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The role of the Graphemic Buffer in spelling: Evidence from a case of acquired dysgraphia*

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Abstract

A dysgraphic patient is described whose deficit is hypothesized to arise from selective damage to the Graphemic Buffer. The patient's roughly comparable difficulties in oral and written spelling and comparable spelling difficulties in written naming, delayed copy and spelling-to-dictation rule out the hypothesis of selective damage to either input or output mechanisms. More importantly, the nature of the errors produced by the patient and the fact that these errors were distributed virtually identically for familiar and novel words were taken as strong evidence for the hypothesis that L.B.'s spelling disorder results from selective damage to the Graphemic Buffer. Various aspects of the patient's performance are discussed in relation to a functional architecture of the spelling process and in terms of the processing structure of the Graphemic Buffer.

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1. Introduction

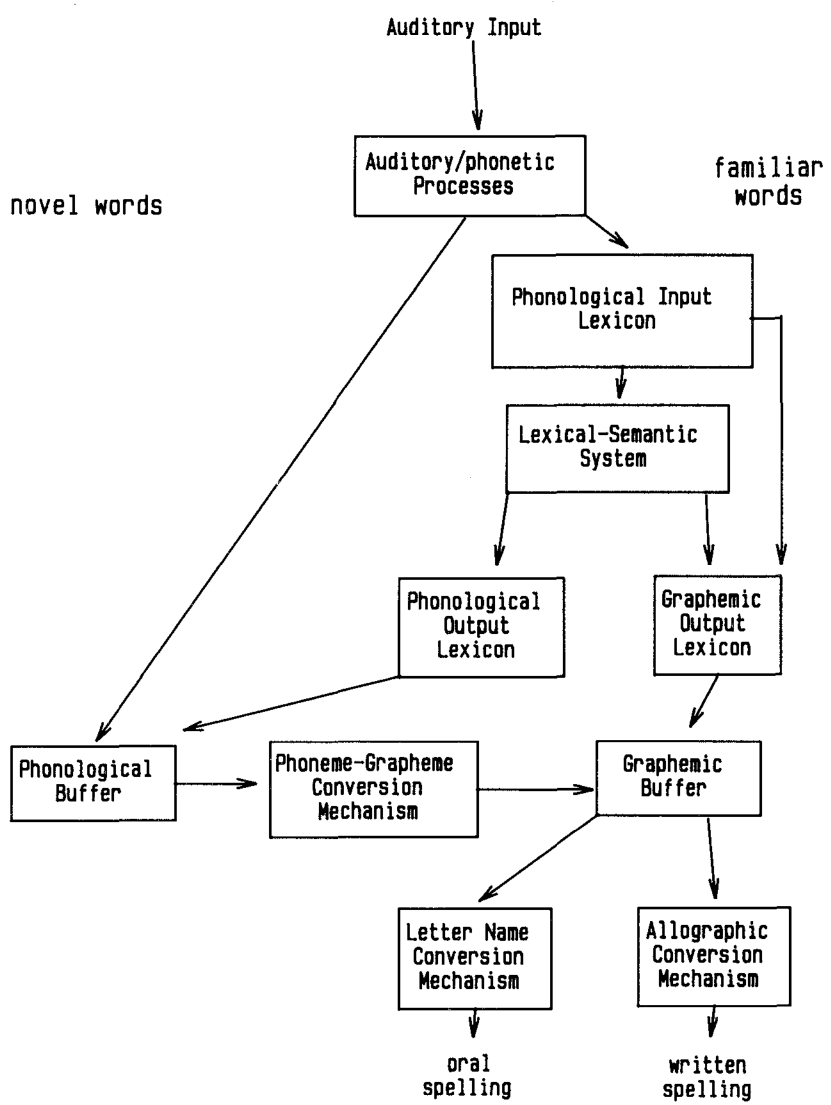
Information processing models of spelling assume that an abstract graphemic representation of the to-be-written word must be generated at some point in the spelling process. This representation specifies the orthographic structure — the sequence of letters — that must be produced. How these graphemic representations are generated in the course of spelling is currently a much debated issue. One class of models assumes that the graphemic representations of familiar and novel words are generated by a single processing mechanism (e.g., Campbell, 1983). Another class of models assumes that the graphemic representations of familiar words are addressed directly in a graphemic lexicon whereas the graphemic representations for novel words (or nonwords) are computed through the application of a Phoneme–Grapheme Conversion Mechanism (e.g., Patterson, in press; Caramazza, Miceli, & Villa, 1986). However, independently of the class of model one adopts for the generation of graphemic representations, there is the issue of how these representations are processed further in the course of spelling. That is, we must specify the types of processes that transform an abstract graphemic representation into a form that is suitable for guiding motor output processes (see Margolin, 1984, for discussion). Thus, we can consider the spelling process as consisting of two major stages: First, those processes involved in the generation of a graphemic representation and, second, those processes involved in using the computed graphemic representation to generate the proper graphomotor processes for oral and written spelling.

The increasingly detailed analyses of acquired disorders of spelling (dysgraphia) in brain-damaged adults have revealed many interesting patterns of deficits. These analyses have served, on the one hand, as the basis for the development of models of the normal spelling process and, on the other hand, as the basis for characterizing the dissolution of the spelling process under conditions of brain damage (see Ellis, in press, for a review). The logic used to constrain models of the normal spelling process through the analysis of patterns of dysgraphia is relatively straightforward. We assume that patterns of dysgraphia are explicable by functionally lesioning one or more components of the cognitive system that underlies spelling. More specifically, we assume that a particular form of dysgraphia constitutes empirical support for a model of spelling (over some alternative model) if the observed pattern of spelling impairment is explicable by specifying a functional lesion to the postulated model. Thus, for example, it has been argued (e.g., Caramazza et al., 1986; Patterson, in press) that models of spelling which postulate distinct procedures for generating graphemic representations for familiar and novel words are supported by the existence of dysgraphic patients who, in the face of considerable difficulties in spelling familiar words, present with absolutely no difficulty in spelling novel words (nonwords). In this case, it is assumed that the procedure for generating graphemic representations for familiar words has been selectively damaged.

Over the past several years a number of quite detailed analyses of dysgraphic patients have been reported which have led to the formulation of a reasonably articulated functional architecture of the spelling process. A diagrammatic representation of a model of the spelling process which is compatible with extant observations of various patterns of acquired dysgraphia is depicted in Figure 1. This model, which assumes that there are distinct procedures for computing graphemic representations for familiar and novel words, can account for the reported double dissociation in spelling these two classes of stimuli. Patients have been described who present with difficulties in spelling nonwords (novel words) in the face of normal ability to spell familiar words. In one case the hypothesized locus of impairment was to the Phoneme–Grapheme Conversion Mechanism (Shallice, 1981), in the other case the hypothesized locus of impairment was to the Phonological Buffer (Caramazza, Miceli, & Villa, 1986). Patients who present with the reverse pattern of dissociation—impaired word spelling with intact nonword spelling—have also been described. In these patients the hypothesized locus of impairment was to the Graphemic Output Lexicon (Beauvois & Dérouesné, 1981; Goodman & Caramazza, 1986; Hatfield & Patterson, 1983). Other patterns of dysgraphia which locate the source of impairment to the Allographic Conversion mechanism (Goodman & Caramazza, 1986; Kinsbourne & Rosenfield, 1974) or to the Graphemic Buffer (Miceli, Silveri, & Caramazza, 1985) have also been reported. There have also been reports of patients with selective damage to relatively peripheral graphomotor processes (Baxter & Warrington, in press; Margolin, 1984). In short, diverse patterns of acquired dysgraphia are explicable by hypothesizing damage to one or more components of the postulated model of spelling and, thus, constitute evidence in favor of the model.

Not all the cited cases are equally unequivocal in the inferences they allow about the hypothesized locus of functional impairment to the spelling process. Thus, although the patient (F.V.) reported by Miceli et al. (1985) could have had a deficit to the Graphemic Buffer, there were features of his performance which resisted clear interpretation. In particular, although the patient presented with similar patterns of spelling errors in various tasks including written naming, writing to dictation, and spontaneous writing, he performed essentially flawlessly in delayed copy of words and nonwords even with a 10-s delay. Miceli et al. interpreted this dissociation in spelling performance as problematic for the hypothesis that the pattern of dysgraphia displayed by

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



F.V. might have resulted from a selective deficit to the Graphemic Buffer. In the present paper we report a case study of a dysgraphic patient (L.B.) whose pattern of spelling errors is less problematically explicable by assuming a selective deficit to the Graphemic Buffer. The detailed analysis of this patient's spelling performance provides the opportunity to explore the role and the structure of the Graphemic Buffer in the spelling process.

Many current models of the cognitive system that underly spelling assume that a critical component of the spelling process is the Graphemic Buffer—a working memory system that temporarily stores a graphemic representation for conversion into specific letter shapes (for written spelling) or letter names (for oral spelling) (e.g., Ellis, 1982; Miceli et al., 1985). Caramazza et al. (1986) have formulated a useful criterion for motivating the inclusion of a working memory component in a cognitive system: A working memory system should be postulated whenever the computational units in a processing component are incommensurate—that is, smaller or larger—with the representations that serve as input to the processing component in question. This criterion is satisfied in the present case. The units of analysis of the Allographic Conversion Mechanism and the Letter Name Conversion Mechanism are single graphemes/letters whereas the representations generated by the Graphemic Output Lexicon and the Phoneme–Grapheme Conversion Mechanism range from whole-word units to single letters (note that the output of the Phoneme–Grapheme Conversion Mechanism may consist of single letters (e.g., /o/ → 'o') as well as several letters (e.g., /o/ → 'ough')). Consequently, the Graphemic Buffer is needed to store multi-grapheme representations temporarily while they are being converted into forms which can be used to guide more peripheral motor processes.

The model of spelling presented here assigns to the Graphemic Buffer a fairly central role. Damage to this component of the system should have clearly specifiable consequences for spelling. Specifically, since the Graphemic Buffer is strategically located in the spelling system so that it mediates between those processes needed to generate graphemic representations for the items to be spelled and the more peripheral processes needed for motor output, damage to this component of processing should affect spelling performance for familiar and novel words independently of the modality of input (i.e., writing to dictation, delayed copy, written naming, or spontaneous writing) or the modality of output (i.e., oral or written spelling or typing). Furthermore, since the representations processed by the Graphemic Buffer consist of a series of graphemic units, selective damage to this component should result in degradation of graphemic representations. In other words, spelling errors should be explicable exclusively by reference to graphemic units; we do not expect lexical (e.g., form class, morphology, etc.)

or phonological factors to play a role in explicating the spelling errors produced by patients with selective damage to the Graphemic Buffer. Finally, since the hypothesized functional role of the Graphemic Buffer is to store information temporarily, damage to this storing function should result in increasingly severe spelling difficulties for longer stimuli.

Although the model we have presented allows relatively specific expectations for a range of performance in the eventuality of selective damage to the Graphemic Buffer, it is obvious that more specific predictions concerning the detailed nature of spelling errors are not possible in the absence of more richly articulated claims about the structure of the Graphemic Buffer. To be sure, there are some intuitively-driven, qualitative expectations about the type of spelling errors that may result from damage to the Graphemic Buffer. The intuition is that the Graphemic Buffer stores a spatially coded sequence of graphemes and that damage to this processing component would result in loss of specific item and/or spatial information. Consequently, errors should take the form of substitutions, insertions, deletions or transposition of letters (Miceli et al., 1985; Nolan & Caramazza, 1983).

2. Case report

L.B.'s case history has been reported in detail elsewhere (see Caramazza, Miceli, Silveri, & Laudanna, 1985). The patient is a 65-year old, right-handed man who suffered a CVA in December, 1982. A CT-scan showed involvement of pre- and post-rolandic areas (both superficial and deep) in the left hemisphere. L.B. has university degrees in engineering and mathematics.

The neuropsychological evaluation at 8 months post-onset, when both the present and the above-quoted study were begun, demonstrated essentially normal results in all language tests, except for reading and spelling. Connected speech was fluent and informative, with occasional hesitations that occurred prior to the (usually successful) production of low-frequency words. Scores on oral naming and word and sentence repetition were normal. On the receptive side, discrimination of CV syllables was within normal limits. In a word–picture matching task L.B. flawlessly matched auditorily (or visually) presented words to their corresponding picture from an array that contained semantically and phonemically (or visually) related items. In an auditory sentence-to-picture matching test, the patient demonstrated normal comprehension of reversible sentences of the declarative and of the relative type (both in the active and in the passive form), and of sentences expressing reversible temporal relations (of the type before/after). L.B. obtained normal scores on the shortened version of the Token Test (30/36 correct responses) and on Raven's Colored Progressive Matrices (31/36 correct responses).

The patient presented with a mild reading disorder that impaired his ability to read nonwords, while leaving word reading unaffected. L.B.'s dyslexic disorder is described in detail in Caramazza et al. (1985). The patient's considerable difficulty in spelling is the focus of the present report.

3. Experimental study

The analysis of L.B.'s performance will be organized into two parts: In the first part we consider those general features of spelling that are relevant to determining whether or not L.B.'s impairment results from damage to the Graphemic Buffer. In the second part we use L.B.'s pattern of spelling errors to constrain hypotheses about the computational structure of the Graphemic Buffer.

3.1. Overall results for a number of spelling tasks

In the Introduction we proposed a set of criteria for determining whether or not the locus of damage, for a particular functional architecture of the spelling process, is at the level of the Graphemic Buffer. One expected feature of spelling performance under conditions of selective damage to the Graphemic Buffer is spelling difficulties for both familiar and novel words (nonwords), independently of modality of input or output. L.B.'s spelling performance satisfies this criterion. As can be seen in Table 1, he encountered difficulties in spelling words and nonwords in oral and written spelling, both in dictation and delayed copy; he also had difficulties in spelling when the stimulus input

Table 1. *Spelling errors for words and nonwords in various tasks (percentages are in parentheses)*

	Words		Nonwords	
Written spelling-to-dictation	305/743	(41)	246/425	(58)
Oral spelling-to-dictation	44/64	(69)	49/64	(77)
Written naming	65/124	(52)	—	
Copy from model	5/57	(9)	2/56	(4)
Delayed copy	21/59	(36)	38/60	(63)

consisted of line drawings of objects (i.e., in a written naming task).[1] This configuration of spelling performance is consistent with the hypothesis of selective damage to the Graphemic Buffer. More detailed analyses where we consider the contribution of stimulus dimensions on performance in each of the spelling tasks are discussed below.

(1) Written spelling to dictation. L.B. was asked to spell to dictation 743 words and 425 nonwords, presented in random order over several sessions. The word sample included sublists controlled for grammatical class, abstractness/concreteness, word frequency and length. The nonword sample included sublists controlled for length and morphological decomposability (the possibility of parsing a nonword stimulus into a real root and a real suffix, not permissible for that particular root—e.g., walken). Word and nonword stimuli ranged in length from 4 to 12 letters.

In this task, as well as in all other tasks of written spelling, L.B. produced his responses to word and nonword stimuli at a normal rate, without any noticeable delay after stimulus presentation. His written output was smooth and fluent. On occasion, he would pause in the middle of a response in order to correct a just-produced letter, or would reconsider his just-completed response, in order to try to identify incorrect letters. Some of these attempts succeeded, but most of them failed. Although he was never explicitly asked, L.B. never mentioned trying to visualize internally the to-be-written stimulus prior to or during response production.

L.B. made 305 errors on words (41%) and 246 on nonwords (57.9%). Results for controlled sublists of words and nonwords are shown in Table 2. None of the lexical factors considered affected spelling performance: There was no effect of grammatical class, abstractness/concreteness nor word frequency. Stimulus length, by contrast, exerted a major influence on performance: L.B. spelled incorrectly only 5/40 (12.5%) short stimuli, ranging from 4 to 6 letters, but made 24/40 (60%) errors on stimuli ranging from 7 to 9 letters. Nonword spelling was not influenced by the morphological decomposability of a stimulus; however, stimulus length was a major factor on performance (8/30 (26.7%) errors on short stimuli and 16/30 (53.3%) errors on long stimuli). The effect of stimulus length on L.B.'s spelling performance

[1]We wish to note that the absolute level of performance across tasks is not easily interpretable for two reasons. First, because we did not use the same stimuli across different tasks and, therefore, we cannot make quantitative predictions about absolute levels of performance. Second, because there could be subtle deficits to cognitive mechanisms required for the normal execution of one task that are not implicated in other tasks (e.g., written naming involves perceptual and cognitive mechanisms needed for processing pictures which are not involved in spelling-to-dictation). In this latter case, too, absolute levels of performance cannot be predicted. Hence the emphasis in this report is on qualitative and grossly quantitative features of performance.

Table 2. *Written spelling-to-dictation: Errors made by L.B. on controlled sublists*

Words	
Sublist 1. (Concreteness/abstractness × frequency; N = 40)	
Concrete words	2/20
Abstract words	2/20
High-frequency words	3/20
Low-frequency words	1/20
Sublist 2. (Grammatical class × frequency × length; N = 80)	
Nouns	7/20
Adjectives	7/20
Verbs	7/20
Function words	9/20
High-frequency words	14/40
Low-frequency words	15/40
Short words	5/40
Long words	24/40
Nonwords	
Sublist 1. (Morphological decomposability; N = 40)	
Morphologically decomposable nonwords	10/20
Morphologically non-decomposable nonwords	11/20
Sublist 2. (Length; N = 60)	
Short nonwords	8/30
Long nonwords	16/30

is even more striking when the entire stimulus sample is considered. A monotonic (roughly linear) relationship exists between stimulus length, for both word and nonword stimuli, and number of spelling errors (see Table 3). This effect of stimulus length remains even when we scale the probability of an error on a word by the number of letters in that word.[2] Furthermore, the mean length of words spelled correctly (5.93 letters) is significantly shorter than the mean length of words spelled incorrectly (8 letters): t = 15.0 (741),

[2]Arbitrarily setting a word length of 4.5 letters as unity and scaling the probability of an error on a word by the discrepancy of word length from unity

$$\left(\frac{\text{probability of an error} \times 4.5}{\text{word length}}\right),$$

we obtained new (scaled) error probabilities for words and nonwords of different lengths. These are: 15.3%, 23.6%, 35.3%, and 36.7% for words of 4–5, 6–7, 8–9, and 10–12 letters long, respectively, and 27.4%, 35.3%, 39.4%, and 40.9% for nonwords of 4–5, 6–7, 8–9, and 10–12 letters long, respectively. As is quite apparent, more errors were made for longer words even when correcting for the number of letters in a word.

Table 3. *Spelling errors as a function of stimulus length produced by L.B. in various spelling tests (percentages are in parentheses)*

Stimulus length	Writing-to-dictation		Oral spelling		Written naming		Copy from a model		Delayed copy	
					Words					
4–5	37/242	(15.3)	4/16	(25.0)	9/36	(25.0)	2/16	(12.6)	2/15	(13.3)
6–7	90/264	(34.1)	11/16	(68.7)	14/33	(42.4)	2/29	(6.9)	9/23	(39.1)
8–9	100/150	(66.7)	13/16	(81.2)	23/34	(67.6)	1/12	(8.3)	10/21	(47.6)
10/12	78/87	(89.7)	16/16	(100)	19/21	(90.5)	—	—	—	—
Total	305/743	(41.0)	44/64	(68.7)	65/124	(52.4)	5/57	(8.8)	21/59	(35.6)
					Nonwords					
4–5	31/113	(27.4)	5/16	(31.2)	—		0/15	(0)	5/15	(33.3)
6–7	79/155	(51.0)	14/16	(87.5)	—		1/29	(3.5)	12/24	(50.0)
8–9	64/85	(75.3)	14/16	(87.5)	—		1/12	(8.3)	21/21	(100)
10/12	74/74	(100)	16/16	(100)	—		—	—	—	—
Total	246/425	(57.9)	49/64	(76.6)	—		2/56	(3.6)	38/60	(63.3)

$p < .001$. The analogous comparison for nonwords also showed a significant length effect (mean length of nonwords spelled correctly: 5.79; mean length of nonwords spelled incorrectly: 8.11; $t = 3.906$ (423), $p < .001$).

Although a detailed error analysis will be reported in a later section of the paper, we wish to note here that the spelling errors produced by L.B. took the form of substitution, insertion, deletion, or transposition of letters or combinations of these single error types.

(2) Oral spelling to dictation. L.B. was asked to spell orally 128 stimuli (64 words, 64 nonwords). Word and nonword stimuli were exactly matched in length, and ranged from 4 to 11 letters.

Performance on this test was poorer than performance on the written spelling task; L.B. incorrectly spelled 44/64 (68.7%) words and 49/64 (76.5%) nonwords. However, at a qualitative level the patient's performance is identical for the two tasks: There was a clear length effect (see Table 3) for both words (mean length of correctly spelled words: 5.43; mean length of incorrectly spelled words: 8.51; $t = 6.418$ (62), $p < .001$) and nonwords (mean length of correctly spelled nonwords: 5.13; mean length of incorrectly spelled nonwords: 8.22; $t = 8.22$ (62), $p < .001$). Furthermore, the same type of errors were produced in this task as in the written spelling task; that is, errors consisted of substitution, deletion, insertion and transposition of letters.

The overall level of performance obtained by our patient on this test must be interpreted very cautiously. It must be stressed that Italian speakers are totally unfamiliar with oral spelling. Oral spelling is not taught in school, and is never practiced in adult life—in fact, L.B. claimed that he had never orally spelled before we asked him to.[3] Thus, the discrepancy in overall level of performance between written and oral spelling should not be given undue importance. The primary value of the oral spelling performance is to rule out the hypothesis that L.B.'s dysgraphia results from selective damage to the Allographic Conversion Mechanism—a mechanism that converts graphemic representations into specific letter forms for graphomotor output (see Ellis, in press; Goodman & Caramazza, 1986).

(3) Written naming. L.B. was asked to write the names of 124 black-and-white pictures of objects. The target responses covered a wide frequency range, and varied in length from 4 to 12 letters.

The patient responded correctly to 56 stimuli (45.2%). He also produced 3 responses that, although orthographically correct, could be considered as visual-perceptual (i.e., misperception of the picture stimuli) or semantic errors (gallo (rooster) → gallina (chicken); cigno (swan) → oca (duck); ciliegia (cherry) → mela (apple)), and 65 orthographically incorrect responses. All but one of the errors consisted of substitution, insertion, deletion, or transposition of letters in the target response (39 (60%) errors) or combinations of two of these error types (25 (38.5%) errors). The only 'anomalous' error consisted of the written response 'fiscocima', produced for 'armonica' (harmonica)—presumably a combined semantic/spelling error ('fisarmonica' (accordion)). Errors were not influenced by frequency, but a highly significant length effect was observed (mean length of correctly written words: 6.13; mean length of incorrectly written words: 8.22; $t = 5.726$ (122), $p < .001$). The distribution of errors as a function of stimulus length is shown in Table 3.

(4) Copying tests. L.B. was asked to copy/transcode from upper to lower case words and nonwords under two conditions: copying with and without the model in view. In both tests, stimuli ranged from 4 to 9 letters in length. Words were drawn from all grammatical classes; half of the words were of high frequency, half were of low frequency. Nonwords were exactly matched in length to words.

[3]Italian has a highly transparent orthography which renders oral spelling unnecessary as a teaching strategy. Indeed, the translation of "spelling" into Italian is "scrivere" which means *written* spelling. For this reason, we even had difficulty finding words to describe the oral spelling task to our patient. We had to use words such as "scandire" (to parse) and locutions such as "dire a voce le lettere che compongono la parola" (say aloud the letters that comprise a word) to communicate the task requirements.

(a) Copying from a model. In this experimental condition, L.B. produced the response while freely looking at the stimulus, typed in large characters and left in view.

He made errors on 5/57 (8.8%) words and on 2/56 (3.6%) nonwords.[4] Lexical factors did not influence his performance, and no length effect was observed (words: $t = 0.601$ (55), $p =$ n.s.; nonwords: $t = 0.113$ (55), $p =$ n.s.). All the errors were close approximations to the target response, and always differed from it by one letter.

(b) Delayed copy. The patient was allowed to look at the stimulus for as long as he wished to, until he felt that he could reproduce it. At this point, he removed the stimulus and after 3 seconds had elapsed he would write his response.

L.B. incorrectly wrote 21/59 (35.6%) words and 38/60 (62.3%) nonwords (see Table 3). Neither grammatical class nor frequency affected word spelling performance. However, stimulus length significantly affected performance both for words (mean length of correctly reproduced words: 6.45; mean length of incorrectly reproduced words: 7.14; $t = 1.720$ (57), $p < .05$) and nonwords (mean length of correctly reproduced nonwords: 5.94; mean length of incorrectly reproduced nonwords: 7.30; $t = 4.511$ (58), $p < .001$). All incorrect responses to words were orthographically related to the target, deviating from target responses by the substitution, deletion, addition, or transposition of letters; that is, spelling errors were qualitatively identical to those produced in the dictation and naming tasks.

The overall pattern of results obtained for L.B., in the various spelling tasks, is consistent with the hypothesis of selective damage to the Graphemic Buffer in the proposed model of spelling. The patient's roughly comparable difficulty in oral and written spelling for words and nonwords rules out the hypotheses of selective damage to either the Allographic Conversion Mechanism or the Letter Name Conversion Mechanism; the presence of comparable spelling difficulties in written naming, delayed copy, and spelling to dictation rules out the hypothesis of selective damage to input mechanisms;

[4]This seemingly paradoxical result—more accurate performance (though not statistically so, $\chi^2 = 1.36$, $p < .30$) with nonwords than words in copying from a model—can be readily explained if one considers the constellation of symptoms shown by L.B. The patient has a reading deficit that impairs his ability to read nonwords, but spares his ability to read words (Caramazza et al., 1985). This deficit led the patient to use different strategies when copying words and nonwords. When copying a nonword stimulus, L.B. read it repeatedly and tended to reproduce it letter by letter, frequently checking his production with the printed stimulus; by contrast, in copying a word he would read it without effort and reproduced it quickly and confidently without checking his spelling response against the target stimulus. This difference in the strategies used to perform the copying task may account for the counterintuitive result obtained for this task.

furthermore, since none of the lexical factors manipulated in the spelling to dictation and copying tasks affected spelling performance, we can infer that the Graphemic Output Lexicon as well as other lexical components are intact in this patient. This configuration of spelling performance together with the fact that both words and nonwords were misspelled, that stimulus length was a major determinant of spelling performance, and that spelling errors were qualitatively identical across tasks and explicable in terms of degradation of graphemic representations, all point to a selective deficit to the Graphemic Buffer.

The one discordant note to the coherent story we have developed concerns the discrepancy in level of spelling performance for words and nonwords: Words were consistently spelled more accurately than nonwords. This difference in level of performance for words and nonwords is not predicted by the hypothesis of a selective deficit to the Graphemic Buffer which, instead, predicts comparable levels of difficulty for the two classes of stimuli. This prediction is motivated by the assumption that the Graphemic Buffer merely stores graphemic representations and, therefore, should be insensitive to lexical factors, including lexicality. Consequently, the consistent and sizeable differences in spelling performance for words and nonwords that have been obtained for L.B. suggest that either this assumption is wrong or that an additional, subtle deficit to some other mechanism is responsible for the patient's relatively poorer performance in spelling nonwords. Unfortunately, however, it has not been possible to obtain evidence to unequivocally distinguish between these two possibilities, although as we shall see shortly the latter possibility is the more likely one.

We should not neglect yet another possibility—that the hypothesis of a selective deficit to the Graphemic Buffer is false. However, the overall pattern of performance obtained for L.B. makes this last possibility quite unlikely, at least for the model of spelling proposed here. We have argued that the reported pattern of performance is most readily explicable by assuming a deficit to a post-lexical, centrally located mechanism that is involved in processing both familiar *and* novel words. In the model proposed in the Introduction the only mechanism that meets these requirements and is compatible with the obtained pattern of results is the Graphemic Buffer. Thus, if we are to reject the hypothesis of a selective deficit to the Graphemic Buffer we must turn to an alternative functional architecture of the spelling process.

Two alternative functional architectures of the spelling process, both of which reject the assumption that distinct mechanisms are involved in spelling familiar and novel words may be entertained. We have already briefly alluded to one such alternative: the lexical analogy model of spelling (e.g., Campbell,

1983) assumes that a single mechanism is responsible for generating graphemic representations of both familiar and novel words. The other "single-route" model of spelling capitalizes on an important feature of Italian orthography; namely, that Italian orthography is highly transparent. That is, sound-to-print mappings in Italian are almost perfectly predictable.[5] This property of Italian orthography suggests the possibility that spelling familiar and novel Italian words may be accomplished by converting phonological representations (*both* lexical and nonlexical) into graphemic representations through the application of phoneme-grapheme conversion rules (Miceli et al., 1985). Even though there is recent evidence (Caramazza et al., 1986) which disconfirms a strong version of this hypothesis, the possibility remains that because of the transparency of Italian orthography *some* speakers of the language may rely on the Phoneme–Grapheme Conversion Mechanism in spelling familiar and novel words. For this reason we thought it necessary to attempt to rule out the possibility that L.B.'s spelling difficulties arise from selective damage to either the Phonological Buffer or the Phoneme–Grapheme Conversion Mechanism in this type of 'single-route' model—mechanisms which if damaged could give rise to the constellation of symptoms thus far reported for our patient. To this end, we administered to L.B. several repetition and spelling tests.

(1) Spelling CV syllables to dictation. In order to rule out damage to the Phoneme–Grapheme Conversion Mechanism, L.B. was asked to spell to dictation 20 meaningless CV syllables. Each stimulus was repeated five times and the whole list of 100 syllables was presented in random order. L.B. performed this test flawlessly. If the Phoneme–Grapheme Conversion Mechanism were damaged in this patient, he should have produced spelling errors in this task. The results indicate that L.B. has an intact Phoneme–Grapheme Conversion Mechanism.

(2) Spelling words with ambiguous phoneme–grapheme mappings. Although Italian orthography is virtually totally transparent there are a few words in the language that contain ambiguous sound-to-print mappings. For example, the word /kwɔkɔ/ (chef) could be spelled as 'cuoco' or 'quoco' by

[5]The regularity of print-to-sound mappings in Italian is almost perfect. There are, however, a few words in the language that contain phonologically ambiguous segments and, therefore, their correct spelling cannot simply be determined by phoneme–grapheme conversion rules. For example, the correct spelling of the phoneme /k/ in the stimulus /kwɔcɔ/ (cuoco = cook) and in the stimulus /kwɔtə/ (quota = share or quote) is lexically determined, as is the spelling of the segment /č/ in /nɔče/ (walnut) and /speče/ (species)—compare *c*uoco vs. *q*uota, and no*c*e vs. spe*c*ie. However, in Italian there are no truly unpredictable spellings, such as /jɑt/ 'yacht' in English.

the application of phoneme–grapheme conversion rules, but only the former spelling is a word in Italian. If L.B. is relying on the Phoneme–Grapheme Conversion Mechanism to spell words, then we expect him to make a significant number of phonologically plausible errors in spelling such words.

L.B. was asked to spell to dictation a list of 80 words; forty words contained ambiguous phoneme-grapheme segments, the other forty words were completely unambiguous. The two sets of words were matched for frequency and length. The patient made 23/40 (57.5%) errors for the ambiguous words and 21/40 (52.5%) errors for the unambiguous words. Only one error for the ambiguous words could be scored as phonologically plausible—he wrote 'squotere' for 'scuotere' (to shake). The remaining errors were qualitatively identical to those he produced for unambiguous words and consisted of substitutions, additions, deletions, and transposition of letters. The performance obtained by L.B. on this task, in terms of proportion of phonologically plausible errors, is comparable to that obtained by 8 matched controls who produced two or three phonologically plausible errors in spelling the ambiguous words. We can conclude, therefore, that L.B. is *not* using phoneme–grapheme conversion rules to spell words.

(3) Repetition of words and nonwords. In order to evaluate the possibility of damage to the Phonological Buffer the patient was asked to repeat single words and nonwords. Seventy-two stimuli of each type were presented in random order. The stimuli ranged in length from 4 to 12 phonemes. L.B. repeated all words flawlessly and made three errors on nonwords (4.2%). If the spelling difficulties encountered by our patient arose from damage to the Phonological Buffer, we would have expected our patient to present with difficulties in repetition (especially for nonwords) *comparable* to those he presents in spelling (see Caramazza et al., 1986, for discussion on this issue).

(4) Spelling and repetition of words and nonwords. L.B. was asked to spell to dictation a list of words and nonwords ranging in length from 4 to 11 letters. The words and nonwords were intermixed and presented in random order. The patient was instructed to first spell the auditorily presented stimulus and immediately upon completion of that task to repeat the presented stimulus. L.B.'s performance on this task is shown in Table 4. As in previous tasks, the patient produced spelling errors for words and nonwords. A striking effect of stimulus length was again present—longer stimuli being much more difficult to spell than shorter stimuli. The important result here, however, is the marked dissociation between spelling and repetition performance; repetition is essentially intact while spelling is severely impaired. Obviously, L.B.'s spelling difficulty cannot be attributed to an impairment

Table 4. *Spelling and repetition errors in response to auditorily presented word and nonword stimuli (percentages are in parentheses)*

	Words				Nonwords			
Stimulus length (in letters)	Spelling		Repetition		Spelling		Repetition	
4–5	1/16	(6.3)	0/16	(0)	6/16	(37.5)	0/16	(0)
6–7	10/16	(62.5)	0/16	(0)	8/16	(50.0)	2/16	(12.5)
8–9	16/16	(100)	0/16	(0)	15/16	(93.8)	5/16	(31.3)
10–11	16/16	(100)	0/16	(0)	15/16	(93.8)	4/16	(25.0)
Total	43/64	(67.0)	0/64	(0)	44/64	(68.8)	11/64	(17.2)

to the Phonological Buffer or other phonological processes since, as revealed by repetition performance, these processes are relatively intact in this patient.

The results reported in this section of the paper argue against the hypothesis that L.B.'s spelling difficulties are due to a deficit to the Phoneme–Grapheme Conversion Mechanism or to the Phonological Buffer. The repetition results suggest, however, that L.B. has a subtle phonological processing deficit that affects his performance in processing nonwords. The precise nature of this deficit has not been determined but, whatever its source, it is likely to be the basis for the discrepancy in overall error rate in spelling familiar and novel words. Finally, whether or not L.B.'s pattern of performance can be accommodated within a Lexical Analogy Model is not clear; this latter possibility can only be evaluated against a more articulated view of this type of model of the spelling process than is currently available in the literature.

3.2. Error analysis

Our analysis of L.B.'s spelling difficulties has focused, thus far, on gross features of performance: We have considered the distribution of errors as a function of stimulus length and type of task. We have argued that the configuration of results obtained is consistent with the hypothesis of damage to the Graphemic Buffer in the proposed model of spelling. A consideration of the *type* of spelling errors produced by L.B. reinforces this conclusion and provides a data base for speculation about the structure of the Graphemic Buffer. For this purpose we analyzed the total corpus of errors produced by L.B. in the written spelling-to-dictation task. This corpus consists of 305 and 204 errors produced in spelling words and nonwords, respectively.

The functional role assigned to the Graphemic Buffer in the proposed model of spelling is sufficiently explicit to permit predictions about the type and distribution of spelling errors that are expected to result from damage to this processing component. The predictions are primarily qualitative in nature, but not the less important for this. These predictions are evaluated in this section.

A critical prediction concerns the type and distribution of errors that are expected to result for words and nonwords as a consequence of damage to the Graphemic Buffer. The role of the Graphemic Buffer is to store graphemic representations temporarily in preparation for conversion into letter names (oral spelling) or specific letter shapes (written spelling). Representations for words and nonwords are indistinguishable at this level of the cognitive system—they are merely spatially coded strings of graphemic units. Therefore, damage to this processing component should lead to the *same* type and distribution of errors for the two classes of stimuli. Furthermore, since the form of representations held in the Graphemic Buffer consists of graphemic units, damage to this system should result in degradation of graphemic representations; that is, in substitution, deletion, addition, and transposition of graphemic units. The behavioral manifestation of these degradations of graphemic representations should be the substitution, deletion, addition, and transposition of letters. These expectations were borne out by our analyses of L.B.'s performance in the written spelling to dictation task.

The total corpus of errors, for word and nonword stimuli, produced by L.B. in the written spelling to dictation task were classified into one of the following error categories: substitution, deletion, addition, or transposition of letters. Since each response might contain more than a single error, we distinguished between responses that contained single errors, responses with multiple errors of the same type (e.g., two substitution errors), and mixed errors (i.e., responses containing at least two errors of different type, e.g., a substitution and a deletion error). Some errors could not be classified by this scheme and were scored as unclassifiable. Examples of each of these types of errors are shown in Table 5.

The distribution of single, multiple, mixed, and unclassifiable errors for word and nonword stimuli as a function of stimulus length are shown in Table 6. As can readily be seen, only a relatively small proportion of errors could not be classified (7.5% and 16.5% of words and nonwords, respectively).

Two aspects of these data are worth stressing. First, and most important, the distribution of error types for words and nonwords is remarkably similar, not only when we consider overall percentage of each error type but also when we consider the distribution of error types as a function of stimulus length. The striking similarity in distribution of error types for words and

Table 5. *Examples of the various error types produced by L.B.*

(1)	*Single errors*		
	Substitutions	giovane (young) → giogane	femasto → femanto
	Insertions	violento (violent) → violeneto	tenomato → tentomato
	Deletions	semplice (single) → sempice	mansote → masote
	Transpositions	recenti (recent) → renceti	serepa → resepa
(2)	*Multiple errors*		
	Substitutions	passare (to pass) → rasiare	arguage → arguece
	Insertions	amerai (you will love) → amerirai	none
	Deletions	raccontare (to tell) → racconae	altiande → atinde
	Transpositions	none	none
(3)	*Mixed errors*		
	Subst. + Insert.	signora (lady) → signiona	esentute → esensunte
	Subst. + Delet.	provvedo (I take care of) → povveto	ondaso → adaso
	Subst. + Transp.	discreto (discreet) → disrteto	imieto → iemeto
	Insert. + Delet.	finestre (windows) → frinetre	none
	Insert. + Transp.	concime (manure) → comicine	none
	Delet. + Transp.	davanti (dread) → danati	fralte → flate
(4)	*Unclassifiable errors*		
		decaduto (decayed) → sedecuto	gotadepo → gattepo
		fradicio (soaking) → friagio	toglieri → terlele

Table 6. *Distribution of Single, Multiple, Mixed and Unclassifiable Errors as a function of stimulus length for words and nonwords (percentages are in parentheses)*

Stimulus length	Single	Multiple	Mixed	Unclassifiable	Total
		Words			
4–5	34 (91.9)	—	3 (8.1)	—	37
6–7	54 (60.0)	6 (6.7)	30 (33.3)	—	90
8–9	54 (54.0)	7 (7.0)	31 (31.0)	8 (8.0)	100
10–12	8 (10.3)	15 (19.2)	40 (51.3)	15 (19.2)	78
Total	150 (49.2)	28 (9.2)	104 (34.1)	23 (7.5)	305
		Nonwords			
4–5	27 (87.1)	—	4 (12.9)	—	31
6–7	46 (58.2)	3 (3.8)	22 (27.8)	8 (10.1)	79
8–9	16 (25.0)	11 (17.2)	25 (39.1)	12 (18.7)	64
10–12	2 (2.7)	9 (12.2)	42 (56.8)	21 (28.4)	74
Total	91 (36.7)	23 (9.3)	93 (37.5)	41 (16.5)	248

Table 7. *Distribution of substitution, insertion, deletion and transposition errors in writing words and nonwords to dictation (percentages are in parentheses)*

	Words		Nonwords	
Substitutions	65	(36.5)	41	(36.0)
Insertions	14	(7.9)	10	(8.8)
Deletions	61	(34.3)	42	(36.8)
Transpositions	38	(21.3)	21	(18.4)
Total	178		114	

nonwords is consistent with the hypothesis that the patient's difficulties in spelling words and nonwords have a common source. The other aspect of these data worth noting is the distribution of Single versus Mixed and Unclassifiable errors as a function of stimulus length (for both words and nonwords): Single errors predominantly occur for short stimuli; Mixed and Unclassifiable errors mostly occur for long stimuli. This result suggests that the degradation of graphemic representations in our patient are more severe for longer than shorter stimuli, as might be expected if the Graphemic Buffer were damaged.

A finer-grained analysis of the distribution of error types for words and nonwords provides even stronger evidence that the spelling difficulties encountered by L.B. for these two classes of stimuli have a common source. For this analysis we considered only Single and Multiple errors, which were combined to make a set of 178 errors for words and a set of 114 errors for nonwords. The distributions of substitution, insertion, deletion, and transposition errors for words and nonwords are shown in Table 7. The two distributions are virtually identical[6] and remain highly similar even when error types are presented as a function of stimulus length (see Table 8). Worthy of special note in this latter Table is the contrasting pattern of deletion and transposition errors as a function of stimulus length. It is quite clear that deletions increase as a function of stimulus length while transpositions have the opposite pat-

[6]The hypothesis being evaluated here predicts a similar pattern of error distribution for words and nonwords in the oral spelling task. We did not have a large enough corpus of errors on this task for detailed analysis due in part to the fact that oral spelling is a strange task in Italian and our patient was unwilling to be tested extensively on this task. Nonetheless, even with the limited data at our disposal the distribution of errors for words and nonwords is consistent with theoretical expectations. The distribution of errors for words and nonwords was as follows: Words—5 (27.8%) substitutions, 1 (5.5%) insertions, 9 (50.0%) deletions, 3 (16.7%) transpositions; Nonwords—7 (24.6%) substitutions, 0 insertions, 18 (69.2%) deletions, 1 (7.2%) transpositions.

Table 8. *Distribution of the various error types as a function of stimulus length (percentages are in parentheses)*

Stimulus length	Substitutions		Insertions		Deletions		Transpositions		Total
				Words					
4–5	10	(29.4)	2	(5.9)	2	(5.9)	20	(58.8)	34
6–7	29	(49.1)	3	(3.4)	15	(25.4)	13	(22.0)	60
8–9	22	(36.1)	7	(11.5)	27	(44.3)	5	(8.2)	61
10–12	4	(18.2)	2	(4.5)	17	(77.3)	—		23
Total	65	(36.5)	14	(7.9)	61	(34.3)	38	(21.3)	178
				Nonwords					
4–5	10	(37.0)	5	(18.5)	—		12	(44.4)	27
6–7	19	(38.8)	2	(4.1)	20	(40.8)	8	(16.3)	49
8–9	8	(29.6)	2	(7.4)	16	(59.3)	1	(3.7)	27
10–12	4	(36.4)	1	(9.1)	6	(54.5)	—		11
Total	41	(36.0)	10	(8.8)	42	(36.8)	21	(18.4)	114

tern. These contrasting patterns, once again, suggest that the degradation of graphemic representations is much greater for longer than shorter stimuli. Thus, for long stimuli, errors frequently take the form of deletions presumably because their graphemic representation is so deformed as to be unusable for guiding the selection of specific letter forms. Contrastively, transposition errors can only occur when the graphemic representation is sufficiently spared to contain information about specific graphemes even if their respective order is not retained. Thus, this latter error type is only likely to occur for short stimuli.[7]

Other aspects of the error data are also consistent with the hypothesis of a selective deficit to the Graphemic Buffer. Since the hypothesized deficit is to a post-lexical mechanism, we do not expect errors to be sensitive to lexical dimensions such as grammatical class, for example. This is indeed the case as already noted. Furthermore, however, neither do we expect errors to result in word responses (e.g., producing 'chair' for 'chain' or 'chair' for 'table', or 'chairs' for 'chair', respectively visual/phonological, semantic, and morphological errors). L.B. produced only one response (1/305) that could

[7]Tim Shallice has drawn our attention to the fact that if we wish to maintain that the reason for the higher level of errors for nonwords results from an additonal deficit to the processing mechanisms involved in processing nonwords, then we should not expect to have such a close correspondence in the distribution of error types for words and nonwords. If this observation is correct, we are forced to reconsider the assumption that the Graphemic Buffer is insensitive to lexicality. However, we remain unclear as to how lexicality exerts its effects at the level of the Graphemic Buffer.

Table 9. *Incidence of incorrect word responses as a function of stimulus length for word and nonword stimuli (percentages are in parentheses)*

Stimulus length	Words		Nonwords	
4–5	6/37	(16.2)	3/31	(9.7)
6–7	8/90	(8.9)	7/79	(8.9)
8–9	2/100	(2.0)	2/64	(3.1)
10–12	0/78	(0)	0/74	(0)
Total	16/305	(5.7)	12/248	(4.8)

be construed as a morphological error—he spelled 'gioco' (I play) for 'gioca' (he plays)—and no semantic errors. He did produce a few word errors both in response to word (16/305 (5.7%)) and nonword (12/248 (4.8%)) stimuli. The distribution of these errors for words and nonwords as a function of stimulus length is shown in Table 9. We note that the very few errors produced are more likely to occur for shorter than longer stimuli and that most (20/28) of these error responses differed from target responses by only one letter. These observations suggest that word errors were most likely chance occurrences that resulted when a letter substitution error occurred, and not lexically induced errors.

Finally, if the spelling errors produced by L.B. reflect degradation of graphemic representations that result from damage to the Graphemic Buffer, we expect that a fair number of these errors should result in violations of orthographic constraints of Italian (e.g., tempo → tempto*; ultimo → utmilmo*). In the total corpus of errors under consideration, 57 of the errors (10.3%) contained at least one violation of Italian orthography. The distribution of errors containing violations of orthographic rules for word and nonword stimuli is shown in Table 10. The occurrence of violations of orthographic rules can be taken as further support for the hypothesis that L.B.'s spelling deficit results from damage to the Graphemic buffer.[8]

The analyses of the type and distribution of errors we have undertaken thus far have focused on two factors: lexicality (word vs. nonword) and stimulus length. There is, however, another stimulus dimension that has been proposed as being relevant to considerations of the processing structure of the Graphemic Buffer—letter position within a word (or nonword). Wing

[8]It should be noted that although violations of orthographic rules are not a common feature of 'slips of the pen' this does not mean that normal 'slips of the pen' may not (in some cases) reflect processing errors at the level of the Graphemic Buffer. The errors produced by our patient occur in the context of a severe limitation of processing capacity of the Graphemic Buffer presumably resulting in a grossly degraded graphemic representation while for normal spellers the graphemic representation is, by definition, unimpaired.

Table 10. *Incidence of incorrect responses containing violations of orthographic rules (percentages are in parentheses)*

Stimulus length	Words		Nonwords	
4–5	3/34	(8.8)	5/31	(16.1)
6–7	7/90	(7.8)	6/79	(7.6)
8–9	14/100	(14.0)	4/64	(6.2)
10–12	7/78	(9.0)	12/74	(16.2)
Total	31/305	(10.2)	27/248	(10.9)

and Baddeley (1980) have suggested that a source of spelling errors, at least for normal spellers, involves 'read-out' failure from the Graphemic Buffer. Specifically, they have proposed that 'read-out' errors from the Graphemic Buffer are more likely to occur for the medial positions of a word than for the flanking positions (both initial and final). The primary impetus for this proposal was the observation that 'slips of the pen' occur more frequently for medial than flanking positions. Unfortunately, however, the proposal of a 'read-out' failure from the Graphemic Buffer is not computationally motivated but is derived instead by analogy to read-out limitations from a visual array in perceptual recognition experiments. That is, it is not obvious what computational characteristic of the Graphemic Buffer might serve to motivate the speculation that medial positions of the graphemic representations stored in this system should be relatively inaccessible. Nonetheless, this intuitively derived property of the Graphemic Buffer can be subjected to test by considering the positional distribution of errors produced by our patient.

The reasoning underlying our contention that L.B.'s spelling performance can serve as a test of the proposal that 'read-out' from the Graphemic Buffer is relatively less accurate from medial than flanking positions is based on two assumptions: that the patient has a selective deficit to the Graphemic Buffer and that this deficit takes the form of a reduction in capacity or processing efficiency of the Graphemic Buffer. If these assumptions are correct and the proposal of relatively inefficient 'read-out' from the Graphemic Buffer for medial positions of a graphemic representation is true, then L.B. should present with a higher incidence of errors for medial than flanking positions for words and nonwords. This complex hypothesis was evaluated by analyzing the distribution of 'single' errors produced by L.B. in the written spelling-to-dictation task.

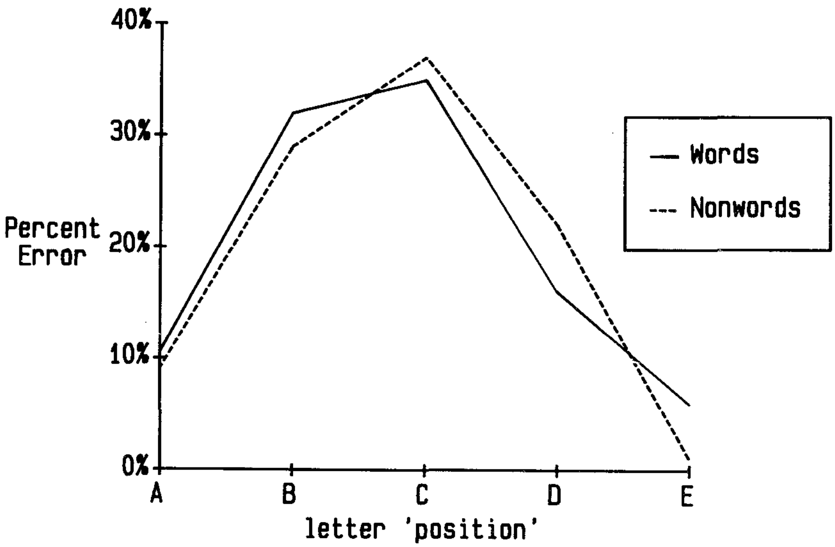
Since stimuli varied in length we used a procedure proposed by Wing and Baddeley to 'normalize' the distribution of errors across all stimulus length.

Table 11. *Number of letters assigned to each stimulus position for the analysis of letter position effect*

Stimulus length	A	B	C	D	E
5	1	2	3	4	5
6	1	2	3–4	5	6
7	1	2–3	4	5–6	7
8	1–2	3	4–5	6	7–8
9	1–2	3–4	5	6–7	8–9
10	1–2	3–4	5–6	7–8	9–10
11	1–2	3–4	5–6–7	8–9	10–11
12	1–2	3–4–5	6–7	8–9–10	11–12

That is, we collapsed performance for stimuli of different lengths into a single, arbitrary stimulus length. In this procedure, each stimulus is divided into five letter 'positions' (four-letter stimuli were excluded from analysis). Each 'position' contains one or more letters, depending on the number of letters that, for each stimulus, exceed 5 or multiples of 5. The letters in excess are distributed across the 5 'positions' so as to maintain a symmetrical structure in the arbitrarily reconstructed stimulus. Table 11 shows the number of letters as-

Figure 2. *Distribution of errors as a function of letter 'position' in a letter string.*



signed to each 'position' for stimuli of various lengths. Using this procedure we were able to include in the analysis 207 word and 146 nonword errors.

The distribution of errors for words and nonwords as a function of letter 'position' in a stimulus is depicted in Figure 2. The results are striking in two regards: First, the two distributions of errors are virtually identical; and, second, the bow-shaped function predicted on the basis of Wing and Baddeley's proposal about the 'read-out' limitation from the Graphemic Buffer is clearly supported. Thus, it would appear that a property of the Graphemic Buffer is that information from this system is not homogeneously accessible but, instead, medially located graphemes are 'read-out' less efficiently than flanking graphemes.

4. Conclusion

The pattern of results we have reported allows us to determine the locus of damage to the proposed functional architecture of the spelling system. The virtually identical distribution of errors for words and nonwords implies that damage to a *single* mechanism is responsible for L.B.'s spelling difficulties for the two classes of stimuli. Furthermore, since we were able to rule out deficits to shared input or output mechanisms as the locus of damage, and since the types of errors produced are most reasonably explicated by reference to the degradation of graphemic representations, we must locate the source of damage to the Graphemic Buffer. Consequently, we are justified in considering the results of this analysis as support for the proposed model of spelling: We assume that a pattern of impaired performance constitutes evidence in support of a model of a cognitive system (over alternative formulations) if it is possible to explain the observed pattern of impairment by hypothesizing a functional lesion(s) to the proposed model.

The degree of confidence we have in a model depends on various factors. A critical one is the extent to which the model allows us to make sense of progressively finer details of relevant performance, presumably because it becomes increasingly more difficult to construct alternative explanations for richly articulated sets of observations. To state this point differently, the degree of detail of performance we are able to account for depends on the richness of detail of our theories of cognitive systems. If we are content to remain at the level of functional architecture without specifying the algorithmic content of postulated components of a model we must be content with explanations of relatively gross features of performance. Thus, for example, a particular model may allow predictions about whether or not spelling performance for familiar and novel words may dissociate, but remain completely silent about the particular types of spelling errors that are expected when the predicted dissociation obtains. In such a case the existence of two patients, both of whom present with a specific dissociation but a different pattern of error types, would be uninformative with respect to such a model. In order to make sense of this latter set of observations the model must be articulated in greater detail, perhaps at the level of specifying the algorithmic content of hypothesized components of the model. It is obvious that this effort may fail, and, thereby, undermine our confidence in the model. Thus, concern for the details of performance is not a luxury we can afford to do without.

What are the implications of this argument for the case under consideration? Under ideal conditions we would have been able to articulate in some detail the computational structure of the Graphemic Buffer. This would have allowed a theoretically motivated account of the relevant details of our patient's performance—that is, we would have been able to make explicit links between such features of the patient's performance and the distribution of error types (e.g., substitution errors) and processing features of the Graphemic Buffer. Unfortunately, as we have noted, we are far from being able to do so. Instead we relied on an intuitive characterization of the processing structure of the Graphemic Buffer to guide our analysis of the patient's performance. In this regard, we exploited the notion of graphemic degradation, a vague one to be sure, to predict the qualitative nature of the expected error types in the case where the Graphemic Buffer is selectively damaged. Thus, although our account of the algorithmic content of the Graphemic Buffer remains unpleasantly underspecified, we have, nonetheless, provided a general framework within which to begin serious discussion of the structure of this component of the spelling system.

We also provided support for an empirical generalization about a feature of the processing structure of the Graphemic Buffer which does not, at this time, have an explicit theoretical justification. Wing and Baddeley (1980) have proposed that a property of the Graphemic Buffer is that it has a 'read-out' procedure which is characterized by nonhomogeneous accessibility of the graphemic string stored in the system. Specifically, they suggested that there is interference between adjacent graphemic units in the Buffer and that, therefore, the medial graphemes in a string will be relatively inaccessible. No clear theoretical justification is provided for this claim. Nonetheless, they report 'slips of the pen' data which are characterized by a bow-shaped function, with a higher incidence of errors in the medial positions. We evaluated the hypothesis of nonhomogeneous accessibility of graphemes from the Graphemic Buffer through an analysis of the effect of letter position on the distribution of errors produced by L.B. We obtained clear evidence in support of the stated hypothesis. In other words, we have provided evidence which empirically, though not yet theoretically, links the bow-shaped function of errors for letter positions in a word to some processing aspect of the Graphemic Buffer.

To conclude, the analysis of L.B.'s spelling performance has provided support for the functional architecture of the spelling system proposed in the Introduction of this paper. Equally, if not more importantly, we have provided evidence in support of some intuitively and empirically driven hypotheses about the computational structure of the Graphemic Buffer.

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Résumé

Cet article décrit un cas de dysgraphie pour lequel nous postulons une lésion sélective de la mémoire-tampon graphémique. Les difficultés analogues que rencontre le patient pour l'orthographe orale et écrite et les difficultés d'orthographe comparables qu'il rencontre pour la dénomination écrite, la copie avec temps de latence et l'écriture sous dictée interdisent de penser qu'il y a eu lésion sélective des mécanismes d'input ou d'output. Plus important, la nature des erreurs du patient et le fait que la distribution de ces erreurs est virtuellement identique pour les mots familiers et les mots nouveaux, nous semble démontrer que les troubles de L.B. résultent d'une lésion sélective de la mémoire-tampon graphémique. Divers aspects de la performance du patient sont analysés par rapport à l'architecture fonctionnelle du processus d'orthographe et en termes de la structure de la mémoire-tampon graphémique.