized deficit. On the third session, D.H.'s spelling of set A words was corrected (i.e., he was given the correct spelling, and copied it), while baseline measures continued for sets B and C. Training continued with set A, until he (unexpectedly) reached 100% accuracy for 2 sessions. Then set B was trained, with an additional component of training to assess potential generalization of improvement to set C. D.H. was taught to sound out each initial response, to check it against the target, and to search for errors where he was likely to make them -- on longer words and at the end of words. Set B words that were not self-corrected were corrected by the clinician, while no feedback or instruction was provided for set C. While simple correction of errors improved only spelling of trained words, teaching a search strategy improved spelling of nontrained words as well (Figure 4).

The unexpected improvement in spelling trained words in the initial condition was superficially problematical to the hypothesis of selective damage to the graphemic buffer (which assumes an intact graphemic output lexicon), since he should not be able to learn spellings he already knows. We postulated that D.H. recalled which words had previously been corrected by the clinician, and was more careful to self-monitor and self-correct spelling of these words on subsequent sessions. His ability to incorporate a self-monitoring strategy to anticipate and correct errors on untrained words in the second treatment condition indicates such a possibility. To evaluate this hypothesis, response time was measured for each word, predicting that more calculated self-monitoring would require a longer response time. Previously corrected words induced significantly longer response times (mean = 26.1 sec.) than other words (mean = 5.1 sec.; $t = 2.68$; $p < .01$) even when word length was controlled, consistent with more assiduous self-monitoring of clinician-corrected words (Table 6).

To teach self-monitoring of written narratives, D.H. searched for errors in passages containing 15 suffix errors, 15 phonemically implausible nonword spelling errors, and 15 phonemically plausible spelling errors.

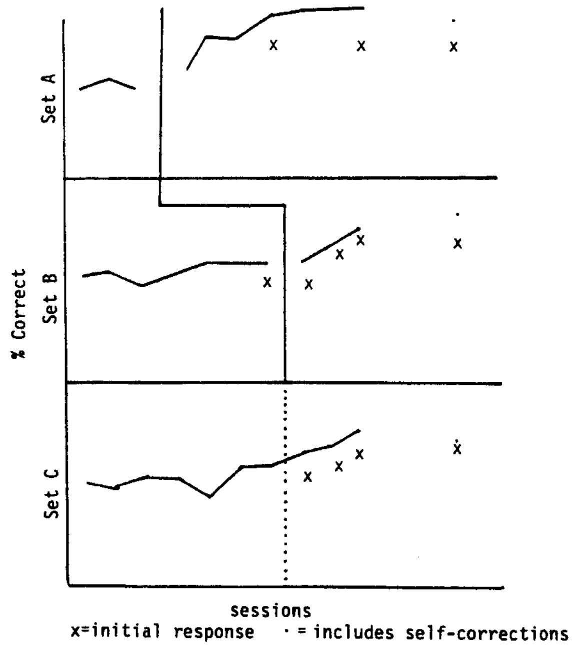

Figure 4. Effectiveness of teaching correct spellings and search strategies to D.H.

Table 6. Mean response time (in seconds) for trained vs. untrained words -- Subject D.H.

	Trained Words*				Non-trained Words**		
Spelling on day timed:	Correct		Incorrect		Correct		Incorrect
Word Length	N	Time	N	Time	N	Time	N
4 letters	2	14.5	1	5	12	5	0
5 letters	6	28.2	0		9	5	0
6 letters	1	15	2	5	12	5.2	0
7 letters	10	19.7	0		5	5.2	0
8 letters	11	21.8	2	8	2	5.5	0

Note. Response time $\leq$ 5 seconds was calculated as = 5 seconds.

*words that had previously been misspelled, and corrected by the clinician

**words that were spelled correctly on all previous trials

Training included instructions to 1) start from the end of the passage, looking for errors at the end of longer words, and 2) sound out each word from the beginning. After four sessions of training using the same passage with different words misspelled, D.H. spontaneously used trained search strategies. He missed only 3 of 45 errors on the posttest compared with 22 of 45 errors on the pretest with the same words misspelled (but the type of error on each word was interchanged; e.g., snail-->snale, snaid). The same search strategies were used for improving spontaneous written narratives. Figure 5 displays the effectiveness of training. Although D.H.'s error rate in initial output did not improve, his self-correction of errors in proofreading improved substantially with the intervention. He was able to resume his previous work by proofreading daily reports, using the trained strategies, before submitting them.

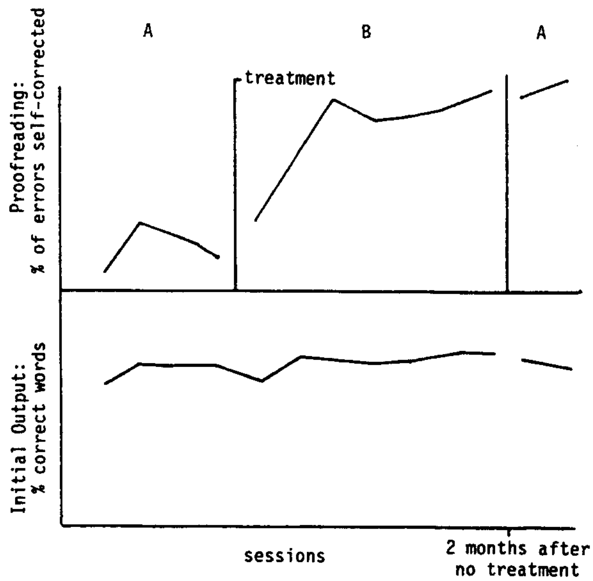

Figure 5. Effectiveness of a trained search strategy on improving self-correction in written narratives.

Contrasting Case.

These treatment strategies were successful for D.H. because they exploited his intact abilities to sound out words and to recognize accurate spellings to compensate for his impairment at the level of the graphemic buffer. They would not benefit patients with impairments at other levels of the spelling process that affect recognition of accurate spellings. For instance, they could not help H.H. (Table 7), who exhibited selective impairment in accessing information in the graphemic output lexicon. His performance on the Dysgraphia Battery is shown in Tables 8-13. H.H. was able to spell nonwords more accurately than words and "regularly spelled" words more accurately than "irregular" words (Table 7). Substantial effects of lexical parameters (frequency, word class, and concreteness) were also evidenced. His predominance of phonemically plausible errors (Tables 11 and 12) on all spelling tasks suggested that he uses intact phoneme-grapheme conversion processes when he fails to access correct spellings in the graphemic lexicon. Therefore, D.H.'s learned search strategy of "sounding out" words should not improve H.H.'s error identification, since his errors all sounded correct. Moreover, he could not self-correct identified errors, since he could not access the spellings. (See Appendix C for examples of H.H.'s spelling errors.)

Table 7. Comparison of patient characteristics.

	D.H.	H.H.
Sex	Male	Male
Age (in years)	49	57
Education	high school	high school
Occupation	quality control supervisor for chemical lab	retired truck driver
Handedness	right	right
Diagnosis	thromboembolic stroke	hemorrhagic-stroke
Time post onset	3.5 months	18 months
Site of lesion (by CT)	left fronto-parietal	left temporo-occipital
Language characteristics		
Auditory comprehension	intact	intact
Spontaneous speech	fluent and grammatical occasional hesitations for word-finding	fluent and grammatical occasional circumlocutions
Repetition	intact	intact
Naming	mildly impaired	mildly impaired
Reading	impaired	impaired
Writing	impaired	impaired

Table 8. Comparison of words with high and low probability* of phoneme-to-grapheme mapping -- Subject H.H.

	# Stimuli	# Correct	% Correct
High Probability Words**	30	28	93.3
high frequency	15	14	93.3
low frequency	15	14	93.3
Low Probability Words**	80	58	72.5
high frequency	40	34	85.0
low frequency	40	24	70.6

*>50% and <10% chance, respectively, of being spelled correctly by implementing most common phoneme-grapheme correspondence rules in English

**4-6 letters and 3-4 phonemes per words; counterbalanced for word probability, word frequency, phonemes per word, and word length

Table 9. Comparison of grammatical word classes -- Subject H.H.

Word Class	# Stimuli	# Correct	% Correct
WRITTEN SPELLING:			
Open-class words*	84	62	73.8
nouns	28	21	75.0
verbs	28	15	53.6
adjectives	28	15	53.6
Function words**	20	11	55.0
Nonwords	34	33	97.1
		(only error:	sarcle --> circle)
ORAL SPELLING:			
Open-class words	36	24	66.7
nouns	12	5	41.7
verbs	12	9	75.0
adjectives	12	7	58.3
Function words	6	3	50.0
Nonwords	20	20	100.0

* 1/2 high frequency & 1/2 low frequency; 1/2 monosyllabic & 1/2 bisyllabic; 4-7 letters; counterbalanced for word class, frequency, syllabicity, and length. Names counterbalanced for concreteness.

** same as above, but all high frequency

Table 10. Comparison of concrete and abstract words* -- Subject H.H.

	# Stimuli	# Correct	% Correct
Concrete Words	21	13	61.9
Abstract Words	21	8	38.1

*bisyllabic nouns; 1/3 low, 1/3 high, & 1/3 mid-frequency; 5-7 letters; counterbalanced for concreteness, word frequency, and length

Table 11. Comparison of word lengths* -- Subject H.H.

Stimuli	# Stimuli	# Correct	% Correct
4 letter words	14	9	64.3
5 letter words	14	9	64.3
6 letter words	14	9	64.3
7 letter words	14	7	50.0
8 letter words	14	4	28.6

*bisyllabic; 1/2 high frequency & 1/2 low frequency; counterbalanced for word length, frequency, and number of phonemes per word

Table 12. Comparison of high and low frequency words* -- Subject H.H.

	# Stimuli	# Correct	% Correct
Written Spelling			
high frequency words	146	108	74.0
low frequency words	146	65	44.5
Oral Spelling			
high frequency words	21	11	52.4
low frequency words	21	11	52.4

*4-8 letters; counterbalanced for word frequency, syllabicity, and word length; word classes distributed evenly across variables

Table 13. Distribution of error types -- Subjects H.H. and D.H.

	Spelling to Dictation		Naming	Total %	
	Written	Oral	Written	H.H.	D.H.
Phonemically implausible nonwords	10 (8.7)	3 (16.7)	2 (20)	10.6	58.8
Phonemically plausible errors	102 (89.5)	15 (88.2)	7 (70)	87.3	15.2
Visually/phonologically similar words*	1 (0.8)	0	0	0.7	13.7
Phonologically similar/visually dissimilar words	1 (0.8)	0	0	0.7	0
Morphological errors	0	0	0	0	1.0
Semantic errors	0	0	1 (10)	0.7	0
Partial responses	0	0	0	0	11.8
"Don't know" responses	0	0	0	0	0.5
TOTAL	114	18	10	(142)	

*also phonemically plausible: basis ---> bases

To evaluate H.H.'s potential learning of certain spellings by rote memorization, or by improving access to correct spellings by repeated practice, we employed the multiple baseline experiment used in training D.H. to spell specific words. Although H.H. exhibited a small improvement in spelling accuracy (25 trained words--Figure 6), the study was discontinued due to the patient's frustration.

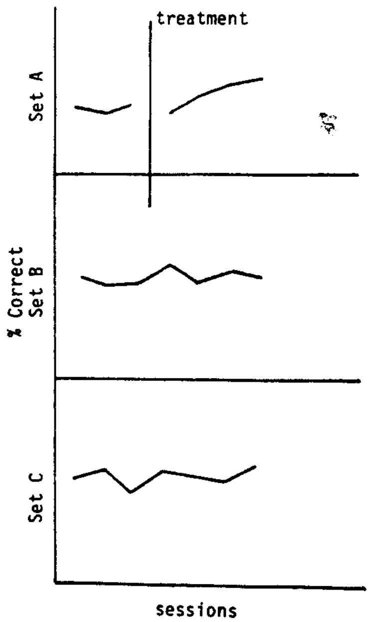

Figure 6. Effectiveness of teaching correct spellings to H.H.

However, H.H. did learn to spell a smaller set of frequently written words (i.e., words written on checks; Figure 7), and he learned to use a dictionary. A dictionary did not help D.H. since he self-corrected any errors that he identified, and he often copied inaccurately from the dictionary.

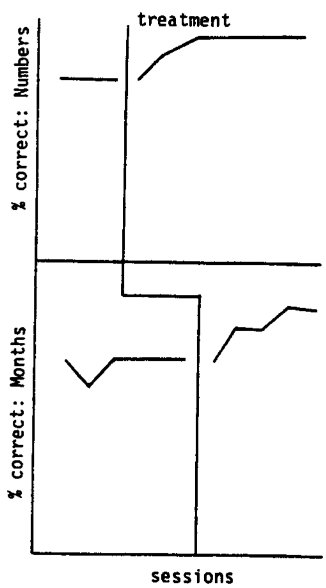

Figure 7. Effectiveness of error correction in improving H.H.'s spelling of a limited set of words.

SUMMARY

We have demonstrated that differentiation of impaired processes in writing enables differentiation of appropriate intervention strategies. Only a sufficiently articulated model of the spelling process can account for all patterns of errors exhibited in our patients' writing, and allow accurate identification of the basis of spelling errors -- a reasonable target for remediation or compensatory strategies. The effectiveness and generalization of a trained search strategy for D.H. exemplifies a successful model-driven approach for treating acquired dysgraphia.

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APPENDIX A

Examples of various types phonemically implausible nonword (PIN) errors produced by D.H.

	Words	Non-Words
1.) Single errors		
substitution	bump -> buep	herm -> hegm
insertions	oyster -> osyster	feen -> feent
deletions	faith -> faih	reesh -> reeh
transpositions	church -> chucrh	ghurb -> grub
2.) Multiple errors		
substitutions	urban -> egban	kittul -> keeful
insertions	----	feen -> frient
deletions	since -> sic	----
transpositions	----	----

	Words	Non-Words
3.) Mixed errors		
substitution & deletion	kitchen -> kicken	----
substitution & trans-position	pursuit -> presuit	reesh -> richs
insertion & deletion	afraid -> affrid	----
deletion & transposition	pierce -> peire	----
deletion & transposition & substitution	fierce -> feist	----
multiple transposition & deletion	vulgar -> vagul	----
multiple substitution & deletion	----	----
multiple deletion & substitution	offense -> offec	----
insertion & deletion & deletion	----	faunch -> frout
4.) Unclassifiable		
fragments	yawn -> y	pytes -> pi
miscellaneous	courage -> gorous	poys -> fesh

APPENDIX B

Examples of spelling and morphological tasks on which D.H. performed normally (without training)

1. Sentence frame tasks:

EX: The snow ________ on the steps.

select one: accumulation accumulated accumulate

How well does the washer ________ clothes?

select one: agitate agitated agitates

Note: After selecting correct response on 148/150 trials, D.H. wrote these sentences to dictation, producing frequent morphological (& spelling) errors.

e.g., in writing the above sentences to dictation, he replaced accumulated with accumulate and agitate with agitates. Remaining words were accurately written.

2. Morphological transformations

EX: Write the past tense form of (given word).

Write the plural of (given word).

D.H.'s responses were accurate for both regular and irregular inflections, with the exception of some spelling errors.

e.g.,

response	stimulus
pennies -> pennys	(penny)
people -> peple	(person)
started -> stared	(start)

3. Spelling recognition (multiple choice format)

EX: Select the correctly spelled synonym:

calm: tranquil tranquill trankwill trannquil tranguil

Annoyance: nuisanse nusiance nusanse nuisance nusance

APPENDIX C

Examples of H.H's spelling errors

Phonemically Plausible Errors:

bottle --> bottel
guitar --> gitar
snail --> snale
island --> iland
thumb --> thum
nuisance --> newsons
pirate --> pirit
urban --> erbin
engine --> engion
fabric --> fabrick
spider --> spyder
fact --> fackt
vague --> vage
cloak --> cloke
phase --> faise
fruit --> frute

dumb --> dum
type --> tipe
group --> groop
speak --> speek
young --> yong
while --> whyle
crisp --> chrisp
column --> colom
conquer --> concker
decide --> deside
grief --> greef
copy --> coppy
rinse --> rence
debt --> det
jerk --> jurk
chief --> cheef

Other types of errors:

Phonemically implausible non-words: (transposition of phonemes or of phonemically plausible graphemes)	poem --> palum schedule --> secgule igloo --> egule
Phonologically/visually similar words	basis --> bases
Phonologically similar/visually dissimilar words	journal --> general

DISCUSSION

Q: How was DH's writing to dictation of nonwords vs. short high frequency words-the sort that you would expect to go straight through the lexical route in the model, rather than have to go out through phoneme-to-grapheme conversion?

A: His spelling of nonwords was identical to his spelling of words when we controlled for length. And he made the same types of errors on high frequency words as he did on low frequency words and nonwords.

Q: Why are you so confident that the problem is in the buffer and not on the grapheme side of the phoneme-to-grapheme conversion mechanism? I'm not sure that you have any words, or that there are any tasks in Bobbi Goodman's battery, that you can say with assurance do not go the phoneme-to-grapheme conversion route.

A: There are several reasons we did not think he used only the phoneme-to-grapheme conversion route. One was that he didn't spell nonwords more accurately than words; they were spelled with the same level of accuracy. Also, I did not think he was using phoneme-to-grapheme conversion to spell all words since there was no difference in spelling accuracy of orthographically regular vs. irregular words. And for highly irregular words, which included exception words like "yacht," he was getting very close to the correct spelling, but producing very similar substitutions or deletions. For instance, when he spells yacht, "y-a-c-h," you have the feeling he's not really trying to use phoneme-to-grapheme conversion. Moreover, the majority of his errors were phonologically implausible nonwords. For instance, when he was asked to spell "chair" and wrote c-h-a-i-t, he was not using phoneme-to-grapheme correspondence.

Q: I don't think you can say that. You can argue just as readily that there is a breakdown on the grapheme side. When you're talking about phoneme-to-grapheme conversion, what you're assuming is that there is intact phonological input to the phoneme-to-grapheme conversion mechanism. Within the conversion mechanism, there could be a breakdown in the match of the appropriate grapheme to the accurately encoded phonological sequence, or phoneme sequence, to the end that the output of the conversion process could very well be implausible phoneme strings.

A: So matching the phoneme to a grapheme is done incorrectly? If that were his only impairment, I would expect him to spell words correctly using a lexical route.

Q: Not necessarily - only assuming there is a lexical route at all and that it was available to him.

A: Yes, you could postulate two separate "lesions" - one at the level of the graphemic output lexicon and one in the phoneme-to-grapheme conversion process - that somehow produce the identical distribution of error types.

Q: Did you at any point simply dictate to him letter sequences, as you would if it were a digit repetition task -- nonword letter strings for him to write?

A: No.

Q: You might want to consider that, because that may be one way of creating a different intercept at the level of the graphemic buffer and then maybe give you stronger evidence to isolate it.

A: Maybe, but I think delayed transcoding task assesses what you're looking for. In that task, it didn't matter whether he was using a phoneme-to-grapheme conversion process or lexical processes for spelling. In the delayed transcoding task, you just show the patient a word, then you take it away and ask him to write it. Actually, you also ask him to convert it to upper or lower case, but with DH that didn't matter. Even if I just asked him to copy it, when I took it away, he made exactly the same types of errors and exactly the same error rate as he did in dictation tasks with words and nonwords. That could not be explained by impaired phoneme-to-grapheme conversion.

Q: Could he do delayed word-to-picture matching?
A: Yes, and he could say the word after I took it away. He always remembered what the word or nonword was supposed to be.

Q: What kind of criteria did you establish for correct spelling of nonwords?
A: Whatever I thought was phonologically plausible. If I could sound it out to produce the nonword I had dictated, I counted it as correct -- a fairly loose definition, I know. I allowed any letter that could produce the target sound in English. So there were sometimes 5 or 10 different responses that would be accurate for a single nonword.

Q: Were some of the real words also abstract or unfamiliar, so that perhaps those same loose criteria should be applied to some of the real words if they were unfamiliar to that person?
A: That's a good point, but on this particular battery, none of the words are really low frequency. I can't remember the exact frequency levels, but they were all words that you would expect to be in the repertoire of a high school graduate.

C: You need to consider your use of terms here. I think you really don't mean he had a lesion to the graphemic buffer whether or not he had selective damage to the graphemic buffer. I think you might want to watch your terminology.
A: I didn't mean a lesion in a physiological sense at all. I used "functional lesion" to a component of the model to refer to a theoretical construct - the selective disruption of one component of a process. I don't imagine there is a graphemic buffer located somewhere in the brain.

Q: Where was that lesion?
A: The patient had a left frontoparietal lesion.

Q: Many of our aphasic patients do. Should we assume that many of our aphasic patients, then, have the same kind of buffer problem or other problems that you describe here?
A: I don't think you can assume they do, but I think you could find out if they do. I think there are other patients who do. Just as Terry Wertz felt he had cured aphasia by trying to study it, I felt like I created an epidemic by studying the graphemic buffer. I've found two other patients who have had the same type of impairment. You can find out if your patients have the same problems, but not by our aphasia tests. You have to do tasks like delayed transcoding, or delayed copying of words, and other tasks that we don't ordinarily do in our aphasia testing. But I think some of our aphasic patients do have this deficit, and some don't.

Q: Because their lesions are different? It would be clinically efficient to be able to correlate certain behavioral observations or expected observations with certain information about locus of lesion. And if, for example, your patients all have a parietal lesion, then identification of that might increase our clinical efficiency.
A: There have only been two other patients reported in the literature that might have a similar deficit. There were some differences; one did not have the same types of errors in delayed copying, both of them were Italian speakers and performed disproportionately poorly on oral spelling. I didn't look at where their lesions were, but since there have been so

few cases reported, we haven't had enough data yet to say whether all patients with graphemic buffer damage have similar lesion sites. It would be interesting if they did, but it wouldn't tell you that all patients with that site of lesion have damage to the graphemic buffer. Actually, one of my other patients has damage to the right hemisphere -- she's left handed and aphasic.

Q: I'd like a point of clarification with regard to what is the graphemic buffer. My recollection is that Sarno and other people talk about a buffer as being a temporary storage capacity of up to 250 msec. or so, whereby information from multiple perceptual inputs can be held, temporarily acted on, and either processed further up the system, or outputted as the case may be. Given that working definition, I guess that I'm a little uncomfortable thinking of language output problems as being related to short-term-memory deficits or short-term processing deficits, especially of such duration. I have trouble associating such short-term storage with the types of problems you're talking about.

A: I don't think there's evidence yet for how long the graphemic buffer can hold a representation. The graphemic buffer must be able to hold the generated representation long enough for normal people to spell the word - to either spell aloud or write all of the letters in that sequence. I'm not sure how long that is. It may be that different buffers within language systems have different capacities in terms of storage time. Ellis has talked a little about the fact that writing is slower than other output processes, so a graphemic buffer would have to hold a representation perhaps longer than other buffer processes.

Q: It's probably inefficient to have an information processing model that has to hypothesize multiple buffers for different types of input.

A: I'm talking about an output buffer - it accepts different inputs.

Q: Did you get any reliability on your scoring of your errors? It sounded as if you didn't; and if so, that's something you might want to follow up on, just because I think it's important, to make any claims about treatment effectiveness.

A: Yes, I did on the written naming test, and I did on the last writing to dictation task in the treatment study. We had 100% interjudge reliability (point-to-point percent agreement on correct vs. incorrect spelling). I did it with another clinician who was observing.

Q: Are there two different lexicons, in terms of a phonological input and an output lexicon? If so, what evidence do we have for that?

A: We do have independent evidence that different forms of the same word exist because they can be disrupted separately. I didn't address that at all because other components of the model are described elsewhere. I can give you references. In a model of spelling, the difference is important to account for patients who recognize the auditory word - indicating they have an intact phonological input lexicon, but have no idea how to spell it - indicating that they can't access information in the graphemic output lexicon. There are also patients with the opposite pattern of dissociation. I can give you references, but I think a complete answer to your question would take longer than we have here.

Q: Are you more concerned about separate phonological and graphemic lexicons or separate input and output lexicons?

A: It's necessary to view them as separate to account for patients who recognize an auditory or printed word (having intact phonologic or graphemic input lexicon) but can't retrieve the phonological form of the same word (in the phonological output lexicon) or the spelling of the same word (in the graphemic output lexicon).

Q: In terms of your route for your familiar words, you're saying that everything is intact up to the graphemic buffer. Is that correct?
A: Yes.

Q: What would happen if you were to continually repeat a word to DH? I would assume or wonder if he would then be able to spell it correctly, because you'd be boosting the representation of that word - what's in the buffer itself - if you're saying that there's degradation within the buffer.
A: Well, the fact that he responded accurately with self-correction means he could regenerate the graphemic representation on his own. When he was just writing he wasn't usually aware of when he was making an error, but when he went back and looked at a word, analyzed the word and sounded it out, he could see that it was an error, and he knew where the error was. He apparently could regenerate the graphemic representation and "home in" on the part he knew was an error, and then correct it. He did, in fact, know how to spell these words; he was just spelling them incorrectly because of errors occurring in storage. If your repeating the word over and over again had him "rethinking" the word or regenerating the graphemic representation over and over again, he probably would spell it correctly.

Q: Could he always self-correct?
A: That was my point; he could. In spontaneous written narratives, he corrected 100% of his errors on the very last session. In the session before that, he correct 18 of 19 of his own errors or something like that. He had a very high rate of self-correction.

Q: Do you think that previous spelling strategies had any effect on this? Some of us approach spelling through phonemic approaches and others through "sight-word." Could you address your model in terms of how we learn to spell?
A: I don't know what DH's premorbid spelling strategies were. I agree with you that people do have different spelling strategies, that they can utilize one strategy or another, and that there may be individual preferences. I only know that DH could use either spelling strategy, since he could spell words and nonwords equally well; or they were equally impaired by his damage to the graphemic buffer - his capacity to store the word or nonword before he wrote it. I can't go back and figure out what his strategy preference was before his stroke.