Serial Order Effects in Spelling Errors: Evidence from Two Dysgraphic Patients

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Abstract

This study reports data from two dysgraphic patients, TH and PB, whose errors in spelling most often occurred in the final part of words. The probability of making an error increased monotonically towards the end of words. Long words were affected more than short words, and performance was similar across different output modalities (writing, typing, and oral spelling). This error performance was found despite the fact that both patients showed normal ability to repeat the same words orally and to access their full spelling in tasks that minimized the involvement of working memory. The pattern of performance locates their deficit to the mechanism that keeps graphemic representations active for further processing, and shows that the functioning of this mechanism is not controlled or ‘refreshed’ by phonological (or articulatory) processes. Although the overall performance pattern is most consistent with a deficit to the graphemic buffer, the strong tendency for errors to occur at the ends of words is unlike many classic ‘graphemic buffer patients,’ whose errors predominantly occur at word-medial positions. The contrasting patterns are discussed in terms of different types of impairment to the graphemic buffer.

Introduction

Spelling errors of normal adults (e.g. Wing and Baddeley, 1980) as well as of brain-damaged patients (e.g. Caramazza and Miceli, 1990; Rapp and Caramazza, 1997) are not randomly distributed. Instead, they follow certain distributions, which can indicate where in the language production system the error occurs. For example, Wing and Baddeley (1980) investigated the spelling errors of normal subjects and found that slips of the pen were more likely to occur in the middle than at the beginning or end of words. Since their subjects wrote the words correctly at other times, the errors were assumed to have arisen after the orthographic representation in the lexicon had been accessed. Wing and Baddeley (1980) attributed the locus of the errors to the graphemic buffer, i.e. ‘a working memory system which temporarily holds graphemic representations for subsequent, more peripheral processes (e.g. orthographic conversion)’ (Caramazza and Miceli, 1990, p. 257–8). The serial position effect of the spelling errors has been interpreted as resulting from interference between neighboring letters in the graphemic buffer (Wing and Baddeley, 1980). Since medial letters of a word have more neighbors than letters at the periphery of a word, they are more prone to being misspelled, resulting in a bow-shaped error distribution.

There are several neuropsychological studies reporting patients who showed a similar bow-shaped distribution of spelling errors. For instance, patient LB, studied by Caramazza (Caramazza et al., 1987; Caramazza and Miceli, 1990), exhibited a bow-shaped distribution of errors in spelling of both words and non-words. The same distribution of errors was found in oral spelling, but oral repetition of words was unimpaired, whereas LB performed poorly when writing it down. Thus, the (sublexical) phonological system was unimpaired and LB’s spelling deficit was localized to the graphemic buffer level (see also Miceli et al., 1987; Postero et al., 1988; Hillis and Caramazza, 1994; Kay and Hanley, 1994; McCloskey et al., 1994; Tainturier and Caramazza, 1994; Jónsdóttir et al., 1996; Freedman and Martin, 1999). Two patients (reported by Hillis and Caramazza, 1989), ML and DH, however, showed a skew deviation from the normal bow-shaped distribution of errors. In both cases, the distribution was bow-shaped, but skewed in opposite directions. Whereas ML’s spelling errors occurred primarily at the beginnings of words, DH showed an increase in errors towards the end of words. However, the overall spelling patterns found with both patients were compatible with damage to the graphemic buffer. The authors proposed...
that the skewed distribution of spelling errors is a variation of the normal bow-shaped pattern that is modulated by a mild hemispatial attentional deficit (neglect).

Caramazza proposed a set of criteria for identifying selective phonemic impairments (Caramazza et al., 1987). (1) Patients with this type of impairment should exhibit similar patterns of spelling errors for words and non-words. (2) They should perform at comparable levels on a variety of tasks (e.g., naming, writing, dictation, delayed copying, etc.) and across different output modalities (oral and written spelling, typing, etc.). (3) Their error patterns should not be affected by lexical factors such as word class (e.g., concrete), because temporary storage in the graphemic buffer is supposed to follow access to the orthographic representations in the lexicon. (4) The errors themselves should include substitutions, deletions, insertions, and transpositions of letters. These types of errors would reflect the degradation of the spatially encoded, accurate graphemic representation of the intended word. Whole-word substitutions, however, should not be found (except as these may result by chance from grapheme substitutions, deletions or insertions). (5) Word length should show an effect on the error pattern, since, with increasing word length, the number of letters in the buffer increases and therefore the probability of making a spelling error increases.

Katz (1991) reported a patient, HR, whose performance followed the above showed a skewed pattern of error distribution: the number of errors increased monotonically from the beginning to the end of a word. The author accounted for this error distribution by claiming that HR’s impairment was due to a rapid decay of letter identity information in the graphemic buffer. Letters that occurred towards the ends of words had to be held longer in the buffer than letters at the beginning and were therefore more likely to be misspelled. In support of this hypothesis, Katz reported data from a backward spelling task in which letters at the end of a word had to be produced before letters at the beginning (Katz, 1991). HR produced fewer errors on the letters at the end of the word than he did in normal forward spelling, supporting the ‘decay-of-information’ hypothesis. Clearly, HR’s performance depended on writing direction (left-to-right). A similar case, CII, was reported by Bub et al. (1987).

Recently, Ward and Romani reported the case of patient BA, who also showed a monotonically increasing serial position effect in her error distribution (like HR and the patients we are reporting in this paper) (Ward and Romani, 1998). BA produced initial letters more accurately than medial letters and non-words more accurately than final letters. In comparison to previous reports (Katz, 1991; Ward and Romani, 1998) argued that BA’s serial position effect in the spelling errors was due to incomplete activation of the orthographic representations of non-words rather than damage to the graphemic buffer. Their patient, unlike HR (Katz, 1991), did not show the same error distribution in the backward spelling task as in the forward spelling task. For example, BA misspelled the word bone backward as NOB, i.e. she made an error on the first spelled letter. This showed that her errors were related to the serial order position in the shortest spelling form and not to the order in which she wrote the letters, prompting Ward and Romani to argue that this result does not support the hypothesis of a deficit to the graphemic buffer.

In this paper, we present data from patients TH and PB, who show a ‘linear’ serial position effect similar to patients BA and HR. TH’s and PB’s pattern of performance is important for (at least) two issues regarding spelling deficits: (1) the relationship between word class and single word impairments (patients (i.e. bow-shaped error pattern versus ‘linear’ error pattern) and (2) understanding the underlying nature of the deficit that results in the specific error pattern displayed by patients like TH, PB, BA and HR (i.e. contrasting hypotheses presented by Katz, 1991 and Ward and Romani, 1998). In addition, TH’s and especially PB’s performance may provide information regarding the role of phonology in spelling. Fosdick claimed that intact phonological processing could help keep the orthographic representations active while the patient is engaging in the sequential output process of spelling (Fosdick et al., 1996). In contrast to patient BA, who ‘was virtually unable to produce any spoken language’ (Ward and Romani, 1998, p. 191), TH and PB are fluent and repeat words perfectly, allowing us to test to what extent phonological support can influence spelling performance.

Case report 1: TH

TH is a 63-year-old, left-handed male who had a cerebrovascular accident in 1982. A CT scan performed 2 years post-onset revealed an old infarct in the territory of the left middle cerebral artery. Unfortunately, no photographic documentation of the CT scan is available. TH presents with a mild lower right facial weakness, a pleagic right upper arm and a paretic right leg. He has also reduced pin-prick sensation over the right side of his body. Visual fields are full on confrontation. Although TH has hemineglect of the right side, he functions normally in daily life. He drives a car, works with a computer at home and uses e-mail. TH attended college for 1 year and worked for more than 40 years as a clerk, but is now retired. He reports that he always enjoyed reading and continues to read a daily newspaper.

TH’s working memory system is impaired. He has a digit span of only four digits forward and two digits backward. Digits were given at a rate of one per second. In the five digits forward condition, his response contained all target digits, but the order was not correct. TH showed no signs of neglect. The number of standard errors from memory, search tasks and line bisection is significant. His speech is fluent and intelligible, and he can follow conversations. However, occasionally he makes semantic errors in oral (and written) spontaneous language production (e.g. grandad → son, Thanksgiving → Easter). His comprehension is normal to mildly impaired. He performed flawlessly (12/12 correct) in an auditory word-picture matching task, but showed mildly impaired performance (15/16; 94% correct) in an auditory sentence-picture matching task. TH did not make any errors in an oral phoneme-phoneme comparison task (10/10 correct in each modality). His single-word and non-word repetition is impaired (50/50 correct).

TH cannot read non-words aloud, indicating damage at some stage of the grapheme-phoneme conversion process. Overall, his single-word reading is fairly good, but not perfect (2059/2219 = 93% correct). TH’s reading performance is reported elsewhere (Key et al., unpublished results).

In oral picture-word matching tasks, TH showed mild improvement (485/533 = 91% correct). For instance, on the Philadelphia Naming Test (Rouet et al., 1996), he performed similarly to other patients of his age (see Ruml et al., 2000), but significantly worse than normal subjects (see Rouet et al., 1996). His phonological output processes, however, were unimpaired, as indicated by his reading aloud of the same picture names (417/435 = 99% correct) and by his perfect repetition (see above).

In written picture naming, TH performed worse (383/531 = 72% correct). He made two morphological and 24 semantic errors (e.g. duck → goose). In addition, he made many spelling errors (e.g. mushroom → mushroom, television → television). Interestingly, he also made spelling errors on semantic substitutions (e.g. archike → cauliflower, straw-berries → strawberries). However, TH’sexcellent discriminations between the same picture names (417/435 = 99% correct) and by his perfect repetition (see above).

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TH does not seem to have specific grammatical problems, but this aspect has not been studied in detail. He participated in this research project from June 1998 to November 1999. After a general screening period, we focused our testing on his spelling abilities. During the testing period, his performance was considered to be stable.

General spelling abilities

Across all tasks, TH spelled 1858 words (oral spelling, writing to dictation, written picture naming, typing to dictation, spelling with letter cards). We will first give a general overview of his spelling abilities and then discuss more specific tasks.

TH was given the Johns Hopkins University (JHU) Dysgraphia Battery (Goodman and Carannuza, 1987), which includes the following tests: part-of-speech, concreteness, regularity, phoneme-phoneme conversion probability (i.e. the probability of spelling a word correctly by applying non-phonematic–phoneme conversion) and word length. The calculated spelling conversion probability test consists of a list of words that vary with respect to the syllabic weight of which a particular phoneme is transcribed into a particular grapheme. For instance, the phoneme /t/ is always transcribed as <ct> in spelling, whereas /k/ can be transcribed as the graphemes <k> or <ck>, varying in probability. Table 1 displays TH’s performance across all tasks and demonstrates that he showed some effects of syntactic word class (part-of-speech), with nouns and function words spelled better than verbs and adjectives (χ² = 10.6, P < 0.05). He spelled all words of the same single-letter nuclei at a rate of P < 0.05, and high-frequency words were spelled better than low-frequency words (χ² = 7.4, P < 0.05). However, TH did not show an effect of regularity nor of phoneme–phoneme conversion probability. In fact, TH showed a strong effect of word length, decreasing from 71% correct for four-letter words to only 36% correct for eight-letter words.

TH’s performance on writing pronounceable non-words was tested using two different lists of non-words. The first one contained non-words that were four or five letters in length, where TH spelled only 3% correctly (2/70). However, in 53% of the cases he got at least the first letter correct, showing that he could convert some phonological information into graphemes. For 47% of the non-words, TH made lexicalization errors, most of them being phonologically similar to the target (e.g. soft → soft or math → mark). The second list included 20 shorter non-words not exceeding three letters (10 CV, 10 CVC, where C is consonant and V is vowel). TH performed much better on this second list. He spelled 50% of the non-words correctly. For 58% of the non-words, he got the first letter correct, and on 75% even the first two letters were correct. This test showed that he could convert some phonological information into graphemes, at least to some degree. Furthermore, the error pattern in non-words resembled the error distribution on words with more errors at the end than at the beginning of words.

TH was also tested in a delayed copying task where he first looked at a string of letters printed in capital letters; the string was then covered and TH was asked to write it down in script form. This test was carried out to see whether knowledge about the spelling of a string influenced his spelling performance. The list of 62 items (4–7 letters in length) contained 20 non-words. Altogether, TH scored 84% correct (52/62). Only two of his errors occurred on non-words; he showed a strikingly non-selective pattern for both letters and non-words, >75% for both. Most importantly, TH’s error pattern on non-words resembled the error distribution on words with more errors at the end than at the beginning of words.

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Table 1. TH's performance in various spelling tasks of the JHU Dysgraphia battery

<table>
<thead>
<tr>
<th>Word list</th>
<th>Sublist</th>
<th>% correct</th>
<th>α (%)</th>
<th>X²</th>
<th>P</th>
<th>Example target</th>
<th>Example error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part-of-speech</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Nouns</td>
<td>82</td>
<td>23/28</td>
<td>10.6</td>
<td>&lt;0.05</td>
<td>nounal</td>
<td>nounal</td>
<td></td>
</tr>
<tr>
<td>Verbs</td>
<td>64</td>
<td>18/28</td>
<td>12/28</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>verbal</td>
<td>verbal</td>
</tr>
<tr>
<td>Adjectives</td>
<td>43</td>
<td>12/28</td>
<td>12/28</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>adjetive</td>
<td>adjetive</td>
</tr>
<tr>
<td>Functions</td>
<td>75</td>
<td>15/20</td>
<td>15/20</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>function</td>
<td>function</td>
</tr>
<tr>
<td>Coexistence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consonant</td>
<td>71</td>
<td>32/28</td>
<td>16/28</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>consonant</td>
<td>consonant</td>
</tr>
<tr>
<td>Vowel</td>
<td>13</td>
<td>13/28</td>
<td>13/28</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>vowel</td>
<td>vowel</td>
</tr>
<tr>
<td>Consonant–grapheme conversion probability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>High</td>
<td>77</td>
<td>23/28</td>
<td>23/28</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Low</td>
<td>77</td>
<td>23/28</td>
<td>23/28</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Word length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four-letter</td>
<td>77</td>
<td>10/14</td>
<td>10/14</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>four-letter</td>
<td>four-letter</td>
</tr>
<tr>
<td>Five-letter</td>
<td>57</td>
<td>8/14</td>
<td>8/14</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>five-letter</td>
<td>five-letter</td>
</tr>
<tr>
<td>Six-letter</td>
<td>64</td>
<td>9/14</td>
<td>9/14</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>six-letter</td>
<td>six-letter</td>
</tr>
<tr>
<td>Seven-letter</td>
<td>57</td>
<td>9/14</td>
<td>9/14</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>seven-letter</td>
<td>seven-letter</td>
</tr>
<tr>
<td>Eight-letter</td>
<td>57</td>
<td>6/14</td>
<td>6/14</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>eight-letter</td>
<td>eight-letter</td>
</tr>
<tr>
<td>Word frequency (collapsed across various sublists)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>55</td>
<td>36/111</td>
<td>36/111</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>HF</td>
<td>HF</td>
</tr>
<tr>
<td>LF</td>
<td>49</td>
<td>34/111</td>
<td>34/111</td>
<td>15.26</td>
<td>&lt;0.05</td>
<td>LF</td>
<td>LF</td>
</tr>
</tbody>
</table>

Lexical factors, such as frequency, syntactic word class (part-of-speech) and coexistence affected TH's performance, indicating that mild damage to the lexical system is a contributing factor to his spelling performance. However, phoneme–grapheme conversion probably did not affect his spelling. Furthermore, his spelling errors were not predominantly phonological (e.g. ab – ahb, abbet – abbet). He made very few etymological errors (less than 1%), is conceptually or intersemantically related lexical substitutions, possibly including a spelling error. Word length was a major determinant of performance and his errors in spelling mostly consisted of neologisms ranging from letter substitutions, deletions, additions, and transpositions in the middle and end parts of the response. In contrast, the number of lexical substitutions errors in spelling was only 11 (out of 1883 words TH had to spell; 0.6%). However, even most of these 11 lexical substitutions maintained some vowel similarity in the target, e.g. ache → thief.

Specifying TH's spelling deficit

The fact that he generally does not make semantic errors in reading, his inability to make complete use of phoneme-grapheme conversion, and his lexical impairments including effects of word frequency, part-of-speech and coexistence in written spelling, and the fact that he makes morphological and semantic errors in written and spoken output, would classify TH as a ‘deep dysgraphic’ patient according to the criteria given in Bub and Kertesz (Bub and Kertesz, 1982). Actually, Bub and Kertesz’s (1982) patient IC performed quite similarly to our patient TH, except that IC was able to read pronounceable non-words whereas TH could not. TH is even more similar to the graphemic buffer patient VS studied by Nolan and Caramazza (Nolan and Caramazza, 1983). TH shows a relatively good overall reading performance (93% correct) compared to his relatively poor overall spelling performance (62% correct). Therefore, TH’s data support the claim that phonological processing for reading is functionally separate from phonological processing for writing (Bub and Kertesz, 1982; Nolan and Caramazza, 1983). TH’s lexical impairments, however, seem to be independent of his spelling deficit. This view is supported by the fact that even in written picture naming his semantic substitutions contain spelling errors, thus indicating that TH can access the semantics of a lexical item correctly, but when he tries to retrieve the orthographic representations, they are either damaged or the correctly retrieved orthographic information is not processed normally at the level of a graphemic buffer. However, whether the spelling problem arises in transferring information from the orthographic representations into the graphemic buffer, whether the graphemic buffer itself is damaged, or whether the deficit is in the transfer of information out of the graphemic buffer to more peripheral output processes, we cannot say.

Effects of serial order in spelling

Altogether, TH spelled 1858 words. Figure 1 shows the proportion of correct responses as a function of word length, and it is quite evident that TH performs much better on shorter words as compared to longer words. Whereas he is over 90% correct on three-letter words and still over 80% correct on four-letter words, TH’s performance falls to less than 30% correct on words that have nine letters or more. This performance is similar to that of LB (Caramazza et al., 1987), who showed an even more pronounced word length effect.

To investigate further the nature of TH’s serial position effect in spelling errors, new word lists were devised to assess various factors thought to have an influence on the serial position effect in spelling. The results of his spelling performance on each of these tests are reported separately below.

Short versus long words

The word-length effect reported above was found with the ‘word-length list’ (see Table 1) used in the JHU Dysgraphia Battery. However, this list only contains 70 items. In order to assess TH’s word-length effect further, we devised a new list of words, which varied word length across a broader range to test specifically whether TH would make more errors on long than on short words. This test includes a whole set of words that have at least eight letters, matched in frequency and word class to a set of shorter words.

Materials. Short words did not exceed two syllables (M = 1.6) and seven letters (M = 5.1); long words had at least three syllables (M = 5.2) or eight letters (M = 8.7). There were equally as many words from different metric classes in both sublists. Mean word frequency was lower for the short words (23 per million word forms) than for long words (34 per million word forms) as determined by CELEX (Baayen et al., 1995). There were 99 words in each of the two sublists. The complete list of 198 words was randomized and given to TH in a writing-diction task over three different testing sessions.

The procedure in this task and all of the subsequent written spelling tasks was as follows. The experimenter said the target word aloud, TH repeated it, and then he wrote it down. In the rare event that TH repeated something other than the target word, the experimenter said the word again until TH correctly repeated it. After his spelling attempt, TH was required to say the target word again.

Results. Although word frequency was higher for the long words, TH made significantly more errors on the long words than on the short ones. He was correct on 64% of the short words (63/99), but only on 30% of the long words (30/99) (X² = 22.2, P < 0.05).

To analyze the proportion of his spelling errors at each letter position across words differing in length, the distribution of errors was normalized according to the principles proposed by Wing and Baddeley (Wing and Baddeley, 1980). This normalization procedure divides each word into five abstract letter positions (1–5). Each abstract letter position contains one or more letters of the target word, depending on its length. The letters of the target word are assigned to the abstract letter positions in such a way that a symmetrical structure is maintained (see Caramazza et al., 1987 for details). The errors are calculated according to the criteria stated below and then divided by the total number of letters in a specific abstract letter position, thus producing a proportional measure of the error distribution normalized for word length.

The error scoring followed the principles outlined in Caramazza and Miceli with some modifications (Caramazza and Miceli, 1990, p. 250). Deletions and substitutions were scored one point; insertions were assigned 0.5 points to the positions before and after the insertion. Letter shifts were assigned 0.5 points to the original letter position in the target word and 0.25 points to the positions before and after the insertion. Letter exchanges were assigned 0.5 points to each of the two positions from which the exchanged letters originated.

Furthermore, the following general principles were applied. First, target word and response were arranged in such a way as to maximize the segmental overlap between them. Second, the scoring was such that the minimal form of a given misspelled word. That is, whenever it was possible to score a word with multiple errors in different ways, the one with the least error points was chosen.

The normalized error distribution collapsed across short and long words revealed a monotonic increase in the relative proportion of error points from the first to the fourth position (13.3, 20.2, 25.0, 37.1) and a slight decrease at the fifth position (22.8). TH was later asked to read this list of words, which he did nearly perfectly (196/198 = 99% correct), demonstrating that he knew the words.

Discussion. TH’s performance on a list of short versus long words supports the linear serial position effect in his spelling errors. Short words were spelled significantly better than long ones, and he made more spelling errors towards the end of words than at the beginning. TH was always correct when repeating the target word, but his spelling errors at the target word after his
spelling attempt. In spite of this, he made many errors in spelling, especially on the long words. The fact that he could repeat the word after his spelling attempt implies that he rehearsed or always kept the target word in immediate memory. Yet, this phonological information did not improve his written spelling.

**Morphologically simple versus complex words**

One factor that was confounded with word length in the list of short versus long words was the morphological complexity of words. Morphologically complex words, e.g. derived or inflected words, were on average longer than simple, monomorphemic words. Therefore, the fact that TH's spelling performance was worse for long than for short words may in fact have been a morphological effect. It could be that his neurological system is impaired such that complex errors are more difficult for him to write than simple words. To test this hypothesis, we constructed another list of words, manipulating the factor of morphological complexity while trying to keep all other factors constant.

**Materials.** Altogether, there were 198 words in this list, half of them simple (i.e. monomorphemic) with a mean length of 2.8 syllables and 7.0 letters, the other half complex (i.e. inflected or derived), on average 2.8 syllables and 6.4 letters long. The number of words from different syntactic word classes was equal in both sublists and both types of words had a roughly equal frequency of occurrence of 18 per one million word forms as determined by CELEX.

**Results.** TH was correct on 46% of the morphologically simple short words (46/99) and 55% of the morphologically complex words (54/99). The normalized distribution of errors followed the same pattern as in the previous spelling tasks; there was a linear increase from the beginning to the end of words (error proportions: 10.9, 15.0, 15.1, 24.2 and 29.1 for the first to the fifth normalized letter position, respectively). As with the previous list, TH read these words nearly perfectly (192/198 = 98% correct).

**Discussion.** In general, morphological complexity did not have an effect on TH's spelling performance. He performed slightly better on the complex than on the simple words. This shows that morphological complexity is not responsible for his reduced word-length effect. The normalized error distribution demonstrated that he made more errors towards the end of words than at the beginning. Thus, TH seems to display a similar, monotonically increasing error pattern as FR and, instead of the bow-shaped error pattern known from graphic buffer patients such as LB or AS. We will discuss these contrasting error patterns in more detail in the General discussion.

**Overall spelling analysis**

The normalized error distribution for all of TH's written spelling errors (n = 1817; multiple spelling errors per word were counted separately) on the whole corpus of 1858 words is depicted in Fig. 2D. The whole corpus includes the JHU Dysgraphia Battery sublists, the written picture naming lists and the two lists reported in the last two sections. As can be seen, the pattern of errors TH made increased monotonically from the beginning towards the end of words.

**Morphological boundaries**

Badecker reported the case of DH, a graphemic buffer patient who showed a marked effect of morphological boundaries on the error distribution for the spelling of morphologically complex words (Badecker et al., 1990). We looked at whether this was also true for TH. To this end, the error distribution in misspelled compounds from a list including 62 compounds was analysed.

**Results and discussion**

TH did not show an effect of morphological boundaries in his spelling errors. His relative error proportions on the normalized positions were 5.3, 6.9, 15.3, 15.7 and 13.9 from the first to the fifth position for the first part of compounds. With respect to the second part of compounds, his relative error proportions were 12.8, 10.8, 12.0, 16.5 and 18.6. In fact, when both parts were combined and analysed as a single word, a monotonically increasing error pattern became visible (19.0, 29.4, 36.7, 37.6 and 31.5). Unlike DH, TH does not show signs of sensitivity to morphological boundaries in his spelling of compound words, at least not in spelling. We will discuss this point further when we report the results of a similar analysis for our second patient PB.

**Graphophonic structure**

Caramazza and Miceli suggested that graphemic representations consist of more structure than a linearly ordered string of graphemes (Caramazza and Miceli, 1990). The re-analysis of patient LB showed that his spelling errors were constrained by graphophonic principles such as graphemic consonants, graphemic vowel and graphemic syllable. LB respected the CV status of the substituted letter in virtually all (99.3%) letter substitution errors (730/741). Furthermore, his performance was significantly different on geminate and other CC clusters, indicating different graphophonic representations. However, LB's errors did not seem to fall phonologically as his errors violated basic phonological constraints such as the sonority constraint. On the basis of the error pattern found in LB, Caramazza and Miceli (1990) proposed a multi-tiered graphophonic orthographic representation. The multidimensional structure of graphemic representations that they suggested includes the following four tiers: a grapheme tier specifying the identity of the graphemes of a word, a quantity tier representing the quantity of the specified grapheme identities (e.g. single or double letter), a CV tier for the CV status of the grapheme and a graphophonic tier specifying the graphophonic bound-
tion errors, he respected the CV status of the substituted letter 251 times (86%). Although TH does not preserve the CV and the double-letter status in his spelling errors to the same degree as LB (or other patients in whom this has been investigated; Kay and Haridy, 1994; McClelland et al., 1994), he does not substitute letters randomly. Furthermore, his spelling errors are graphophonetically legal, except for some very exceptional cases like knife → knife, but he tends to substitute letters in his misspellings (see above). This supports the hypothesis that orthographic representations encode the CV status, and thereby orthographic constraints, as well as the double-letter status in a distributed manner.

In summary, TH is a dysgraphic patient who showed a marked effect of word length (more errors on long than on short words). His spelling errors include all kinds of segmental errors, but hardly any whole-word substitutions. Although we cannot exclude damage to the lexical representations in the orthographic lexicon, TH's spelling deficit possibly involves the grapheme-to-phoneme buffer. His spelling abilities were worse in a context and output modalities. For delayed copying and oral spelling, the error curves displayed a monotonic increase from the first to the fifth position, whereas for reading and writing he exhibited a bow-shaped response distribution. Most importantly, however, the error types were the same across tasks, and errors were not influenced by lexical factors such as word class or frequency. The distribution of errors in TH's spelling showed a monotonic increase from the beginning to the end of words. TH could repeat without any problems the words he misspelled, demonstrating that his phonological output processes were intact. Nevertheless, he could not use the information from his phonological output buffer to improve his spelling difficulties. This dissociation is possibly due to the autonomy of phonological and orthographic representations in the lexicon. However, TH had problems spelling non-words without the presence of his phonological (sublexical) dysfunctional phoneme-grapheme conversion route. Therefore, it could be argued that this is the reason why he is unable to improve his spelling even though the phonological information is readily available to him. The second patient we present in this article, VB, is very similar to TH, except that her ability to spell non-words was better.

Case report 2: PB

PB is a 69-year-old, right-handed, highly educated woman who, as a consequence of a left-hemispheric stroke, has become hemiparetic, aphasic and dysgraphic. PB is a highly educated woman and has earned a BA in history, an MA in special education, and is finishing her PhD (Doctor of Philosophy) dissertation when she suffered a subarachnoid hemorrhage. In April 1992, a vascular MRI scan revealed a subdural/patellar left massive middle cerebral artery territory infarction with subcortical changes and ventricular expansion. The frontal horn, occipital horn and the choroidal fissure were expanded, and the lenticulo-striate territory was not spared by the infarct. At the time of testing (1996–1997), PB was classified as a Broca's aphasic with poor comprehension for syntactically complex sentences. Her ability to repeat single words (103/104 = 99% correct) and non-words (33/34 = 97% correct) was excellent, if mildly apraxic. Her reading performance is mildly to moderately impaired. Most of her reading errors are visually similar or morphologically related words (75% of all errors), but she also made semantic errors. Her spelling performance, which is the focus of this paper, will be reported below in detail.

PB's spelling performance was also assessed with the JHU Dysgraphia Battery (Gleitman and Carpenter, 1987). Overall, in writing to dictation, she spelled 39.3% or 351/894 of the words correctly (excluding three-letter words), indicating that her spelling was severely impaired. Table 2 shows her performance across all tasks and demonstrates that PB showed an effect of syntactic word class with nouns and function words spelled better than verbs and adjectives (P < 0.01). She spelled concrete words from an abstract words (P < 0.005) and high-frequency words better than low-frequency words (P < 0.001). Phoneme-grapheme conversion variability, however, did not influence her spelling behavior (P > 0.10). Most importantly, PB showed a marked word-length effect: while she wrote four-letter words with relatively high accuracy (93%), her performance decreased drastically (7%) for eight-letter words (P < 0.001). Compared to TH, her performance distribution was displayed a monotonic increase from the beginning to the end of words. TH could repeat without any problems the words he misspelled, demonstrating that his phonological output processes were intact. Nevertheless, he could not use the information from his phonological output buffer to improve his spelling difficulties. This dissociation is possibly due to the autonomy of phonological and orthographic representations in the lexicon. However, TH had problems spelling non-words without the presence of his phonological (sublexical) dysfunctional phoneme-grapheme conversion route. Therefore, it could be argued that this is the reason why he is unable to improve his spelling even though the phonological information is readily available to him. The second patient we present in this article, VB, is very similar to TH, except that her ability to spell non-words was better.

Table 2. PB's performance in various spelling subtests of the JHU Dysgraphia Battery

<table>
<thead>
<tr>
<th>Word list</th>
<th>Subject</th>
<th>% correct</th>
<th>n</th>
<th>X²</th>
<th>P</th>
<th>Example target</th>
<th>Example error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts-of-speech</td>
<td>Nouns</td>
<td>52.6</td>
<td>15/38</td>
<td>12.79 &lt;0.01</td>
<td>member</td>
<td>meeting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Verbs</td>
<td>25.0</td>
<td>7/28</td>
<td>8.02 &lt;0.01</td>
<td>begin</td>
<td>begin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adjectives</td>
<td>14.3</td>
<td>4/28</td>
<td>4.12 &lt;0.05</td>
<td>bright</td>
<td>bright</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pronouns</td>
<td>20.0</td>
<td>5/25</td>
<td>3.08 &lt;0.05</td>
<td>they</td>
<td>them</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nouns</td>
<td>63.3</td>
<td>25/40</td>
<td>9.64 &lt;0.005</td>
<td>determine</td>
<td>support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Verbs</td>
<td>65.0</td>
<td>21/32</td>
<td>3.63 &lt;0.05</td>
<td>give</td>
<td>support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adjectives</td>
<td>63.0</td>
<td>21/33</td>
<td>3.63 &lt;0.05</td>
<td>support</td>
<td>support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nouns</td>
<td>44.7</td>
<td>13/29</td>
<td>1.45 &lt;0.05</td>
<td>write</td>
<td>write</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Verbs</td>
<td>59.5</td>
<td>23/38</td>
<td>2.09 &lt;0.05</td>
<td>write</td>
<td>write</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adjectives</td>
<td>55.0</td>
<td>20/36</td>
<td>3.58 &lt;0.05</td>
<td>write</td>
<td>write</td>
<td></td>
</tr>
<tr>
<td>Word length</td>
<td>Four-letter</td>
<td>92.9</td>
<td>13/14</td>
<td>29.67 &lt;0.001</td>
<td>order</td>
<td>order</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Five-letter</td>
<td>64.3</td>
<td>13/20</td>
<td>1.45 &lt;0.05</td>
<td>ord</td>
<td>ord</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Six-letter</td>
<td>21.4</td>
<td>5/24</td>
<td>1.45 &lt;0.05</td>
<td>ness</td>
<td>ness</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seven-letter</td>
<td>7.7</td>
<td>1/14</td>
<td>1.45 &lt;0.05</td>
<td>ness</td>
<td>ness</td>
<td></td>
</tr>
</tbody>
</table>

Frequency, grammatical class and context (revised test) affected PB's performance, indicating that mild damage to the lexical system is a contributing factor to her spelling performance. However, phoneme-grapheme registries did not affect her performance in spelling words, and the word list makes phonologically plausible spelling errors (e.g., chairs for chair). She made very few semantic errors (1.1%). Word length affects performance and her errors in spelling words and non-words contained almost entirely of morfosemes (e.g., skelt → skelt; travel → trawl) resulting from letter substitutions, deletions, additions, and transpositions in the middle and end parts of the response. Her letters were consistently well formed. Her ability to spell words only could not be tested extensively because of an independent deficit in naming letters. Thus, for example, when asked to spell wine, she wrote all the letters correctly in the palin of her hand or on the table in front of her, but could not produce the names of the letter N and F. For the word the, she spontaneously named correctly all the letters in the palin of her hand, but was only able to name the letters H and F. The PB's difficulty in naming letters was a source of considerable frustration to her, and she refused to be tested further on oral spelling. However, she was able to trace the letters correctly in the palm of her hand or on a table in front of her, and was able to spell with comparable performance to written spelling by arranging spelling cards.

PB was better able to spell non-words than TH. Whereas TH's ability to spell non-words correctly was limited to two- and three-letter non-words (50% correct; see above) he was virtually unable to spell four- and five-letter non-words correctly (3% correct; <0.01). PB was able to spell six-, seven- and eight-letter non-words correctly. Although her overall error proportion was higher for non-words than for words (only 68% or 7.23% correct), PB exhibited the same monotonic increase in error rates by length for non-words as for words, showing that the nature of her spelling deficit was not influenced by the lexical status of the stimulus per se (see Fig. 2A, B and D). Furthermore, her spelling of non-words demonstrated that she was able to transcode phonological information into graphemic information. Together with the fact that PB was able to repeat words and non-words correctly before, after, and even during her spelling attempt, this patient strongly supports the view of the autonomy of phonological and orthographic representations. Although the patient's (sublexical) output phonology is intact and although her phoneme-grapheme conversion was highly impaired, this does not help PB in improving her spelling behavior.

PB's spelling deficit cannot be attributed to auditory misperception or forgetting of the stimulus since she almost invariably repeated the words correctly orally after she spelled them (she only made four repetition errors in 947 trials (<1%), all of which were morphologically similar words), implying that her phonological buffer was intact—just as in the case of TH. Her spelling deficit cannot be attributed to a lack of knowledge of, or selective damage to, the end of words since she performed nearly flawlessly (97 and 94% correct for six- and eight-letter words, respectively) in a modified spelling-diction task minimizing the involvement of working memory (see Fig. 3A and B). In this task, she was required to fill in the missing letter in a word. By calculating expected performance based on trigram frequencies, PB performed far better than would be expected if she performed only using informations based on trigram frequencies alone (six-letter word ABXY yields an expected performance of 27.5% with X in the fifth position; six-letter word ABXY yields an expected performance of 36.4% with X in the sixth position, and six-letter word ABX yields an expected performance of 42.6% with X in the fifth position; eight-letter word ABXY yields an expected performance of 21.6% with X in the seventh position; eight-letter word ABXY yields an expected performance of 42.8% with X in the eighth position, and eight-letter word ABX yields an expected performance of 41.3% with X in the seventh position). When a similar task was administered to TH in November 1999, he was correct on 83% of the trials (779 correct). Words were between seven and nine letters in length. Compared with his low proportion of correctly spelled words of the same length in writing-to-diction (approximately 20–24% correct), this is a significant increase, although still not perfect. PB's good performance in this task was not merely due to a letter guessing strategy on the basis of the visual context provided by the word name since she performed similarly well in letter probe tasks (93% correct for the last letter) in which she was asked to decide, on separate trials, whether a written letter was in the first two or last two positions of an actually presented word (see Fig. Sc and D). This pattern of performance locates PB's deficit to the
Fig. 3. Serial position performance for six- and eight-letter words in a modified writing-to-dictionary task and for six-letter words in letter probe tasks. (A) and (B) illustrate the errors in which FB had only to produce the single missing letter in six- and eight-letter words. PB performed very well on these two tasks, whereas FB performed more poorly on the letter probe tasks. The six-letter word completion task involved 60 trials (six sets with n = 10). The eight-letter word completion task involved 100 trials (eight sets with n = 12). FB's performance on both was significantly better than that of the letter-probe task (one-tailed t-test). On one task, FB was asked to determine whether the probe letter was contained within the first two positions of the word (position 1 and 2). On the other task, FB was asked to determine whether the probe letter was contained within the two first two positions of the word (position 2 and 3). All other positions were probed on both tasks. Each position was probed 150 times: 104 positive trials and 52 negative trials. Overall correct performance for each position was determined by averaging correct positive responses and correct rejections across the two tasks.

Morphological boundaries
In contrast to TH, PB showed an effect of morphological composition in her spelling performance. For compounds such asighthand, for instance, the made fewer errors on the first few letters of the second part of the compound (e.g., b and t) than on the last letters of the first part (e.g., b and t), even though the former occurred later in the word as a whole (see Fig. 4) (n = 54 for both the first and second words within the compound, where words 5–7 letters in length were normalized to five letter positions). Comparing performances for the first letter of the first word (57.4% correct) to performance on the first letter of the second word (79.6%) yielded a significant difference (χ² = 6.18, P < 0.025).

Discussion
PB's error distribution in compound words indicates that she could control the placement of graphemic information in the buffer (i.e., spelling the compound as two separate words), and the unit of control is the lexical morpheme. This is in contrast to TH, who did not show such an effect. Whether this effect is due to a strategy based on meta-linguistic awareness (dividing words into their constituent morphemes and spelling one morpheme after the other) that some patients can use but others cannot, remains an open question.

General discussion
We have presented the cases of two dysgraphic patients, TH and PB, who showed a strong word-length effect in their spelling errors, making more errors on long than on short words. Furthermore, the probability of making a spelling error increased monotonically from the beginning to the end of words. Although both patients showed some small influences of lexical factors on spelling, their overall spelling performance satisfies the criteria given by Caramazza and therefore most closely resembles a deficit to a graphemic buffer, i.e., a working memory component that keeps graphemic information active for further output processing (Caramazza et al., 1987). The pattern of TH's and PB's errors suggests that the longer this information has to be stored in the graphemic buffer, the more likely it is to be lost. TH and PB are very similar to BA (a patient studied by Ward and Romani, 1998), and to HR (a patient studied by Katz, 1991). All four patients show an increase in spelling errors from the beginning to the end of words. Like Katz, we interpret TH's and PB's serial position effect to be most likely due to a graphemic buffer deficit, although we cannot exclude damage to lexical orthographic representations. This does not necessarily imply an inherently rapid decay rate such that letters at the end of the word are lost due to their position (i.e., items at the end require the most maintenance and would be most affected by an aberrant decay rate). Ward and Romani, however, presented an alternative interpretation for the data. They argue that the linear increase in errors shown by their patient, BA. They argued that their patient suffered from incomplete activation of the abstract orthographic form and the incomplete activation had a great impact on the beginnings of words. The main basis for Ward and Romani's preference for this interpretation over a graphemic buffer deficit was their patient's performance on a backward spelling task (i.e., the patient was given a word, and he had to spell it backwards). BA did show a linear increase in errors towards the end of the word (e.g., in the word XXABC, but instead made many errors on the last letter of the abstract word form (e.g., XXABC)). Ward and Romani argued that if BA had a graphemic buffer deficit, she would have made more errors on the end of the string, regardless of the order of the letters as they appear in the abstract word form (Ward and Romani, 1998).

The main problem with this argument is the lack of understanding of how the backward spelling task is carried out. In order to spell backward, access to information from the graphemic buffer is required, but we can imagine at least two ways in which the task could be performed. The patient could generate a left-right representation (chair) and then scan (right-left) to spell the word backwards. Or, the patient could access the information by working repeatedly towards the end (ch, cha, cha, chair). In the latter case, no improvement would be expected on the end of the word since the spelling task would ultimately be the same as spelling in a forward direction. Thus, any improvement in performance on the ends of words when spelling backwards does not necessarily localize the deficit, since we can imagine at least two ways in which a patient could perform the task. Moreover, BA's performance did not differ when spelling non-words, which suggests that she was retaining the representations of words. The lack of understanding of how a backward spelling task is completed, and thus the uncertainty about what performance on this task is revealing about the underlying deficit, lead us to question the interpretation presented by Ward and Romani regarding their patient's deficit (Ward and Romani, 1998).

TH's and PB's deficits fits most clearly the pattern established as a graphemic buffer deficit, with one main difference. Although all of the reported patients presumably have a deficit at the level of the graphemic buffer and little or no damage to abstract orthographic representations, the error patterns differs. TH's and PB's error pattern (linear increase), as well as the error patterns for HR and BA, contrast dramatically with the pattern reported for other 'graphemic buffer patients' (bow-shaped function; e.g., Caramazza and Miceli, 1990; Kundeët al., 1996). It may be that the error pattern emerges regardless of damage of a broader disorder to what has been called the 'graphemic buffer'. Patients who exhibit a bow-shaped function in the error pattern are exhibiting a normal but exacerbated pattern of performance (see Wing and Baddeley, 1980) for analysis of normal error patterns in spellings. Thus, these patients may suffer from a reduced level of activation in the lexical system that results in many spelling errors. This reduced lexical activity level decreases performance overall, but does not interfere with the normal workings of the graphemic buffer. In contrast, patients who show a linear increase in errors towards the ends of words may have a deficit in the graphemic buffer, as noted above, and as to alter the actual functioning of this working memory system. These error patterns do not resemble error patterns found with normal spellers and seem to reflect an abnormal rapid decay of information such that information at the end of words is lost.

Recently, Houghton and colleagues (Houghton, 1990; Houghton et al., 1994; Shalllice et al., 1995) proposed a spelling model that works without postulating a (graphemic) buffer. This so-called 'competitive queuing' model is a connectionist model that comprises three layers of nodes: one layer of control nodes, one layer of nodes representing the letters and one layer that functions as a 'competitive filter'. The letter nodes are activated by weighted connections from a pair of control nodes whose activation pattern varies with time. This pair of nodes consists of an inhibit (I) node and an end (E) node. Each letter node has weighted connections to the other nodes, based on their distance in the word.
connections to both the I- and the E-nodes. Letter nodes with strong connections to the I-node will receive most activation at the beginning of the word (e.g., the initial letters) and those with strong E-node connections (e.g., the final letters) will receive the least. As time passes, the competitive filter identifies the most highly activated letter node at any given time, selects the corresponding filter node and inhibits the rest. The selected filter node then feeds inhibition back to the letter node, resulting in suppression of the node that was just selected previously.

At the beginning of the spelling process, only the I-node is active (and the E-node is inactive). As time passes, the I-node's activation decays while the activation of the E-node increases. This time-varying activation pattern allows different letters in the sequence to become maximally active at different times. For the spelling of double (or geminate) letters, the model requires a special mechanism implemented by a 'geminate feature node'. Spelling of repeated letters, such as the 'a' in damage, does not pose a problem to the model. Even after selection and suppression of the first 'a', the letter 'a' can be activated and selected again due to connections to the E-node, which enables previously activated and suppressed letters to be activated again.

Could the competitive filtering model be used to account for the patient data we presented in this study? Shalliee damaged a competitive queuing model in such a way as to simultaneously account for the letter distribution pattern, as measured by graphemic buffer patient like LB and AS (Shalliee et al., 1995). However, our patients show a markedly different error pattern. Nevertheless, it might be conceivable that selective damage to the E-node would result in a linear serial position effect of errors as exhibited by TH, PB, and BA. This is because the activation of letters will decrease linearly over the word because of the strength of the weights from the I-node to the letter node layer gradually decreases. However, as pointed out by Ward and Romani (1998), lesioning of the E-nodes leads to the prediction of a particular spelling problem with repeated letters. To test whether this prediction could be supported by TH's data, we looked at his spelling performance in the 'word-length' subtest of the NIH Dysgraphia Battery. Excluding those words that had double letters or the digit 'e' (eight words on errors including repeated letters and spotted 11 repeated letter words correct). The same was true for patient BA (Ward and Romani, 1998). BA was no worse at writing words with repeated letters than writing words without repeated letters. The NIH Dysgraphia Battery's double-letter list, PB scored 48/68 (49.0%) correctly for words without a double letter and 53/62 (53.8%) correctly for words with a double letter, but this difference was not statistically significant (P = 0.10).

Thus, although selective damage to the E-node in a competitive queuing model could account for the linear increase in errors of patients like TH and PB, performance on repeated letters is inconsistent with the model. Ward and Romani (1998) recently showed that damage to both the I- and the E-node could reproduce the spelling pattern of patient BA and yielded similar effects as selective damage to the E-node alone.

The fact that TH and PB seem to suffer from a rapid decay of information in their graphemic buffer raises the issue of whether our patients were using a single graphemic buffer using phonological information. In fact, Jänsdottr et al. (1996) claimed that intact phonological processing can help keep the orthographic representations active while the patient is engaged in the sequential output process of spelling. The authors offered this as an explanation as to why their graphemic buffer patient's overall performance level was much lower than another graphemic buffer patient, LB, presented by Caramazza and colleagues (Caramazza et al., 1987; Caramazza and Miceli, 1990). The patients reported here, TH and PB, flawlessly repeated quite long words before and after they wrote them down, indicating no damage to their phonological buffer. However, although their phonological buffer was unimpaired, they showed severely impaired spelling behavior, suggesting that the good phonological information does not necessarily lead to improved spelling performance, as Jänsdottr et al. have argued. But why would TH and PB not use this information if it were available? If TH and PB used lexical information to refresh information in the graphemic buffer, it could be done on a whole-word basis, rather than segmentally, and would provide additional information to help them retain the final repeated letters. In addition, TH's non-word spelling was quite poor, suggesting a fairly restricted ability to transcode phonological information into graphemic information. Thus, refreshing information in the graphemic buffer sublexically, which could be done segmentally, was not an option for TH. Therefore, regardless of how well he could retain phonological information, as demonstrated by his repetition of the target word after he attempted to spell it, TH could not use this information to improve his spelling performance. For PB, however, this was not the case. She could spell non-words to some degree, indicating the limited ability to transcode phonological information into graphemic information. Nevertheless, her error pattern was similar to TH's. In our view, this demonstrates that phonological and orthographic representations are autonomous (for further evidence with regard to the autonomy of orthographic representations, see Rapp et al., 1999).

A final contrast in performance between TH and another graphemic buffer patient (LB), who shows a bow-shaped representation pattern for words, was made by the HRP. When TH was asked to read a list of short versus long words, he performed at a very high level (99.6% correct, 190/198). In this difference was not statistically significant (P = 0.48, P > 0.10). Thus, although selective damage to the E-node in a competitive queuing model could account for the linear increase in errors of patients like TH and PB, performance on repeated letters is inconsistent with this model. Ward and Romani (1998) recently showed that damage to both the I- and the E-node could reproduce the spelling pattern of patient BA and yielded similar effects as selective damage to the E-node alone.

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Serial order effects in spelling errors: evidence from two dysgraphic patients

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Abstract
This study reports data from two dysgraphic patients, TH and PB, whose errors in spelling most often occurred in the final part of words. The probability of making an error increased monotonically towards the end of words. Long words were affected more than short words, and performance was similar across different output modalities (writing, typing and oral spelling). This error performance was found despite the fact that both patients showed normal ability to repeat the same words orally and to access their full spelling in tasks that minimized the involvement of working memory. This pattern of performance locates their deficit to the mechanism that keeps graphemic representations active for further processing, and shows that the functioning of this mechanism is not controlled by phonological (or articulatory) processes. Although the overall performance pattern is most consistent with a deficit to the graphemic buffer, the strong tendency for errors to occur at the ends of words is unlike many classic ‘graphemic buffer patients’ whose errors predominantly occur at word-medial positions. The contrasting patterns are discussed in terms of different types of impairment to the graphemic buffer.

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O210

Primary diagnosis of interest
Left hemisphere stroke

Author’s designation of case
TH
PB

Key theoretical issue
• Dysgraphia, effects of serial order

Key words: neuropsychology; dysgraphia; serial order effects in spelling; graphemic buffer disorder

Scan, EEG and related measures
CT scan, vascular MRI scan

Standardized assessment
The Johns Hopkins University Dysgraphia Battery, the Philadelphia Naming Test

Other assessment
Self-contained spelling tests

Lesion location
• TH: infarct in the territory of the left middle cerebral artery
• PB: superior/parietal left middle cerebral artery territory infarction

Lesion type
TH: left hemisphere stroke
PB: subarachnoid haemorrhage

Language
English