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The Role of the Graphemic Buffer in Reading

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We report the reading performance of an acquired dyslexic and dysgraphic whose impaired spelling had previously been shown to result from damage to the graphemic buffer. The analysis of this patient's errors in reading pseudowords indicates that this deficit may also be largely attributable to damage to a common graphemic buffer which is used both in reading and spelling words and pseudowords. The crucial evidence in favour of this hypothesis is the substantial presence of letter transposition errors in reading and spelling.

INTRODUCTION

On one point there is wide agreement among theoretical accounts of the processes that underlie our abilities to read and to spell: Both tasks are assumed to involve the computation of a representation that specifies the sequence of graphemes or abstract letter identities that comprise the to-be-read or to-be-spelled word. Thus, for example, it is typically assumed that early processes of the reading system abstract away from the details of the visual stimulus to compute a graphemic representation (or abstract letter identities) that serves as input to the lexical-orthographic recognition system (e.g. Adams, 1979; Besner, 1983; Caramazza & Hillis, 1990; Coltheart, 1981; McClelland & Rumelhart, 1981; Monsell, 1987; Rayner & Pollatsek, 1987; Saffran, 1980). And, in the case of spelling, it is assumed that a graphemic representation—

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which is either accessed from the orthographic (output) lexicon or assembled from a sublexical phonology-to-orthography conversion procedure—serves as input to more peripheral processes for oral or written spelling (Caramazza, Miceli, Villa, & Romani, 1987; Ellis, 1988; Houghton, Glasspool, & Shallice, 1994; Kay & Hanley, 1994; Margolin, 1984; Wing & Baddeley, 1980). To be sure, there remain important theoretical disagreements concerning the structure and organisation of graphemic representations, but these will not be pursued here (for different hypotheses about the structure of graphemic representations in spelling see Caramazza & Miceli, 1989, 1990; Cubelli, 1991; Jonsdottir, Shallice, & Wise, in press; Kay & Hanley, 1994; McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994; Tainturier & Caramazza, in press; and for reading see Prinzmetal & Millis-Wright, 1984; Rapp, 1992; Seidenberg, 1987; Treiman & Chafetz, 1987). Instead, we will be concerned with the relatively general issue of the role of graphemic representations in reading and spelling, side-stepping the thornier question of the exact nature of these representations. For present purposes, it will be enough to assume that graphemic representations specify, among other properties, the identity and the order of the graphemes that comprise the spelling of the visual stimulus to be recognised or of the word to be spelled. We will further assume that these representations are temporarily held in a buffer[1]—the graphemic buffer—in preparation for subsequent processes. In this report, we explore the role of the graphemic buffer in reading through the analysis of the performance of an acquired dyslexic/dysgraphic.

A number of recent studies of patients with acquired cognitive disorders have provided evidence concerning the role of the graphemic buffer in

[1]A buffer component in a cognitive architecture has typically been understood to be a type of working memory storage system—a storage space of limited capacity in which information is temporarily held in preparation for further processing (e.g. the visuo-spatial sketchpad or the articulatory loop; for discussion see Baddeley, 1986). However, we could also think of buffer components as the temporary activation functions of representations at specific levels of processing. In the latter case, there is no assumption about a separate storage space in which representations are temporarily held (see Monsell, 1984, for discussion of this alternative view). Thus, we could assume that once a representation has been activated (or computed), it remains active for a brief period of time during which it can be used by other processing mechanisms. For example, we can think of the lexical-graphemic representation activated in the course of spelling a word as remaining temporarily active while allographic procedures are applied sequentially to compute the visuo-motor patterns that are used to guide writing processes. Similarly, in spelling pseudowords, we could assume that the graphemic patterns computed by the phonology-to-orthography conversion procedures remain temporarily active in preparation for subsequent, more peripheral processes. A similar set of arguments could be offered for reading. Here we will not distinguish between these two possible interpretations of the graphemic buffer.

spelling (Caramazza et al., 1987; Hillis & Caramazza, 1989; Jonsdottir et al., in press; Katz, 1991; Kay & Hanley, 1994; McCloskey et al., 1994; Miceli, Silveri, & Caramazza, 1985; Piccirilli, Petrillo, & Poli, 1992; Posteraro, Zinelli, & Mazzucchi, 1988). Two sets of issues have been addressed: (1) the patterns of co-occurrence of impairments across spelling tasks, and (2) the patterns of error types. Since the function of the buffer is to hold temporarily the graphemic representations computed by the lexical or sublexical phonology-to-orthography conversion components in preparation for subsequent, more peripheral spelling processes (e.g. allographic conversion), damage at this level of the system should affect all spelling tasks and all types of stimuli equally[2]. Thus, the same types of errors should be produced across all spelling tasks and all types of stimuli. Furthermore, damage to the graphemic buffer should result in the loss of graphemic information and, consequently, should lead to errors characterised by orthographic deviation from the target response (and should not be explicable by appeal to lexical, semantic, or phonological principles). As already noted, a number of patients have been reported whose performance has been used not only to support the hypothesised role of the graphemic buffer in spelling but also as the basis for articulating specific hypotheses about the structure of graphemic representations in spelling.

Two types of issues arise if we assume that in reading, as in spelling, one stage of processing involves the computation of a graphemic representation that is temporarily held in a buffer in preparation for subsequent processes. One set of issues concerns the kind of consequences for reading performance that are expected to follow from damage to the graphemic buffer. For example, should lexical status (word vs. pseudoword) affect reading performance? What kinds of errors are expected to occur? Are different error types expected for different types of stimuli? And so on and so forth. The other major issue concerns whether the hypothesised graphemic buffer involved in reading is the same or a different mechanism from the one implicated in the spelling process. Thus, for example, we could ask whether patients with putative damage to the graphemic buffer in spelling are also necessarily impaired in reading.

One possibility is that the graphemic representations computed in reading and in spelling are held in a common buffer and that, therefore, damage at the level of this common mechanism would impair performance

[2]By contrast, selective damage to any other component should result in a dissociation in performance between spelling tasks or types of stimuli; for example, damage to the allographic conversion mechanism should result in impaired writing performance in the context of spared ability to spell orally.

in both tasks[3]. However, the specific forms that the impairments would take in reading and in spelling should differ because of the different roles graphemic representations play in the two tasks. In spelling, graphemic representations serve as input to processes for the *serial* conversion of individual graphemes into modality-specific forms for output—letter names in oral spelling and letter shapes in written spelling. By contrast, in reading, graphemic representations serve as input to word recognition processes that are applied in *parallel* over the entire graphemic string. If damage to the buffer were to interact differently with those processes that involve serial (spelling) from those that involve parallel processing (reading) of the graphemes held in the buffer, we would expect damage to this mechanism to have different consequences for reading and for spelling (to be discussed later).

Support for the hypothesis that a common graphemic buffer is used in reading and in spelling comes from the performance of NG (Caramazza & Hillis, 1990). The patient showed neglect for the right half of visually presented words (and objects) following damage to the left parietal white matter and the left anterior basal ganglia. Of particular relevance is the fact that in reading she systematically made errors on the right halves of words, irrespective of their length and of their topographic arrangement (horizontal, vertical, or mirror-reversed). Thus, for example, she read the horizontally presented stimulus *hound* as "house," she read the vertically presented stimulus *vivid* as "vivian," and she read the mirror-reversed stimulus *common* as "comet[4]." The fact that NG's reading performance remained invariant under topographic transformations of the stimuli implies a deficit in processing at a level of representation that has abstracted away from the physical details of the stimulus. This and other properties of NG's performance were taken as evidence for the hypothesis that her impairment arose from damage at a level of processing at which graphemic information is represented—the graphemic buffer.

Consistent with the view that a common graphemic buffer is used in reading and in spelling, it was also found that NG made spelling errors on the right halves of words irrespective of their length and of the modality

[3]The contrast between a single versus distinct input and output graphemic buffers for reading and spelling is analogous to the contrast between a single vs. separate input and output orthographic lexicons (on the latter contrast see Allport & Funnell, 1981; Coltheart & Funnell, 1987). However, the two issues are orthogonal: Whatever we decide for the graphemic buffer will have no consequence for the organisation of the lexical system.

[4]The following conventions are observed throughout this paper. Written stimuli and written responses are reported in italics. Auditorially presented and orally produced words are in quotation marks. Oral pseudowords are transcribed phonetically, and are reported between slanted lines.

(written or oral spelling) and order (forward or backward spelling) of output. Thus, for example, she orally spelled "career" as c-a-r-r-e-d and wrote "sneeze" as *sneed*; in backward spelling she produced i-s-b-r-a-g (garbsi) for the stimulus "garbage." In addition, NG's spelling performance was mostly unaffected by lexical status (word vs. pseudoword) and lexical factors such as frequency, grammatical class, and concreteness; and her spelling errors principally consisted of deletions, additions, and substitutions of letters. These features of NG's spelling performance are consistent with the hypothesis that her impairment in spelling is the result of a spatially-specific deficit in processing information at the level of the graphemic buffer. Furthermore, the fact that qualitatively similar patterns of deficits were observed in reading and in spelling—in both cases a spatially-specific deficit in processing graphemic representations—invites the hypothesis that a common graphemic buffer is implicated in these two tasks.

Not all aspects of NG's spelling performance were qualitatively or quantitatively similar to her reading performance. In fact, there were important differences in performance between the two tasks. Thus, in spelling NG was roughly equally accurate in responding to words (33%) and pseudowords (21%), but in reading she responded far more accurately to words (89.3%) than to pseudowords (29.4%). And in terms of error types, NG's spelling errors to both word and pseudoword targets resulted in orthographically related pseudowords (e.g. "jury" → *jurd*; "skart" → *skarr*), but in reading most of her errors to both words and pseudowords were visually similar word responses that differed from the stimulus only on the right half (e.g. *humid* → "human"; *aftes* → "after").

As anticipated, the observed differences in NG's performance in reading and spelling can be accounted for by the different roles played by the graphemic buffer in the two tasks. In reading, but not in spelling, the graphemic representation held in the buffer is processed in parallel to activate stored lexical representations. Thus, NG read words better than pseudowords because even though she could not process the right half of words normally, the left part of words (but not of pseudowords) frequently contained sufficient information to activate the correct lexical response. Thus, for example, confronted with the stimulus *elegant* NG had a high probability of producing the correct response: The sequence of letters *eleg* . . . strongly invites the response "elegant." However, in reading pseudowords (e.g. *dronkle*) there are no such constraints on correct performance—information on the left half of a pseudoword (e.g. *dron*. . .) in no way determines the identity of the remaining letters in the stimulus.

The hypothesis of a deficit to a common graphemic buffer also accounts for the fact that most of NG's errors in reading words and pseudowords were incorrect word responses, whereas most of her errors in spelling words and pseudowords were incorrect nonword responses. In reading, the normally processed left part of a word or pseudoword can lead to the activation of an incorrect entry in the input lexicon. Thus, for example, given the stimulus word *elevation*, the letter sequence *eleva* ... activates the lexical entries "elevation," "elevator," "elevated," etc., creating the possibility for a lexicalisation error; similarly, the sequence of letters *dron* ... in the pseudoword *dronkle* activates the lexical entries "drone," "drones," "droner," "dronish," etc., also creating the possibility for a lexicalisation error. In writing, because graphemes are processed for output serially, the spared left part of a representation can only lead to local constraints on the selection of specific allographs. Thus, the expectation is that spelling errors should consist primarily of incorrect nonword responses.

Finally, a buffer deficit can also account for the fact that word frequency affected NG's performance in reading but not in spelling. The contrasting effects arise because of the differential roles played by word frequency in processing graphemic representations in reading and in spelling. In reading, graphemic representations are used to access lexical orthographic representations—a process that is sensitive to the frequency of lexical representations; in spelling, graphemic representations are used to compute letter forms (for written spelling) or letter names (for oral spelling)—processes that concern only local graphemic properties and not lexical factors such as frequency.

The hypothesis of damage to a common level of graphemic representation for reading and spelling offers a plausible account for NG's performance. An implication of this hypothesis is that if a patient's spelling deficit were assumed to arise from damage at the level of the graphemic buffer, we would also necessarily expect the patient to present with corresponding difficulties in reading. This expectation has been confirmed in the performance of a patient, LB, whose acquired dyslexia and dysgraphia are, in relevant respects, very similar to NG's. However, the explanation that has been given for this patient's co-occurring impairments in reading and spelling is at variance with the account proposed for NG: Although LB's spelling impairment has been described as resulting from damage at the level of the graphemic buffer, his reading impairment was *not* attributed to the same cause.

LB's impairments in reading and in spelling have been analysed in great detail and have been the subject of several reports (Caramazza & Miceli, 1990; Caramazza, Miceli, Silveri, & Laudanna, 1985; Caramazza et al., 1987). LB has a marked deficit in spelling both words and pseudowords. His spelling performance is influenced by stimulus length, but not by form class, frequency, or concreteness; most spelling errors resulted in nonwords. In reading, LB responded more accurately to words (97.1% correct) than to pseudowords (57.7% correct), and his errors consisted mostly of incorrect word responses. The qualitative features of his pattern of performance in reading and spelling are similar to those described for NG (except for the right-sided neglect). However, LB's dysgraphia and dyslexia were accounted for by positing two independent forms of damage for the two deficits. LB's dysgraphia was ascribed to a deficit at the level of the graphemic buffer, as was NG's; but, unlike NG, the marked difference in his reading performance for words and pseudowords was accounted for by hypothesising damage to sublexical, orthography-to-phonology conversion (OPC) procedures, which are assumed to be implicated selectively in pronouncing unfamiliar letter strings (Beauvois & Derouesné, 1979; Coltheart, 1985). Thus, the seemingly identical (in relevant respects) pattern of performance in reading and in spelling in the two patients was given a unitary explanation in one case (NG: damage at the level of graphemic representations both in reading and in spelling) but not in the other (LB: damage at the level of graphemic representations in spelling and damage to OPC procedures in reading).

Can this apparent contradiction be resolved? One way out of the impasse would be to show that one of the two interpretations is wrong. Thus, for example, closer inspection of LB's performance might lead us to conclude that Caramazza et al. (1985) were wrong in interpreting his reading impairment as the result of damage to OPC procedures and that in fact, like NG, his reading problem has the same cause as his spelling disorder—damage to the graphemic buffer in both cases. If this were the case, we would confirm the hypothesis that reading and spelling implicate a common graphemic buffer which, when damaged, necessarily results both in deficits of reading and of spelling[5]. Alternatively, we might decide that it is Caramazza and Hillis (1990) who were wrong in concluding that NG's reading and spelling deficits have a common cause, thereby undermining the motivation for hypothesising the existence of a common graphemic buffer used both in reading and in spelling. In the latter case, the fact that LB's spelling deficit was interpreted as resulting from damage to the graphemic buffer (for spelling) whereas his reading deficit was interpreted as resulting from damage to OPC procedures would not be problematic in the least. However, we would then have to find some

[5]Although we refer to the deficit in NG as "damage to the graphemic buffer," we actually intend to say "damage to those processes that take place at the level of the graphemic buffer." The shorter phrase is used for stylistic purposes only. There is no implication that the hypothesised damage necessarily affects the buffer itself. In fact, in NG's case the damage does not seem to affect the buffer directly but, rather, processes that operate over the representations held in the buffer.

other explanation for NG's strikingly similar patterns of errors in reading and in spelling.

In this paper, we attempt to resolve the conflicting claims about the role of the graphemic buffer(s) in reading and in spelling that have emerged from the analyses of the performance of patients NG and LB. We do so by carrying out a new analysis of LB's reading performance, focusing in particular on the types of errors he makes in reading pseudowords. The reason for focusing on this type of analysis is because the hypothesis of damage to the graphemic buffer and that of damage to OPC procedures make different predictions about the types of errors that would be produced in reading pseudowords. Specifically, damage to the graphemic buffer, but not damage to OPC processes, is expected to result in letter transposition errors (e.g. *revina* [/revina/] → /re'niva/). These contrasting expectations are motivated by the assumption that graphemic representations specify the identity and order of graphemes, and that damage to these representations will result in the loss of information about identity and order of graphemes. The behavioural consequence of this damage is the production of letter substitution, addition, deletion, *and* transposition errors in reading[6]. By contrast, damage restricted to OPC procedures should only affect the conversion of grapheme sequences (graphemes, grapheme clusters, or graphosyllables) into phonological patterns. Behaviourally, this form of damage should result in substitutions, additions, and deletions but *not* in transpositions of letters. The production of deletion and addition errors is expected on the assumption that the procedure of orthography-to-phonology conversion operates with units larger than a single grapheme (either letter clusters or graphosyllabic units). Thus, damage to the OPC procedures should result in the production of phonological units (syllable or demi-syllable) that share many but not all the phonemes with target responses, resulting not only in the production of substitution errors but also in deletion and addition errors. However, since order information in the input grapheme string is intact, there is no obvious way to get transposition errors simply as the result of damage to OPC procedures (except where multiple substitutions result in transposition errors by chance). In addition, this hypothesis, but not the graphemic buffer deficit hypothesis, predicts the substantial

[6] It is relatively easy to see how damage to a representation that specifies the identity and order of graphemes could result in the production of substitution, deletion, and transposition errors. Although it is not as obvious how this type of damage would lead to the production of addition errors, it is not unreasonable to expect such errors as well. Damage may result in "noisy" representations such that it is not possible to determine whether or not there is a grapheme in a specific location in the representation. In this case, the system's response to the noise could be the production of an extra grapheme.

presence of errors that violate context-sensitive rules of pronunciation (e.g. *ceta* [/četa/] → /keta/).

The two hypotheses considered here also make subtle, but clearly distinct, predictions concerning word reading performance. The distinctions occur both in the overall level of correct performance and in the types of errors that are produced. The hypothesis of OPC damage predicts normal performance in reading familiar words, and impaired performance in reading unfamiliar words. Operationally, this translates into the expectation of a word frequency effect in reading performance. By contrast, the hypothesis of damage to the graphemic buffer predicts impaired performance in word reading. However, as already noted, the level of impairment should be relatively mild for a wide range of damage. The reason for the relative mildness of the word reading impairment (as compared to the impairment in reading pseudowords and in spelling words and pseudowords) is based on the fact that even an impoverished graphemic representation is often sufficient to activate the correct lexical entry at the word recognition stage.

The two hypotheses also make different predictions concerning the types of errors that should be produced in word reading. Although both hypotheses predict the occurrence of a substantial proportion of visually similar word substitution errors (due to the fact that in both cases reading is accomplished principally through the lexical system), they differ with respect to the type of nonword error responses that are expected. Thus, for errors that result in nonwords, the OPC deficit hypothesis predicts errors that violate context-sensitive rules of pronunciation whereas the graphemic buffer deficit hypothesis predicts the presence of transposition errors. The former type of error is expected because of damage to the OPC procedures themselves; the latter type of error is expected because normally functioning OPC procedures are applied to degraded graphemic representations in which grapheme position information may be lost.

Although the two hypotheses make distinct predictions for word reading performance, in practice it is difficult to distinguish between them when the damage suffered by the patient is in the mild/moderate range. This is because both hypotheses predict low levels of errors. And since most errors consist of incorrect word responses, we will not be able to get a large enough corpus of nonword reading errors to analyse error types. Furthermore, incorrect word substitutions have a complex relation to the stimuli that gave rise to the error responses and, thus, are not easily interpretable. That is, the activation of an incorrect word response is not only a function of visual similarity, but also of such factors as word frequency. Therefore, an analysis of the visual similarity between a stimulus and the incorrect response is not appropriate for word substitution errors. In light of these considerations, the analyses that follow will concentrate on LB's performance in reading pseudowords, and we will consider his performance in reading words only briefly.

The reason for carrying out a new investigation of LB's reading performance is because the data reported in Caramazza et al. (1985) were not obtained with the current theoretical contrasts in mind and, thus, do not allow a clear choice between the two hypotheses considered here. However, there are features of his reading errors that encourage the new study: Although the nonword responses produced by LB in reading pseudowords are generally consistent with the original hypothesis of damage to OPC procedures, these responses also seem to be qualitatively similar to his writing errors, suggesting the possibility of damage to a common graphemic buffer. Thus, most of LB's incorrect responses in reading pseudowords could be classified as substitution (*letiti* → /lɛtimi/), insertion (*arrasti* → /ar'ryasti/), deletion (*mansete* → /ma'sɛte/), or transposition errors (*sceluvo* → /ʃe'vulo/). As already noted, the occurrence of transposition errors in reading is difficult to explain strictly on the basis of damage to OPC procedures. Therefore, if it could be shown that LB produces a substantial number of transposition errors in reading, we would be able to reject the OPC damage hypothesis of his reading deficit in favour of the hypothesis of damage to a single graphemic buffer. In order to decide between these two hypotheses, LB's reading performance was re-tested with an extensive list of words and pseudowords.

CASE HISTORY

Since the relevant medical, neurological, and neuropsychological information on LB has been described in detail elsewhere (Caramazza et al. 1985; Caramazza et al. 1987; Caramazza & Miceli, 1990), and since his condition has been very stable over the past several years, only a very succinct summary is reported here.

When this study was carried out, LB was 75 years old, and almost 10 years post-onset to a left-hemisphere CVA involving the pre- and post-rolandic gyri and extending deeply into the white matter. He has no motor or sensory deficits. His language disorder consists of very occasional anomic pauses, and the writing and reading impairments are summarised in the Introduction. These deficits remain unchanged. LB also suffers from a mild verbal memory deficit. He has been taking carbamazepine (200mg three times a day) over the past four years, for temporal lobe seizures.

EXPERIMENTAL STUDY

Materials and Methods

Stimuli used for all tasks were printed in upper-case letters (font: Courier; point size: 14), and were shown one at a time. LB was presented with 984 words and 1167 pseudowords, randomly distributed across several lists. He always responded quickly, with very few self-corrections. Whenever more than one attempt at responding was produced, the last response was scored. LB never failed to produce a response to a stimulus.

Overall Results

LB demonstrated a clear-cut advantage for word as opposed to pseudoword reading. Overall, he read correctly 925 (94%) words, and 503 (43.1%) pseudowords—a highly significant difference ($\chi^2 = 617.7$; $P < 0.001$). Incorrect responses resulting in a word accounted for 44/59 (74.6%) errors in word reading and for 99/664 (14.9%) errors in pseudoword reading ($\chi^2 = 117.9$; $P < 0.001$). On a subset of 1119 stimuli controlled for length, he correctly read 319/342 (93.3%) words and 300/777 (38.6%) pseudowords ($\chi^2 = 284.9$; $P < 0.001$). Incorrect word responses accounted for 16/23 (69.6%) errors in word reading and for 63/477 (13.2%) errors in pseudoword reading ($\chi^2 = 48.236$; $P < 0.001$)[7]. The effect of stimulus length on reading accuracy is shown in Table 1. Word reading was unaffected by stimulus length: LB correctly read 371/390 (95.1%) stimuli of 4–5 letters and 118/124 (95.2%) stimuli of 8–10 letters. By contrast, length markedly influenced pseudoword reading: Performance decreased from 86/98 (87.8%) correct responses for 2–3 letter stimuli to 108/301 (35.9%) correct responses for 8–10 letter stimuli[8].

[7]The low incidence of word responses to pseudoword stimuli in this task is largely due to the fact that the stimuli were chosen to be as visually dissimilar to words as possible. In fact, the incidence of word responses to pseudoword stimuli that were similar to words was substantially higher (21/69 [30.4%]) than for pseudowords that were not similar to words (42/408 [10.4%]; $\chi^2 = 19.2$; $P < 0.001$). The reason for maximising the dissimilarity of pseudowords to words was to ensure that a large number of responses could be assumed to involve the application of sublexical, orthography-to-phonology conversion procedures. After all, it is a major contention of this paper that one type of evidence that may allow us to distinguish between the two hypotheses under consideration in this report consists of responses that are assumed to result from the application of OPC procedures.

[8]As in previous analyses of this case (Caramazza et al., 1985), LB again performed better (54% vs. 35%) in reading "morphologically" structured than unstructured pseudowords (e.g. *dormevo*, composed by inappropriately combining the stem dorm- with the affix -evo vs. *dermivo*, which cannot be parsed into two morphemes). However, since this variable does not distinguish between the two hypotheses being evaluated here, we will not pursue this aspect further.

TABLE 1
Correct Responses Produced to Word and Pseudoword Stimuli of Various Lengths (Percentages in Parentheses)

Number of Letters	*Stimulus Type*	
	Words	*Pseudowords*
2–3	—	86/98 (87.8)
4–5	371/390 (95.1)	62/89 (69.7)
6–7	436/470 (92.8)	247/679 (36.4)
8–10	118/124 (95.2)	108/301 (35.9)
Total	925/984 (94.0)	503/1167 (43.1)

Qualitative Error Analysis

The reading performance profile described thus far—greater accuracy in word reading than in pseudoword reading, and an effect of length in pseudoword reading—replicates our previous report of LB's dyslexia (Caramazza et al., 1985), but it does not distinguish between the OPC and the graphemic buffer deficit hypotheses. A qualitative analysis of the types of reading errors produced by the patient may afford a better opportunity for deciding between the two possibilities. As already noted, both the hypothesis of a deficit in the processes that convert orthographic into phonological representations and the hypothesis of a deficit in the processes that temporarily hold a representation in a graphemic buffer can account for the production of letter substitution, insertion, or deletion errors in oral reading. However, only the graphemic buffer deficit hypothesis predicts the conspicuous presence of transposition errors in reading pseudowords—that is, the presence of errors such as the following: exchanges: *revina* (/revina/) → /re'niva/; shifts: *biocro* (/'byɔkro/) → /'bryɔko/; and exchanges/shifts: *spigro* (/'spigro/) → /'spirgo/. By contrast, only the OPC deficit hypothesis predicts the significant presence of grapheme/phoneme mapping errors that would be expected to result from the incorrect application of context sensitive rules—that is, the presence of errors such as *logero* (/lodjero/) → /lo'gero/, which represents the violation of the context sensitive rule for the pronunciation of "g" in Italian: g{i, e} → /dj/; g{a, o, u} → /g/.

The principal focus of the error analyses reported here is on the presence of transposition and grapheme/phoneme (G/P) mapping errors in reading pseudowords. The motivation for focusing on the patient's performance with pseudowords instead of words is strictly pragmatic: Consistent with expectations derived from the two hypotheses considered here, we have a much larger corpus of errors for pseudowords than for words. Furthermore, as noted in the Introduction, predictions about the types of errors that are expected in word reading are not nearly as clear as those that are expected for pseudoword reading. The hypothesis of damage to a graphemic representation does not severely constrain expectations about the types of errors that might be produced in reading words. We can certainly exclude one type of error: Damage at the level of the graphemic buffer should not result in the production of semantic paralexias. Aside from this (weak) constraint, all that can be said is that the dominant error type should be visually-similar word responses (in the measure to which a stimulus has visually similar cohorts). However, in the absence of an articulated theory of the process by which graphemic representations activate lexical orthographic entries, it is not possible to give a more detailed characterisation of the relationship between a stimulus and the errors it might give rise to. Nonetheless, for present purposes it may be sufficient to note that the latter relationship does not exclude the presence of transposition errors. Despite its limited value, we will briefly discuss a qualitative analysis of LB's word reading errors after a discussion of his performance in reading pseudowords.

Analysis of LB's Errors in Reading Pseudowords

Responses in which a letter was substituted (*elibra* [/elibra/] → /'etibra/), deleted (*trelpe* [/'trɛlpe/] → /'trɛpe/), or added (*ecrova* [/e'krɔva/] → /es'krɔva/) were respectively scored as letter substitution, deletion, or addition errors[9]. Responses scored as letter transposition errors were of three types. When a letter in the stimulus was moved to a non-adjacent position in the response (*duscro* [/duskro/] → /'drusko/), the response was scored as a letter shift; when two non-adjacent letters were switched (*relune* [/re'lune/] → /le'rune/), the response was scored as a letter exchange; when two adjacent letters were switched (*oflipa* [/o'flipa/] → /ol'fipa/), the error could not be classified unambiguously as either a shift or an exchange, and was thus scored as an exchange/shift.

Grapheme/phoneme mapping errors were also considered in this analysis. The notion of a "grapheme/phoneme mapping error" in Italian must be clarified since it does not correspond exactly to the more familiar notion in English. The orthography of English is segmentally opaque: The same orthographic sequence frequently admits to more than one pronunciation (consider for example *ea* in *bead* and *bread*, *ough* in *tough*

[9]The relation between a written stimulus and the spoken response is only described in terms of "letters" for the sake of convenience. This is possible in Italian because its orthography is highly transparent at the segmental level. In the few cases where there might be ambiguity, we will distinguish between phonemes and letters.

and *though*, etc.); furthermore, some orthographic sequences have unique pronunciations (*yacht*, *choir*, *colonel*, etc.). As a consequence, identification of the to-be-read word is usually necessary for correct pronunciation. Failure to activate lexical-orthographic information could result in "phonologically plausible" errors, in which a plausible but inappropriate G/P mapping is applied to the grapheme string (e.g. *bread*→/brid/, *though*→/tof/, *yacht*→/jot/). In Italian, segmental G/P mapping errors such as these cannot occur. With one exception (*gli* is mapped onto /ʎi/ in almost all words except a few cases such as *glicine*, *glicerina*, and words derived from *Anglia*, such as *anglicano* and *anglicismo*, in which it corresponds to /gli/), the relationship between orthography and phonology is entirely transparent at the segmental level. However, some letters have two possible pronunciations depending on the context in which they occur. In these cases, the correct G/P mapping is determined by the letter(s) that follows the ambiguous letter. Thus, for example, *c* and *g* correspond to /č/ and /dj/, respectively, when followed by *i* or *e*, but to /k/ and /g/, respectively, when followed by *o, a, u, he,* and *hi*; and, the sequence *sc* corresponds to /ʃ/ when followed by *i* or *e*, but to /sk/ when followed by *o*, *a*, *u*, *he*, and *hi*. In other words, in Italian there are no truly ambiguous orthographic sequences (except for the very few exception words containing *gl*): Sequences that admit to two pronunciations are always read correctly if the local orthographic context is correctly analysed. Thus, in this paper, the term "G/P mapping" error refers to incorrect responses in which LB failed to apply a context-sensitive rule as, for example, in *scurme* (/'skurme/)→ /ʃurme/, which is the pronunciation for *sciurme*.

The failure to use context-sensitive G/P mapping rules correctly is not the only possible source of errors that might be coded as G/P mapping errors. A response like /'ʃurme/ to the stimulus *scurme* could also be scored as a letter insertion error since /ʃurme/ is the correct pronunciation of the pseudoword string *sciurme*. Similarly, the stimulus response pair *cherbo* (/'kerbo/)→/'čerbo/, also a potential G/P mapping error, could result from the deletion of the letter *h* (*cerbo*). Thus, these errors could only be classified correctly if we knew the mechanism responsible for their production. At this stage in our study, we will arbitrarily treat them as G/P mapping errors. The possibility that these errors result from deletions/ insertions of letters, rather than from damage to context-sensitive G/P mapping rules, will be taken up later in the paper.

Incorrect Responses Retained for Analysis. All incorrect responses resulting from the substitution, insertion, deletion, or shift of a letter, from the exchange of two letters, or from violation of G/P mapping rules, were retained for analysis. Responses that contained two or more instances of the same error type were also retained. Examples of the latter type of errors were multiple substitutions (*iterpo* [/i'tɛrpo/] → /i'tɛlbo/), insertions (*lotino* [/lotino/] → /lyon'tino/), deletions (*sfrugli* [/'sfruʎi/] → /'frudji/), transpositions (*efrila* [/efrila/] → /el'fira/). There were no instances of multiple G/P mapping in the same response.

Incorrect responses containing two errors of different types were retained, provided that they could be scored unambiguously. In particular, responses in which the two errors occurred in distinct positions were retained. Among such errors were responses that contained a substitution and an insertion (*ledine* [/lɛdine/] → /lɛn'dini/), an exchange and an insertion (*marota* [/marɔta/] → /'mantɔra/), a substitution and a deletion (*recono* [/rekɔno/] → /i'kɔno/), a G/P mapping error and a substitution (*cherlo* [/'kerlo/] → /čerbo/), and so on.

Results. Six hundred and fifty-nine incorrect responses (involving 806 letters) were retained for analysis (Table 2).

Overall, substitutions represented the most frequently occurring error. They accounted for 236/659 (35.8%) errors. "Pure" substitutions occurred 162 times (141 involved 1, 17 involved 2, and 4 involved 3 letters). Insertions accounted for 161/659 (24.4%) errors. They occurred in isolation 93 times (86 insertions of 1 letter, and 7 insertions of 2 letters). Deletions were observed in 91/659 (13.8%) errors. There were 55 "pure" deletions, of which one involved 2 letters. However, the occurrence and distribution of these errors does not allow us to distinguish between the hypothesis of damage to the graphemic buffer vs. the hypothesis of damage to OPC procedures. The relevant evidence for this purpose concerns the occurrence of transposition and G/P mapping errors.

TABLE 2
Pseudoword Reading: Incidence of Various Error Types and Number of Letters Involved in Each (Percentages in Parentheses)

	No. of Errors of Each Type[a]	*No. of Letters in Each Error Type*
G/P mapping errors	20 (3.0)	20 (2.5)
Substitutions	236 (35.8)	261 (32.4)
Insertions	161 (24.4)	169 (21.0)
Deletions	91 (13.8)	92 (11.4)
Transpositions	151 (22.9)	264 (32.8)
Exchanges	25 (3.8)	52 (6.5)
Shifts	43 (6.5)	44 (5.5)
Exchanges/Shifts	83 (12.6)	168 (20.8)
Total	659 (100.0)	806 (100.0)

[a] Errors observed in the responses retained for analysis.

Transpositions occurred very frequently; they accounted for 151/659 (22.9%) errors, involving a total of 264 (32.8%) letters. Transposition errors occurred as the only error in a response 75 times, and consisted of 12 letter exchanges (one of which involved 4 letters), 18 letter shifts (one of which involved 2 letters), and 45 exchange/shift errors.

Errors interpretable as the consequence of failure to apply context-sensitive G/P mapping rules occurred only 20/659 (3%) times. There were 7 incorrect responses in which a G/P mapping error was the only error in a response; the remainder occurred in the context of more complex errors. Although the incidence of G/P mapping errors would seem to be quite low, this may only reflect the fact that not all pseudowords contained sequences of letters that called for the application of a context-dependent G/P mapping rule. Thus, the results presented so far might obscure a more substantial OPC deficit. A more representative index of LB's difficulty in applying OPC procedures is obtained by considering the incidence of G/P mapping errors in terms of the actual opportunity for making such errors. In the corpus of stimuli used in this study there were 387 occurrences of context-sensitive G/P mapping rules. LB made 20/387 (5.2%) errors.

Are G/P Mapping Errors Truly Due to Failure to Apply OPC Procedures or Are They Simply Other Instances of Letter Deletion and Insertion Errors? The type and distribution of reading errors clearly indicate that a principal cause of the patient's reading impairment is damage at the level of the graphemic buffer: LB made a substantial number of transposition errors that are difficult to explain in terms of damage to OPC procedures but which follow naturally from the assumption of damage to the graphemic buffer. However, LB also produced a small but non-negligible number of G/P mapping errors, which seem to indicate damage to OPC procedures. As already noted, however, these errors need not necessarily reflect damage to OPC procedures; they could result from the deletion or insertion of letters. For example, putative G/P mapping errors like *chebo* (/'kebo/) → /'čebo/, and *ciala* (/'čala/) → /'kyala/ could be the result of a letter deletion and a letter insertion, respectively. Deciding between these two possibilities is critical in order to determine whether LB's reading impairment is fully explained by damage to the graphemic buffer or whether his reading difficulty reflects damage to both the graphemic buffer and to OPC procedures. If responses scored as G/P mapping errors actually result from letter deletions and insertions, then the graphemic buffer deficit hypothesis can fully account for LB's reading disorder. If, on the contrary, these errors are best interpreted as the result of failure to apply G/P mapping rules correctly, then we would have to assume that LB's reading impairment results from damage to both the graphemic buffer and OPC procedures.

If putative G/P mapping errors are actually letter deletions or insertions, they should occur as often as other deletions and insertions in similar syllabic contexts. In other words, if responses like *chebo* → /'čebo/ result from the deletion of a letter (the letter *h*), they should occur as often as errors like *preco* (/'prɛko/) → /'pɛko/, in which a consonant in the onset cluster of a CCV syllable is deleted. Similarly, if responses like *ciala* → /'kyala/ result from the insertion of a letter (the letter *h*), they should occur as often as errors like *pelfo* (/'pɛlfo/) → /'prɛlfo/—insertions of a consonant in the onset of a CV syllable. By contrast, if damage to OPC procedures is responsible for LB's reading errors, the incidence of responses like *chebo* → /'čebo/ and *ciala* → /'kyala/ should differ from that of errors like *preco* → /'pɛko/ and *pelfo* → /'prɛlfo/.

Of the 387 context-dependent G/P mapping rules included in the corpus administered to LB, 349 involved rules concerning *c* and *g*, and 38 involved rules concerning *ch* and *gh*. LB made 11/349 (3.2%) errors on *c* and *g*, and 9/38 (23.7%) errors on *ch* and *gh*. He was significantly more accurate in responding to *c* and *g* than to *ch* and *gh* ($\chi^2 = 25.437$; $P < 0.001$).

If these errors were to be treated as letter insertions (in the case of *ciala* → /'kyala/) or deletions (in the case of *chebo* → /'čebo/), we would be arguing in effect that LB inserted a consonant in the onset of 11/349 (3.2%) syllables and deleted a consonant in 9/38 (23.7%) syllables with 2-consonant onsets. The incidence of these errors was compared to the incidence of unequivocal letter insertions and deletions in identical syllabic contexts. The corpus administered to LB contained 2207 syllables with a simple onset (1971 CV syllables and 236 CVC syllables) and 398 syllables with 2-consonant onset (328 CCV syllables and 70 CCVC syllables). LB inserted a consonant in a simple syllabic onset 26/2207 (1.2%) times and deleted a consonant in a 2-consonant syllabic onset 20/398 (5%) times. Thus, responses interpretable as either G/P mapping errors or insertions occur more frequently than unambiguous insertions (3.2% vs. 1.2%); and errors interpretable as G/P errors or deletions occur more frequently than unambiguous deletions (23.7% vs. 5%). Both differences are statistically significant: G/P mapping/insertions vs. unambiguous insertions: $\chi^2 = 9.873$, $P < 0.001$; G/P mapping/deletions vs. unambiguous deletions: $\chi^2 = 18.471$, $P < 0.001$. These results suggest that at least some of the responses that were initially scored as G/P mapping errors are in fact the result of failure to apply OPC procedures correctly.

Summary. There are three main results in this section. First, a substantial number of pseudoword reading errors were lexicalisations. Second, a large proportion of errors involved letter transpositions. And, third, there were a number of G/P mapping errors which, though small in number, could not be dismissed as letter insertion or deletion errors. The first two results are consistent with expectations derived from the hypothesis of damage to grapheme level representations in reading. The third result suggests that LB may also have a mild deficit in the application of OPC procedures.

Analysis of LB's Errors in Reading Words

As already noted, LB made 59 (6%) errors in reading aloud 984 words. Of these, 44 (74.6%) resulted in words (e.g. *viva*, alive → "vita," life) and 15 (25.4%) in nonwords (e.g. *dorati*, golden → /norati/). In all cases, incorrect responses bore a clear orthographic relationship to the target. The qualitative analysis of LB's errors in reading words was based on 51 incorrect responses. The remaining eight responses (six resulting in an incorrect word, two in an incorrect pseudoword) were excluded from this analysis. Of these, six resulted in complex errors (*dotare*, to provide with → "tornare," to go back; *mirare*, to aim → "meritare," to deserve; *porgere*, to give → "premere," to press; *schiere*, formations → "scegliere," to choose; *banale*, banal → /bar'bena/; *caro*, dear → /'garko/); the remaining two were stress errors (*cercó*', he tried → "cerco," I try; *degnó*, he deemed worthy → "degno," worthy of).

Results. The distribution of the various error types in the 51 responses retained for analysis is reported in Table 3. Substitutions were the most frequent error type. They accounted for 26 (51%) errors, and involved only 1 letter in all but 2 cases (in which 2 letters were reproduced incorrectly). Insertions also occurred frequently; they accounted for 16 (31.4%) errors, and involved a single letter in all but 1 case. Deletions occurred in 3 (5.9%) cases, in 1 of these they involved 2 letters. LB also produced 5 (9.8%) transpositions and 1 (2%) G/P mapping error.

Comparison of performance on words and pseudowords is made difficult by the much lower incidence of incorrect responses to word stimuli. Some general trends can be detected, however. Two differences have already been noted—errors resulting in a word response occurred much more frequently to words than to pseudowords; and stimulus length affected performance accuracy on pseudowords but not on words. Other similarities and differences emerge from the qualitative error analysis. G/P mapping errors, letter substitutions, insertions, and deletions occurred with not too dissimilar frequency to both stimulus types (but for G/P mapping errors see later). Transpositions, however, occurred with lower frequency in responses to words (7/57, or 12.3% of total incorrect letters) than to pseudowords (264/806, or 32.8% of total incorrect letters). This difference

TABLE 3
Word Reading: Incidence of Various Error Types and Number of Letters Involved in Each (Percentages in Parentheses)

	No. of Errors of Each Type[a]	*No. of Letters in Each Error Type*
G/P mapping errors	1 (2.0)	1 (1.8)
Substitutions	26 (51.0)	28 (49.1)
Insertions	16 (31.4)	17 (29.8)
Deletions	3 (5.9)	4 (7.0)
Transpositions	5 (9.8)	7 (12.3)
Exchanges	1 (2.0)	2 (3.5)
Shifts	3 (5.8)	3 (5.3)
Exchanges/Shifts	1 (2.0)	2 (3.5)
Total	51 (100.0)	57 (100.0)

[a] Errors observed in the responses retained for analysis.

could have resulted from several complex factors and is not easily interpretable. Most of the errors in reading words were other words. This means that the distribution of error types in these responses is determined, in part, by the orthographic structure of the words that are visually (orthographically) similar to a stimulus. Thus, the frequency with which transposition errors might occur in the production of lexical errors depends, in part, on the fortuitous existence of words that have the same graphemes as the stimuli but in a different order[10]. For example, the stimulus *trota* (trout) has the following same length visual cohort: torta, trita, trova, trote, and rotta. This set of visually similar words allows the production of a response that could be scored as involving a letter transposition (torta) or letter shift error. By contrast, the stimulus *corta* (short, feminine) has a large visual cohort (e.g. torta, costa, corto, carta, corna, corte, . . .), but none of the words in the cohort could be scored as involving the transposition of letters. This constraint on the probability of producing a transposition error does not apply to errors resulting in pseudowords. And, as already noted, since the pseudoword stimuli were chosen so as to minimise the number of lexical responses, the errors produced to these stimuli were not constrained by the fortuitous structure of lexical cohorts. This contrast between words and pseudowords may explain the different rates of transposition errors produced for the two types of stimuli.

[10] Of course, there are also other factors at play. Thus, the relative frequency of the members of a visual cohort of a word could play a role in determining which error response is produced and, therefore, what type of "orthographic" error is made.

Additional Analyses of Substitutions and G/P Mapping Errors. The corpus of words administered to LB included 295 contexts (in 282 words) that allowed G/P mapping errors. Of these, 14 (in 11 words) would have resulted in an incorrect word if the context-sensitive G/P mapping rule had been incorrectly applied (e.g. GALLO, rooster → /'djallo/, yellow, instead of /gallo/). As we have seen, LB's performance on word reading was not flawless, as he produced 59/984 (6%) incorrect responses. However, only one incorrect response could be interpreted as the result of an error in applying a G/P mapping rule (the word *traggo*, I draw, that resulted in the pseudoword response /'traddjo/, instead of /'traggo/). Thus, LB incorrectly mapped 1/295 (0.3%) context-sensitive G/P rules in word reading. This figure contrasts with his performance on nonword reading, where he failed to apply a context-sensitive G/P mapping rule in 20/387 (5.2%) instances. The difference between performance on words and pseudowords is statistically reliable ($\chi^2 = 11.507$; $P < 0.001$).

Summary. The results of LB's word reading performance are consistent with the hypothesis of damage to the graphemic buffer: He is impaired in reading words, his errors consist mostly of incorrect word responses, and he makes transposition errors.

DISCUSSION

In the Introduction we put forward the claim that a common graphemic buffer may be involved in the processes of reading and spelling. The principal evidence for this hypothesis was provided by the performance of a patient, NG, who made errors at the end of words and pseudowords in all types of reading and spelling tasks. The strict co-occurrence of the same types of errors across all types of reading and spelling tasks was interpreted to reflect damage to a common level of processing. The only possible level of representation that could be shared in reading and spelling words and pseudowords is the level at which graphemic information is represented: A graphemic representation must be computed in order to recognise or pronounce a string of letters and in order to spell a word or pseudoword. If this level of representation were in fact shared by the reading and spelling processes, damage to it would necessarily result in the co-occurrence of impairments in the two tasks. However, the form of impairment that would be observed in any specific case would depend on the particular nature of the damage sustained by the processing system. We can distinguish between at least two forms of damage: (1) damage that directly affects the graphemic buffer's ability to store and represent graphemic representations adequately and (2) damage that affects those mechanisms that operate over graphemic representations. In the case of

NG, it was hypothesised, on the basis of her spatially specific reading and spelling impairment, that the damage concerned a mechanism that directs the "pick up" of information from spatially organised graphemic representations[11].

We also noted in the Introduction the possible existence of counter-evidence to the hypothesis of a common graphemic buffer used for reading and spelling. The co-occurring dysgraphic and dyslexic symptoms in a patient, LB, were ascribed in one case to damage to the graphemic buffer and in the other to damage to OPC procedures. These interpretations of LB's deficits in reading and spelling are inconsistent with expectations derived from the hypothesis of a common graphemic buffer, which predicts that the reading impairment should have the same cause as the spelling deficit[12]. That is, since LB's spelling impairment was attributed to damage that supposedly affected the buffer's ability to store and represent graphemic representations adequately, his reading performance should also have reflected the system's failure to represent graphemic information adequately. In other words, we would have expected his reading and spelling errors to be characterised by the loss of graphemic information: Loss of information about the identity and order of graphemes. This expectation was not tested in the earlier studies of LB, and therefore, it remained possible that, independently of whether he additionally does have damage to OPC procedures, his performance might also reflect the effects of damage to the graphemic buffer as predicted by the common buffer hypothesis. The results of the present study confirm this expectation and thus provide support for the hypothesis that a common graphemic buffer is involved in reading and spelling[13].

The results we have reported present a complex picture. The fact that LB produced G/P mapping errors, even if only infrequently, confirms the earlier claim that his reading impairment is due, at least in part, to damage to OPC procedures. Nonetheless, the results also unambiguously demonstrate that LB's reading impairment is not merely the consequence

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[11] Actually, the mechanism in question is one that is implicated in processing not only graphemic representations but all types of spatially organised information. The evidence for this claim is that NG showed the same type of spatially specific impairment in processing words as well as objects (see Caramazza & Hills, 1990).

[12] Of course, this does not exclude the possibility that a patient might have an additional deficit to the OPC procedures.

[13] Alternatively, the pattern of impaired performance we have interpreted as resulting from damage to the graphemic buffer could be explained as reflecting a pathologically rapid decay of the activated graphemic representations. Then, in order to explain the co-occurrence of deficits in reading and spelling of words and pseudowords, we would have to argue that a common set of graphemic representations are computed in the four cases, and that the decay function of the activated graphemic representations is damaged.

of damage to OPC procedures. The crucial evidence in support of this contention concerns the substantial presence of letter misorderings in the corpus of pseudoword reading errors (just as in his spelling performance). These errors, which would be otherwise inexplicable in the context of a hypothesis of damage to OPC procedures, can readily be accounted for by the hypothesis of damage to graphemic representations temporarily held in a buffer in the process of reading. We are thus led to conclude that LB's reading performance is a function of damage both to the graphemic buffer and to OPC mechanisms. The fact that LB's reading performance is most plausibly explicable by postulating that he has sustained damage at a level where graphemic representations are temporarily held in a buffer in preparation for lexical access (or for the application of OPC procedures in the case of pseudowords), encourages us to pursue the hypothesis of a common graphemic buffer in reading and spelling[14]. And, in fact, there is other evidence that converges with the account proposed here, with the consequence that there is now a relatively strong basis for the common buffer hypothesis.

Further indirect evidence for the hypothesis is provided by the performance of several patients who have been "classified" as having a deficit at the level of the graphemic buffer in spelling. All the patients whose spelling performance has been interpreted as resulting from a spatially specific deficit in processing graphemic representations—i.e. neglect dysgraphia at the level of word-centred graphemic representations, as in the case of NG—have also shown reading impairments that are qualitatively similar to those that characterise their spelling performance. Thus, JL (Barbut & Gazzaniga, 1987), ORF (Baxter & Warrington, 1983), and DH, HB, and ML (Hillis & Caramazza, 1989, 1995) not only made one-sided spelling errors but also one-sided reading errors. Also consistent with the hypothesis of a common graphemic buffer is the performance of two other well-studied patients whose spelling performance was attributed

[14]It also has more practical consequences. Thus, one implication that follows from the claim that LB's reading impairment results from damage to a common graphemic buffer used in reading and spelling is that the disproportionate difficulty in reading pseudowords relative to words cannot be taken, *on its own*, as evidence for damage to OPC procedures. In order to interpret poor performance in reading pseudowords as indicative of damage to OPC procedures, we will have to rule out the possibility of damage to the graphemic buffer. In practical terms this means going beyond the simple observation that a patient fails to read pseudowords correctly and to demonstrate that the errors in reading these stimuli are explicable by appeal to misapplication of OPC procedures. As part of this effort we will have to consider not only patients' performance in reading tasks but also their performance in spelling tasks. Since these precautions were not always followed in previous cases, this means that not all reported cases of selective deficit to the sublexical, orthography-to-phonology conversion system may in fact have had damage to this system.

to damage to the graphemic buffer: HR (Katz, 1991; Friedman & Kohn, 1990) and AS (Jonsdottir et al., in press). These patients presented with the spelling performance profile characteristic of damage to the graphemic buffer. Both patients were also reported to show mild deficits in reading words and much greater difficulties in reading pseudowords, as predicted by the hypothesis of damage to graphemic representations.

Unfortunately, not all reported cases of damage to the graphemic buffer in spelling conform with expectations derived from the hypothesis of a common buffer for reading and spelling. Patient SE (Posteraro et al., 1988) presents with a spelling profile which, in most respects, is consistent with the hypothesis of damage to the graphemic buffer but his reading performance would seem to be quite good. We do not know what to make of this case, expect to note that, unlike other cases of damage to the graphemic buffer, this patient did not make transposition errors in spelling. The implication of the latter fact for claims about the nature of the damage responsible for the spelling impairment has not been worked out. It is possible, therefore, that SE's deficit affects different processing structures from those that are responsible for the spelling impairment in LB, HR, and AS.

Finally, direct evidence in favour of the common buffer hypothesis is provided by the performance of MC (Tainturier & Caramazza, 1994), who sustained damage to the left parietal lobe and who presents with a severe spelling deficit for words and pseudowords and a marked reading impairment for pseudowords. His spelling difficulties are typical of patients with graphemic buffer damage: He spells words and pseudowords equally poorly, his performance is markedly affected by stimulus length, and his errors consist of letter substitutions, deletions, additions, and transpositions (e.g. "congress" → *congross*; "shampoo" → *shampo*; "mineral" → *minerial*; and "giraffe" → *graffie*, respectively), which principally occur near the middle of the stimulus. Of particular interest here is the fact that his performance in reading words was much better than that for pseudowords, and that performance with the latter stimuli was remarkably similar to his spelling deficit. Specifically, his reading errors also consisted of substitutions (e.g. *imming* → "imping"), deletions (e.g. *spimble* → "simble"), additions (e.g. *fecan* → "frecan"), and misorderings of letters (e.g. *africop* → "arifcop"). Furthermore, as in spelling, his reading errors tended to occur near the middle of the stimulus. Thus, this patient's performance fully conforms with expectations derived from the hypothesis of a common graphemic buffer in reading and spelling.

In conclusion, we have described the pattern of reading errors produced by a dysgraphic patient, LB, whose spelling impairment was ascribed to damage to the graphemic buffer. The pattern of errors he makes in reading are very similar to those he makes in spelling. We have interpreted the co-occurrence of similar patterns of spelling and reading errors as indicative of damage to a common process used in reading and spelling—the temporary storage of graphemic representations in a buffer in preparation for lexical access (in reading) and allographic conversion (in writing)[15]. We also reviewed a fairly large body of evidence which, with one possible exception (patient SE), is highly consistent with the hypothesis. Further research will have to resolve whether the noted exception seriously undermines the hypothesis of a common buffer used in reading and spelling or whether it simply points to the existence of fundamentally different forms of spelling deficits that are incorrectly classified as being of the same type.

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[15]The functional architecture of reading and spelling proposed here attributes a central role to the graphemic buffer. Can we account for the results we have reviewed within a functional architecture that does not include a graphemic buffer (or its equivalent)? It is difficult to answer this question in the abstract—the answer obviously depends on the specific properties of the proposed functional architecture. Thus, for example, it could turn out that a connectionist architecture of the reading and spelling processes might be able to dispense with the notion of a graphemic buffer altogether. However, until such a comprehensive architecture of these two systems has been worked out, it is not possible to decide the issue.

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