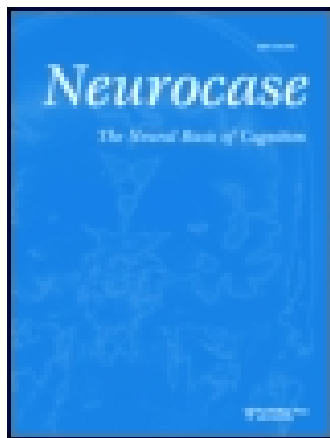


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Gabriele Miceli ^{a b c}, Rita Capasso ^b, Barbara Benvegnù ^b & Alfonso Caramazza ^c

^a Dipartimento di Neuroscienze, Università Cattolica, Rome, Italy

^b Fondazione Santa Lucia, IRCCS, Rome, Italy

^c Cognitive Neuropsychology Laboratory, Harvard University, Cambridge, Massachusetts, USA

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The Categorical Distinction of Vowel and Consonant Representations: Evidence from Dysgraphia

Gabriele Miceli^{1,2,3}, Rita Capasso², Barbara Benvegnù² and Alfonso Caramazza³

¹Dipartimento di Neuroscienze, Università Cattolica, Rome, Italy, ²Fondazione Santa Lucia, IRCCS, Rome, Italy and ³Cognitive Neuropsychology Laboratory, Harvard University, Cambridge, Massachusetts, USA

Abstract

Subject GSI presents with a graphemic buffer deficit following a massive left fronto-parietal lesion. His errors involved essentially only consonants (98.2%). However, he always spelled correctly the first consonant in a string, and produced steadily increasing numbers of errors on the following consonants, while always spelling all the vowels in the target correctly. The pattern of performance observed in this subject provides strong evidence for the separate (categorical) representation of consonants and vowels, and suggests that working memory interacts with independent consonant and vowel representations in spelling.

Introduction

Neuropsychological studies of dysgraphia have led to detailed proposals about the functional architecture of the spelling process, and about the formal properties of orthographic representations (for a recent review, see Tainturier and Rapp, 2001). Investigations of subjects suffering from disorders at the level of the graphemic buffer have provided particularly valuable information in this regard. These subjects present with an impairment of the working memory component that keeps active the orthographic representations of words and pseudowords for the time needed to carry out further stages of spelling. Since the graphemic buffer comes into play after the target string has been retrieved from the lexicon or assembled by sublexical conversion procedures, performance accuracy in a subject with buffer damage is unaffected by semantic and lexical variables, as well as by the lexical status of the target string (familiar or novel word), but is sensitive to length. In these cases, reduced capacity of the buffer or pathologically fast decay of the information it temporarily stores result in segmental spelling errors, characterized by letter substitutions, omissions, insertions or transpositions (Caramazza *et al.*, 1987).

Analyses of spelling errors resulting from graphemic buffer damage have provided evidence consistent with the view that orthographic representations are multidimensional objects that specify suprasegmental as well as segmental features of the target string (Caramazza and Miceli, 1990; McCloskey *et al.*, 1994; Jónsdottír *et al.*, 1996). Whether suprasegmental

information specifies the graphosyllabic structure of the target (Caramazza and Miceli, 1990) or merely the sequence of nucleus/non-nucleus positions that comprise it (Caramazza and Miceli, 1989; McCloskey *et al.*, 1994) is still debated. However, there is a large consensus on the assumption that, at the segmental level, the relevant dimensions include the Consonant-Vowel (CV) status of each grapheme, its identity, and its quantity. For example, the orthographic representation of the word *pizza* specifies that *z* is a consonant, that it corresponds to the grapheme <z> and that it is doubled. This report focuses on the Consonant-Vowel distinction.

The suggestion that the CV status of a grapheme is represented autonomously from other types of orthographic information was prompted by the observation of a striking regularity in the substitution errors produced by a subject with graphemic buffer damage (Caramazza and Miceli, 1990). The incorrect responses produced by LB resulted in 741 letter substitutions. Detailed analyses showed that these errors almost always (736/741, or 99.3% of the cases) involved substituting a consonant for a consonant, or a vowel for a vowel. This observation has been replicated in several subjects with graphemic buffer damage. Thus, the letter substitution errors produced by subjects HE (McCloskey *et al.*, 1994), AS (Jónsdottír *et al.*, 1996), John (Kay and Hanley, 1994), BA (Ward and Romani, 1998) and TH (Schiller *et al.*, 2001) preserved the CV status of the target

in 95%, 85%, 93%, 99%, and 86% of the cases, respectively. The preservation of the consonant or vowel status of the letter produced incorrectly can be best accounted for by assuming that CV status and grapheme identity are represented independently. When information on letter identity is lost, but knowledge of whether that letter is a consonant or a vowel is retained, the latter information is sufficient to ensure that the incorrect letter preserves the CV status of the target.

Another argument for the autonomous representation of consonants and vowels in spelling emerges from the observation that some dysgraphic subjects present with a disproportionate difficulty with a specific letter type, while preserving the ability to produce the other. In the literature, there are three reported cases of a selective deficit for vowels, and one for consonants. During the first week following his stroke, subject CF (Cubelli, 1991) spelled consonants flawlessly, but systematically omitted vowels when asked to write his name, the name of the city where he lived, and five other words. Quick recovery prevented detailed testing of this subject. In two further subjects with a stable spelling disorder, the dissociation was not nearly as complete, but a disproportionate number of errors involved vowels as opposed to consonants. Across a series of tasks, CW (Cubelli, 1991) and LiB (Cotelli *et al.*, 2003) misspelled vowels much more frequently than consonants (CW: 83% vs. 17%; LiB: 85% vs. 15%). The reverse pattern of impaired performance has also been reported. After a stroke, case John (Kay and Hanley, 1994) misspelled consonants more frequently than vowels. For example, of his 253 letter substitutions 201 (79.4%) involved consonants, and only 52 (20.6%) involved vowels.

These observations in the domain of dysgraphia nicely converge with the independent evidence provided by neuropsychological studies of aphasics with disorders of spoken production (Caramazza *et al.*, 2000). In two subjects with a phonological disorder, performance on a series of repetition tasks documented contrasting error patterns. Subject IFA presented with a selective difficulty producing consonants, whereas subject AS presented with a selective difficulty producing vowels. Furthermore, in these cases detailed analyses ruled out the possibility that the double dissociation was determined by damage to subphoneme features. In both subjects, neither the sonority dimension, nor the articulatory place dimension could account for the observed pattern of performance. Of course, the results obtained for IFA and AS do not rule out the possibility that in other subjects greater impairment of consonants over vowels, or vice versa, may result from a subphonemic deficit. However, they demonstrate that, at least in some cases, a dissociated impairment of consonants and vowels results from damage to an abstract level of representation, which represents vowels and consonants as distinct categories.

Both the preservation of CV status in substitution errors and the reports of selective damage for consonants and vowels support the argument that consonants and vowels are represented separately also in spelling. However, the evidence is still incomplete. Reports of selective damage for one repre-

sentational type with respect to the other are not entirely clear. An undisputable dissociation was reported on in only one case, but the selective impairment for vowels in CF did not last long enough to allow a proper experimental investigation. Subjects CW (Cubelli, 1991) and LiB (Cotelli *et al.*, 2003) did show a significantly greater number of errors on vowels, but they produced incorrectly a sizeable number of consonants. A reverse, quantitatively similar pattern of impairment was observed in case John (Kay and Hanley, 1994).

This type of dissociation might be problematic for those architectures of the cognitive system that assume graded representations. The degree to which selective impairments for vowels and for consonants are problematic for these accounts is proportional to the discreteness of the disorder – the more a deficit is of the all-or-none type, the more difficult it is to account for in a theoretical framework that assumes graded representations.

Finding a subject with a stable deficit who presents with a complete dissociation between vowels and consonants would strengthen the argument for the separate representation of the two grapheme types, and would rule out any type of model which does not explicitly assume a categorical separation between consonants and vowels. We report here on such a subject. As a consequence of a stroke, GSI presented with a selective inability to spell consonants, in the presence of entirely spared ability to spell vowels. His performance across various tasks provides the clearest evidence yet for the categorical representation of consonants and vowels. Furthermore, analyses of the within-string distribution of his errors encourage speculation on the working memory system involved in the spelling process and on its interaction with orthographic representations.

Case history and background neuropsychological testing

GSI is an Italian-speaking, right-handed, 56-year old professor of physics. In 1996, he suffered from a left hemispheric stroke, which resulted in a small, almost entirely cortical lesion at the junction of the parietal and occipital lobes. In the acute phase, his only deficit was a mild anomia, which lasted approximately two weeks. GSI quickly resumed his work without any limitations. In May 2000, he suffered from a second, massive stroke in the territory of the left middle cerebral artery. He was referred to the authors in December 2000.

Our subject suffered from a dense right hemiplegia. During bedside confrontation tasks, he presented with mild right-sided extinction phenomena in the tactile, in the auditory and in the visual modality.¹ An MRI (February, 2001) demonstrated extensive damage to the frontal and parietal lobes, with the exception of the angular gyrus, and partial damage to the first temporal gyrus (Fig. 1), in addition to the old lesion.

GSI presented with a mild Broca's aphasia. His speech was mildly dysarthric, dysprosodic and dysfluent. His results on a screening battery for aphasia (Miceli *et al.*, 1994) are

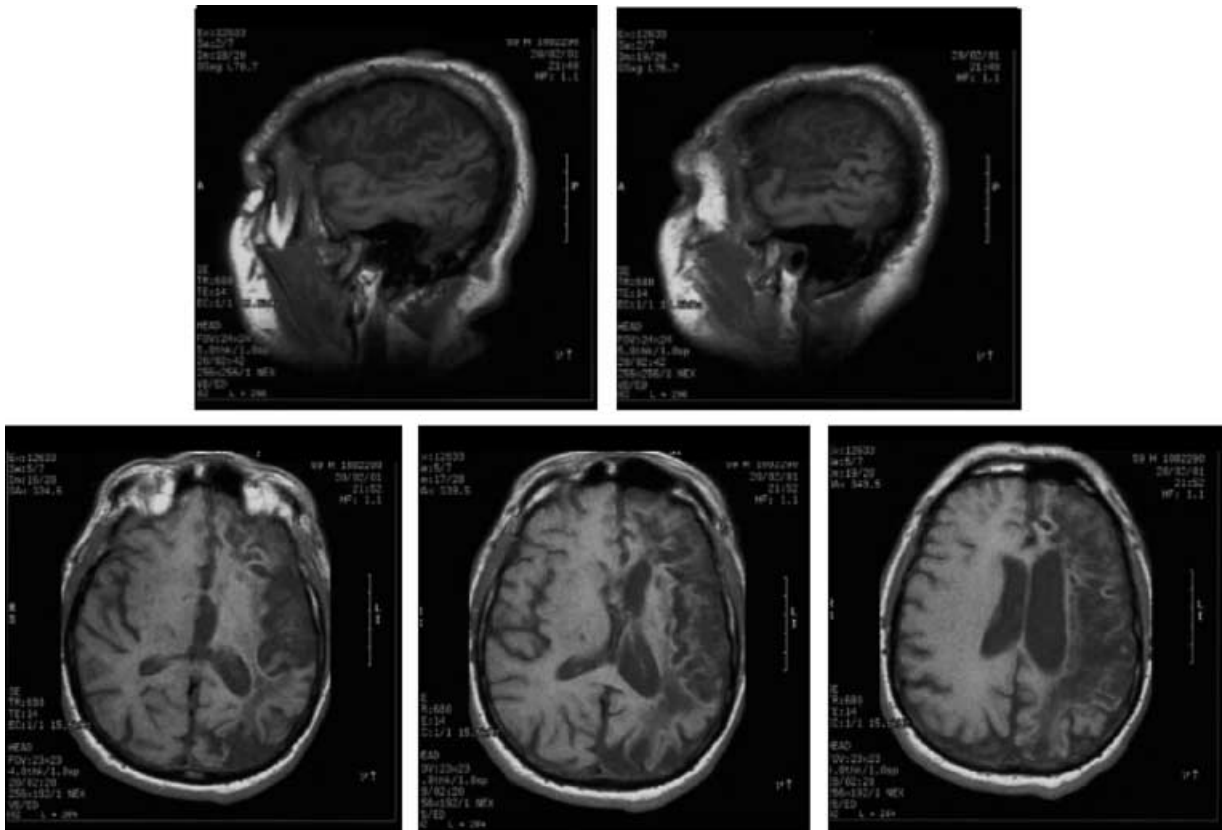


Fig. 1. Representative sections of the MRI, showing a massive (superficial and deep) left hemisphere lesion involving the frontal and parietal lobes (with the partial exception of the angular gyrus) and the superior temporal gyrus, and a smaller lesion in the left posterior-inferior parietal lobe.

summarized in Table 1. He achieved normal (or nearly normal) scores on most tasks. Reading aloud and repetition were slow but reasonably accurate for both words and pseudowords. The few errors in both tasks resulted from articulatory difficulties, affecting primarily the initial consonant in words

and pseudowords (repetition: perfino (even): /fer'fino/; fupro, pseudoword: /vu/ . . . /'supro/; reading aloud: dilatava (he was dilating): /tila'tava/; geba (pseudoword): /'djeva/). Reading aloud also yielded two possible morphological errors (*sistemare* (to fix): sistema (he fixes, or the system); *cenare*

Table 1. Correct responses produced by GSI on the subtests of the Batteria per l'Analisi dei deficit Afasici [13]. Percentages are in parentheses. The battery was administered on two separate occasions (September 2001 and December 2001), with essentially identical results. Hence, this table displays the results collapsed across the two administrations. N/A: not administered

Phoneme discrimination	4/120 (3.3)	"Same" pairs: 4/60 (6.7)	"Different" pairs: 0/60 (0.0)
Auditory-visual matching	2/120 (1.7)	"Same" pairs: 2/60 (3.3)	"Different" pairs: 0/60 (0.0)
Pseudoword transcoding tasks			
a. Repetition	9/72 (12.5)		
b. Writing to dictation	see text		
c. Delayed copy	N/A		
d. Reading aloud	7/90 (7.8)		
Lexical decision			
a. Auditory	3/160 (1.9)	Words: 1/80 (1.3)	Pseudowords: 2/80 (2.5)
b. Visual	3/160 (1.9)	Words: 1/80 (1.3)	Pseudowords: 2/80 (2.5)
Word transcoding tasks			
a. Repetition	4/90 (4.4)		
b. Writing to dictation	see text		
c. Delayed copy	N/A		
d. Reading aloud	3/184 (1.6)		

(continued)

Table 1. (*continued*)

Auditory word-picture match				
a. Nouns	2/80 (2.5)	Semantic foils: 0/40 (0.0)		Phonemic foils: 2/40 (5.0)
b. Verbs	2/40 (5.0)	Semantic foils: 2/20 (10.0)		Phonemic foils: 0/20 (0.0)
Visual word-picture match				
a. Nouns	1/80 (1.3)	Semantic foils: 1/40 (2.5)		Visual foils: 0/40 (0.0)
b. Verbs	5/40 (12.5)	Semantic foils: 3/20 (15.0)		Visual foils: 18/20 (10.0)
Spoken naming				
a. Nouns	10/60 (17.7)			
b. Verbs	17/56 (30.4)			
Written naming				
a. Nouns	15/44 (34.1)			
b. Verbs	19/44 (47.7)			
Spoken naming to definition				
Nouns	4/32 (12.5)			
Grammaticality judgements				
a. Auditory	7/96 (7.3)	Grammatical: 0/48 (0.0)		Ungrammatical: 7/48 (14.6)
b. Visual	5/48 (10.4)	Grammatical: 0/24 (0.0)		Ungrammatical: 5/24 (20.8)
Sentence transcoding tasks				
a. Repetition	6/40 (15.0)			
b. Reading aloud	0/12 (0.0)			
Sentence-picture matching				
a. Auditory	7/120 (5.8)	Reversals: 2/40 (5.0)	Morpho foils: 2/40 (5.0)	Semantic foils: 3/40 (7.5)
b. Visual	5/90 (5.6)	Reversals: 2/30 (6.7)	Morpho foils: 0/30 (0.0)	Semantic foils: 3/30 (10.0)

(to dine): *cena* (he dines, or the supper)). Picture naming was mildly impaired for nouns, moderately impaired for verbs. Errors were mostly lexical, resulting in semantic substitutions and failures to respond; in spoken naming, two phonological/articulatory errors also occurred (*scimmia* (monkey): /'simmya/, and *tigre* (tiger): /'tige/). Word-picture matching was normal for nouns, and slightly below normal for verbs. Sentence-picture matching tasks demonstrated mildly agrammatic comprehension. Sentence reading was errorless, and sentence repetition was reasonably accurate, except for occasional function word omissions. Narratives, both constrained and unconstrained, were mildly agrammatic due to syntactic simplification, occasional omissions of free-standing grammatical words and errors on verb agreement, but otherwise conveyed a normal amount of information, except for some difficulties with verbs (omissions of the main verb, use of generic verbs). Probe tasks for series of words and pseudowords were normal. Forward and backward verbal spans were clearly reduced for letters (3 and 3), bisyllabic words (3 and 2) and pseudowords (1 and 1), and at low normal levels for digits (5 and 4). Spatial span also was reduced (4 and 3).

General spelling abilities

GSI's principal difficulty involved oral and written spelling. He wrote with his left hand, slowly but legibly. On a preliminary task, he flawlessly wrote to dictation the 21 letters of the Italian alphabet (stimuli were administered 5 times, in different random orders). By contrast, he made many errors when asked to spell to dictation familiar and novel words. His difficulties were quantitatively and qualitatively comparable

across tasks involving different forms of input (picture naming vs. writing to dictation vs. spontaneous narratives) and output (written vs. oral spelling-to-dictation). In spelling to dictation (see Table 2), response accuracy to words was unaffected by lexical-semantic variables (concreteness/abstractness; grammatical class; morphological structure; frequency of usage). Performance on words and pseudowords matched for length and orthographic structure did not differ (words: 56/89, 62.9% incorrect; pseudowords: 13/21, or 61.9% correct). By contrast, response accuracies to words and pseudowords were significantly affected by length (words: $\chi^2 = 117.5$; $df = 2$; $p < .001$; pseudowords: $\chi^2 = 42.037$; $df = 2$; $p < .001$).²

Overall, GSI spelled incorrectly to dictation 376/731 words (51.4%). With the exception of 13 fragments (*superano* (they surpass): *sur* . . .) or unscorable responses (*costruirono* (they built): *cortudano*), spelling errors resulted from unambiguous letter omissions (*timbro* (stamp): *timb_o*), transpositions (*belva* (wild beast) \rightarrow *bevla*), substitutions (*scopa* (broom): *spopa*) and rare insertions (*appena* (barely): *appenna*). In some cases, two error types were combined in the same response (*paradiso* (heaven): *padasi_o*). GSI also spelled incorrectly 66/80 pseudowords (82%). The number of fragments and unscorable responses was higher than with words ($n = 15$), but the 51 scorable incorrect responses to pseudowords contained the same error types as his incorrect responses to words (e.g., *sagnodi*: *saglodi*, *nedasbori*: *necasboti*; *pesivi*: *pe_i_i*, *abitire*: *abici_e*; *nortedi*: *norde_i*).

Very similar results were obtained in other tasks. In written naming of pictures, spelling errors occurred with comparable frequency in responses to nouns (22/51, 43.1%) and verbs (21/46, 45.7%); and, in responses to high-frequency and to low-frequency items (nouns: high frequency: 11/26, 42.3%; low

Table 2. Summary of GSI's performance in written-spelling-to-dictation tasks. Incorrect responses are reported; error percentages are in parentheses. The qualitative error analysis includes simple-type errors, and complex errors that could be unambiguously scored as a combination of simple-type errors (e.g., telefono (telephone) → *tefe_ono*, scored as 1 omission and 1 transposition)

<i>A. Quantitative analysis</i>		
(1) Abstractness/Concreteness		
Concrete words	11/20 (55)	$\chi^2 = 0.000$
Abstract words	12/20 (60)	$p = \text{n.s.}$
(2) Grammatical class		
Nouns	10/20 (50)	
Adjectives	10/20 (50)	
Verbs	15/20 (75)	$\chi^2 = 3.350$
Functors	10/20 (50)	$p = \text{n.s.}$
(3) Frequency		
High frequency words	23/40 (57.5)	$\chi^2 = 0.051$
Low frequency words	21/40 (52.5)	$p = \text{n.s.}$
(4) Length		
4–5 letters	87/295 (29.5)	
6–7 letters	160/260 (61.5)	$\chi^2 = 117.5$
8 or more letters	129/163 (79.1)	$p < .001$
(5) Words and pseudowords matched for length and orthographic structure		
Words	56/89 (62.9)	$\chi^2 = 0.027$
Pseudowords	13/21 (61.9)	$p = \text{n.s.}$
<i>B. Qualitative error analysis</i>		
Omissions	428 (78.4)	
Transpositions	69 (12.6)	
Substitutions	46 (9.4)	
Insertions	3 (0.5)	
Total	546	

frequency: 11/25, 44%; verbs: high frequency: 10/22, 45.5%; low frequency: 11/24, 45.8%). For all these comparisons, $\chi^2 < 1$; $df = 1$; $p = \text{n.s.}$ By contrast, performance accuracy was significantly affected by length. GSI spelled incorrectly 87/295 (29.5%) items ranging in length between 4 and 5 letters, 60/260 (61.5%) items ranging between 6 and 7 letters, and 29/163 (79.1%) items of 8 or more letters ($\chi^2 = 117.5$; $df = 2$; $p < .001$). In oral spelling, error rate was unaffected by grammatical class (on a subset of 105 words, nouns: 16/53, 30.2%; verbs: 22/52, 42.3%, $\chi^2 = 1.186$; $df = 1$; $p = \text{n.s.}$) and frequency (on a subset of 80 stimuli, high-frequency words: 18/40, or 45%; low-frequency words: 15/40, or 37.5%; $\chi^2 = 0.206$; $df = 1$; $p = \text{n.s.}$), but was significantly influenced by length. GSI responded incorrectly to 6/41 (14.6%) 4–5 letter stimuli, to 17/47 (36.2%) 6–7 letter stimuli, and to 18/23 (78.3%) 8-letter stimuli ($\chi^2 = 25.629$; $df = 2$; $p < .001$). These two tasks yielded the same error types as writing to dictation.

Across tasks, omissions were by far the most frequent error type. In spelling words to dictation, for example, GSI misspelled 546 letters in 363 interpretable incorrect responses. Of these letters, 428 (78.4%) were omitted, 69 (12.6%) were transposed, 46 (8.4%) were substituted and 3 (0.6%) were inserted. In all tasks, GSI very frequently left blank spaces or marked slots for omitted consonants, and sometimes volunteered comments such as “There is a consonant here, but I don’t know which one”. For example, when attempting to

write to dictation ‘ricchezza’ (wealth), he produced *ricche_a*, and provided the commentary “two identical letters are missing”; and when attempting to spell orally ‘albero’ (tree), he produced the following: “*a, l, b, e, . . .* I cannot see the consonant, *o*.” Similar errors occurred in picture description (e.g., *La guardia acchi_a i lad_i* for La guardia acchiappa i ladri, The policeman catches the thieves) and picture naming (e.g., *lucche_o* for lucchetto, lock). A peculiar feature of GSI’s writing, reported also in other dysgraphic subjects (Katz, 1991; Morton, 1980; Ward and Romani, 1998) was that he did not always spell letters sequentially, from the first to the last. A few times, he wrote the initial letters and left one or more blank spaces between subsequent letters, which he subsequently tried to fill. At times, he managed to successfully complete his initial response (motto: *mo_ o* → *motto*; semaforo (traffic light): *sema_o_o* → *sema_oro* → *semaforo*). Not infrequently, attempts at self-correction failed. In some cases, GSI only filled some blanks (forca (gallows): *fo_a* → *for_a*; moneta (coin): *mo_e_a* → *mo_eta*; persero (they lost): *pe_e_o* → *perse_o*); in others, his final response was complete but incorrect, due to letter substitutions (chiarire (to clarify): *chia_ire* → *chiavire*) or transpositions (difficile (difficult): *diffi_i_e* → *diffilice*).

GSI’s pattern of performance results from damage at the level of the graphemic buffer, that is, at a post-lexical access level where orthographic strings are kept temporarily active, while more peripheral spelling processes are engaged. This conclusion is suggested by the fact that, regardless of input modality (a line drawing, or a word or pseudoword pronounced by the examiner) and of response type (oral or written spelling), his performance is unaffected by lexical dimensions (grammatical class, frequency), and by the lexical status of the to-be-spelled string (word or pseudoword), but is sensitive to length. Also consistent with this account is the observation that across tasks, errors result from loss of segmental information about the target string (Caramazza *et al.*, 1987).

These features are similar to those reported on in previously described subjects with acquired dysgraphia (Caramazza *et al.*, 1987; Cubelli, 1991; Katz, 1991; McCloskey *et al.*, 1994; Jónsdóttir *et al.*, 1996; Kay and Hanley, 1994; Ward and Romani, 1998; Schiller *et al.*, 2001; Cotelli *et al.*, 2003). However, some aspects of GSI’s performance make his disorder unique. We will discuss them in the following sections.

Qualitative analyses of GSI’s spelling disorder

(a) Selective disorder in spelling consonants

A striking aspect of GSI’s performance is that he virtually only made errors on consonants. The distribution of errors on consonants and vowels across the various tasks administered to GSI is reported in Table 3. It is clear that, regardless of task, errors selectively affect consonants, while sparing vowels. Collapsing across tasks and across unequivocally interpretable responses to words and pseudowords, our subject spelled

Table 3. Error rate on consonants and vowels across various spelling tasks. Percentages are in parentheses. Only the letters included in stimuli reproduced correctly and in stimuli that yielded scorable errors were retained for analyses. Uninterpretable errors produced to 15 pseudowords and to 18 words (13 in writing to dictation, 5 in picture naming) were not counted. Also 28 short (2–3 letters) grammatical words produced in the written narrative were excluded from this analysis. To prevent overestimation of errors on consonants, geminate clusters were counted as 1 consonant (e.g., gatto was considered as containing 2 consonants and 2 vowels; consequently, errors like *ga__o* were scored as omissions of 1 consonant).

	Dictation nonwords (n = 65)	Dictation words (n = 379)	Naming pictures (n = 97)	Spontaneous narrative (n = 31)	Oral spelling (n = 111)	Total
Incorrect letters/Total letters (%)	100/412 (24.3)	546/4452 (12.3)	58/556 (10.4)	18/180 (10.0)	47/640 (0.07)	769/6240 (12.3)
Errors on consonants/Consonants in corpus (%)	99/217 (45.6)	536/2324 (23.5)	57/293 (19.5)	17/91 (19.7)	46/312 (14.7)	755/3237 (23.3)
Errors on vowels/Vowels in corpus (%)	1/195 (0.5)	10/2128 (0.5)	1/263 (0.4)	1/89 (1.1)	1/328 (0.3)	14/3003 (0.5)

incorrectly 769/6240 (12.3%) letters: 755/3237 (23.3%) consonants and 14/3003 (0.5%) vowels. In other words, 98.2% (755/769) of the letters he spelled incorrectly were consonants. In the literature, a disproportionate difficulty spelling vowels with respect to consonants has been reported in three cases (Cubelli, 1991; Cotelli *et al.*, 2003), and the reverse pattern of performance has been reported in another case (Kay and Hanley, 1994). GSI resembles the last subject, since his spelling impairment involves consonants, but he provides the first case of a total dissociation between consonants (severely damaged) and vowels (completely spared). Taken together, these cases strongly suggest that vowels and consonants can doubly dissociate in spelling, as has been already demonstrated in speech (Caramazza *et al.*, 2000).

(b) Serial position effect

The second feature of GSI's dysgraphia is a clear serial position effect. Errors increased as a function of position within a word. Thus, in spelling 6-letter words, our subject produced incorrectly 4/286 (1.4%) letters in positions 1–2, 42/286 (14.7%) letters in positions 3–4, and 59/286 (20.6%) letters in positions 5–6 (Fig. 2).

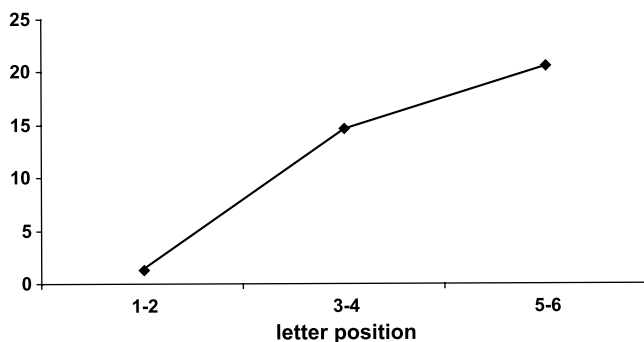


Fig. 2. The overall distribution of error performance on 6-letter words. Errors on positions 1–2, on positions 3–4 and on positions 5–6 are collapsed. Error rate increases monotonically from initial to final positions.

(c) The interaction of letter type by position

The pattern of performance documented for GSI differs from that of other subjects with putative deficit at the level of the graphemic buffer (Caramazza *et al.*, 1987; McCloskey *et al.*, 1994; Jónsdóttir *et al.*, 1996; Kay and Hanley, 1994), whose errors are concentrated in the middle portions of the word, but is consistent with the performance of several other cases who presented with a monotonic increase of errors as a function of serial position (Katz, 1991; Ward and Romani, 1998; Schiller *et al.*, 2001). However, there is an important feature that sets GSI's performance apart from that of the other cases of the latter type. In all the subjects who presented with a monotonic increase of error rate, accuracy of performance in spelling a letter in a word or pseudoword was entirely predicted by its distance from the beginning of the string – i.e., by its absolute position.

In stark contrast with this pattern, the combination of the performance features described in Sections a. and b. results in another striking aspect of GSI's dysgraphia: a clear interaction of letter type by position. Our subject invariably produced correctly the first but not subsequent consonants, with error rates increasing as a function of serial position. In the same words, vowels were systematically produced flawlessly. This behavior is shown by the results reported in Fig. 3, in which the occurrence of errors in various within-word positions is presented for words of the same length and CV structure.

In order to study in greater detail this aspect of GSI's performance, we considered the sequence of consonants contained in a word or in a pseudoword, and scored the errors involving the various consonants in each sequence. We considered words that contained 2, 3, 4 or 5 consonants, and scored the errors that occurred in each consonant position, in each group of words. This allowed us to compare the error rate on consonants that occupied the same absolute position in words with different numbers of consonants – for example, the occurrence of spelling errors on the second consonant of words containing 2, 3, 4 and 5 consonants. As a consequence of this scoring procedure, words with the same number of letters were assigned to different groups depending on the number of consonants, and words with different numbers of

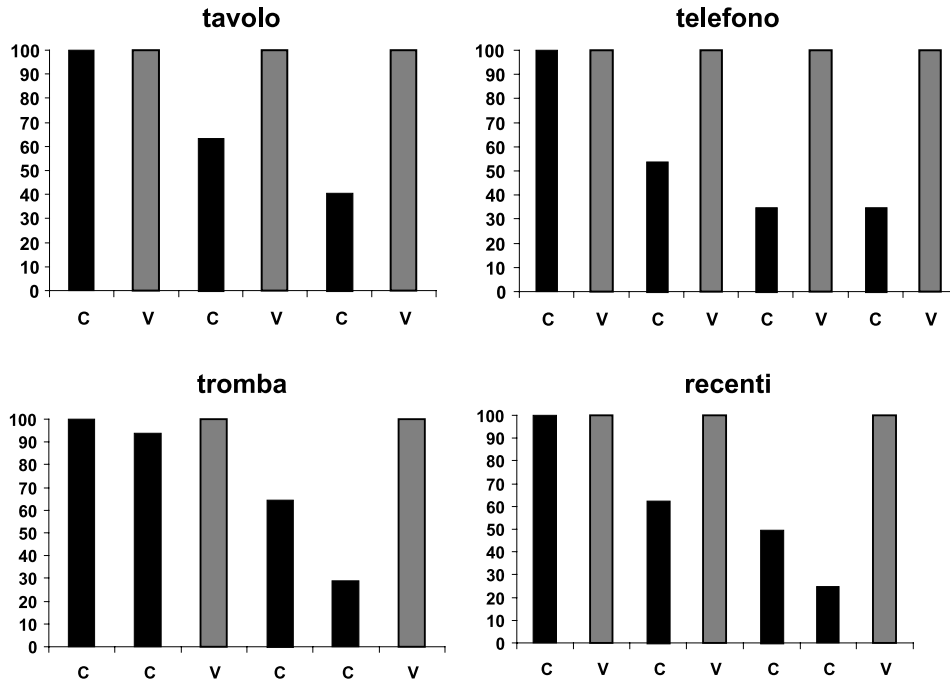


Fig. 3. Distribution of correct letters produced by GSI in responding to words of several different consonant/vowel structures: CVCVCV structure (N = 34; e.g., *tavolo*, table), CVCVCVCV structure (N = 25; e.g., *telefono*, telephone), CCVCCV structure (N = 17; *tromba*, trumpet), and CVCVCCV structure (N = 8; *recenti*, recent). Errors involve only consonants, and increase as a function of within-word consonant position.

letters but the same number of consonants were assigned to the same group. For example, the 6-letter words *ariete* (ram), *tavolo* (table) and *nastro* (ribbon) were scored in different word groups as they contain 2 (*rt*), 3 (*tv*) and 4 (*nstr*) consonants, respectively. By the same token, the words *anche* (too), *carota* (carrot), *piovvere* (to rain), *coesione* (cohesion) were all scored as 3-consonant words, even though their graphemic length ranges from 5 to 8 elements. The results of this analysis are reported in Fig. 4. It is obvious that the probability of correctly producing a consonant decreased as a function of its position from the beginning of the sequence of

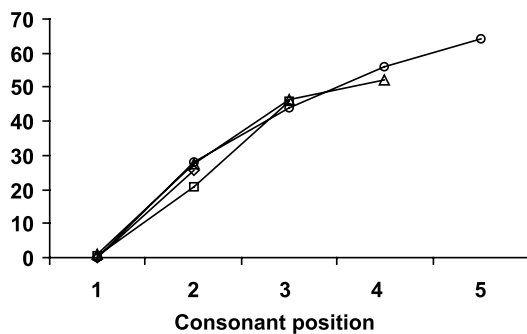


Fig. 4. The overall distribution of error performance shown separately for consonants as a function of their respective serial positions within words. Errors on consonants increase monotonically as a function of their absolute position within the sequence of consonants in a word (performance on vowels remains normal across the entire string).

consonants in a word or nonword (Fig. 4). For example, the probability of writing incorrectly the third consonant in a word containing 3 consonants (46%) was higher than the probability of producing the second consonant in the same word (21%), but identical to the probability of producing the third consonant in words containing 4 or 5 consonants (46% and 44%, respectively). Statistical analyses demonstrate that error rate was comparable for the same consonant position, irrespective of the number of consonants in the target string. Thus, for the consonant in second position, $\chi^2 = 2.252$; $df = 3$; $p = n.s.$; for the consonant in third position, $\chi^2 = 0.040$; $df = 2$; $p = n.s.$; and, for the consonant in fourth position, $\chi^2 = 0.331$; $df = 1$; $p = n.s.$

An additional question is whether the performance on consonants in this subject is constrained only by the position of a consonant relative to other consonants in the string, or also by its absolute position in the string. Inspection of Fig. 3 suggests that the latter might be the case. In fact, the consonant in second position is produced more accurately in strings like *tromba*, where it takes the second absolute position, than in *tavolo*, *telefono* and *recenti*, where it is in the third absolute position.

To try to clarify this issue, we conducted two separate analyses, which yielded contrasting results. In the first analysis, we considered accuracy in producing the second consonant in words of various lengths, whose beginnings were of three types: CC- (e.g., *prato*, field), CVC- (e.g., *telefono*, telephone) or CVVC- (e.g., *tiepido*, lukewarm). In these three groups of targets, the second consonant appears in the second,

third and fourth absolute position in the string, respectively. GSI misspelled the second consonant in 6/115 (5.2%) stimuli beginning with a CC-cluster, in 81/422 (19.2%) stimuli beginning with a CVC-initial sequence, and in 23/71 (32.4%) stimuli beginning with a CVVC-sequence ($\chi^2 = 23.010$; $df = 2$; $p < .001$). These results are consistent with the hypothesis that GSI's ability to produce a consonant is constrained by the absolute position of that consonant in the string. However, this conclusion is challenged by two further observations. We considered response accuracy on the third consonant, in words in which this consonant occupies the third (e.g., *strano*, strange), fourth (e.g., *trono*, throne), fifth (e.g., *tavolo*, table) and sixth (e.g., *anziano*, elderly) position. In responses to these types of stimuli GSI produced incorrectly the third consonant in 4/15 (26.7%), 95/322 (29.5%), 92/177 (52%), and 18/45 (40%) cases, respectively. In this analysis, then, the error incidence does not increase from the first to the second group of stimuli; and it decreases in the fourth group of stimuli compared to the third. Furthermore, the analysis of GSI's responses to stimuli with the third consonant in fourth absolute position shows a clear, albeit non significant effect of CV structure: our subject produced incorrectly this consonant 6/16 times (16.3%) when it was in a singleton position, as in *trono*, but 37/79 times (46.8%) when it was in a cluster, as in *carne*, meat ($\chi^2 = 1.047$; $df = 1$; $p = n.s.$).

To sum up, variable accuracy on the second consonant as a function of the number of intervening vowels suggests that GSI's performance on consonants may be constrained by their absolute positions in the orthographic string. However, performance on the third consonant suggests that orthographic context (e.g., whether the consonant is a singleton or part of a cluster) may also play a role. It is quite possible that spelling accuracy on a consonant results from the complex interaction of several dimensions, such as absolute position in the to-be-written string and syllabic structure. Unfortunately, the relatively small number of observations does not allow more detailed analyses.

Even though at this stage a firm conclusion on this issue is not possible, one unquestionable fact is clear: in this subject, the probability of a letter being produced correctly is a function of both its representational type and its position. GSI almost invariably spells vowels correctly, and selectively makes errors on consonants, whose probability increases with position.

(d) Does the consonant/vowel dissociation result from a grapheme frequency effect?

Having documented both the selective inability to spell consonants and the sparing of the first consonant in GSI's responses, we are in a better position to carry out analyses aimed at answering an important question. We would like to argue that the spelling disorder in this subject results from a categorical impairment of consonants with respect to vowels. Could this profile result from a grapheme frequency effect

instead? After all, consonants are less frequent than vowels, and this simple fact might render them more vulnerable to working memory deficits.

On the face of it, this possibility is remote, since GSI systematically produced correctly the consonant in first position – and there is no reason to assume that the consonants in initial positions are systematically more frequent than those that appear later in the graphemic string. However, for a more detailed evaluation of this possibility, we compared the distribution of errors on the various consonants in GSI's spelling corpus, with their frequency of occurrence in Italian. We considered the corpus of 183,642 letters (in 22,732 words) included in a frequency lexicon for Italian words (Bortolini *et al.*, 1971). Since GSI never made errors on the first letter of a string, all the initial letters in this corpus (5,240 vowels and 17,492 consonants) were excluded from further analyses, thus leaving 160,910 graphemes (77,120 vowels and 83,790 consonants). Only consonants were entered in the analyses that follow.

The corpus of 718 words administered to GSI in writing to dictation was considered for this analysis. The corpus included 4,616 letters (2,128 vowels and 2,488 consonants). After stripping off the first letter, 2,040 vowels and 1,858 consonants were left. The frequency of occurrence of the letters in the corpus analyzed for GSI closely matched that observed in the frequency lexicon (Pearson's $r = 0.955$; $df = 20$; $p < .001$). This was true also when the analysis was restricted to consonants (Pearson's $r = 0.915$; $df = 15$; $p < .001$).

An account of GSI's performance based purely on the frequency of occurrence of a letter predicts that letters with low frequency of occurrence should be misspelled more often than those that occur more frequently – it predicts a strong negative correlation between frequency of occurrence and error rate. Contrary to the prediction, an insignificant positive correlation was observed between these two dimensions (Pearson's $r = 0.419$; $df = 15$; $p = n.s.$). Qualitative analyses confirm this statistical observation. Graphemes with comparable frequency of occurrence yielded very different error rates; and a similar error rate was observed for graphemes of disparate frequencies. For example, *d* and *v* occur with similar frequency in Italian (both account for 2.4% of total graphemes), and yet they were misspelled by GSI in 47.3%, and 12.7% of the cases, respectively. In addition, *f*, *l*, *m*, *n*, *r* and *t* were misspelled to comparable extents (between 30.3% and 34% of the times) even though their frequencies of occurrence are very different: *f* is one of the least frequent graphemes in Italian (0.9%), *m* and *l* are of intermediate frequency (2.9% and 3.7%, respectively), and *n*, *t* and *r* are the most frequent consonants (7.4%, 8.1% and 8.3%, respectively). The frequency account is further undermined by the comparison between consonants and vowels. With the exception of *u*, vowels are more frequent than consonants in Italian. However, the frequencies of *o* (10.3%) and of the most frequent consonant, *r* (8.3%), are not very different, and yet *o* was always spelled correctly, whereas the error rate

for *r* was 31%. An even more striking contrast emerges from the comparison of performance on letters *u* and *d* (2.3% and 2.4% of total graphemes in the language, respectively): the error rates were 0% for *u*, and 47.3% for *d*.

We cannot rule out completely that very subtle differences among consonants, regarding their probability of occurrence in various within-word positions, may have influenced GSI's performance to some extent. For example, GSI might have produced *v* more accurately than *d* because, even though these two graphemes are comparably frequent, they might occur systematically in different word positions (*v* might more often occur in initial positions, *d* more often in final positions). Such an outcome would be very surprising, however. In the specific contrast considered here, *v* is the final consonant of all the verbs in the imperfect indicative (a high-frequency form of the Italian verb paradigm), whereas *d* is the final consonant of the gerund (a low-frequency verb form in Italian). In short, the dissociation between consonants and vowels observed in GSI's errors is not reducible to a grapheme frequency effect.

Discussion

Two main facts have emerged from this research. The first is that the monotonic decline in spelling accuracy as a function of error position, restricted to consonants, reveals the interaction between a working memory system and the content of orthographic representations. The second is that consonant representations in a word can be damaged completely independently of vowel representations. These facts place important constraints on our understanding of a neurally defensible theory of written language production.

(a) *The interaction of representational types with working memory*

Two types of serial position effect have been documented in subjects with graphemic buffer damage. In the first, errors tend to cluster in the middle positions within a letter string; in the second, they tend to monotonically increase from initial to final positions.

The first pattern has been observed in several cases (Caramazza *et al.*, 1987; McCloskey *et al.*, 1994; Jónsdóttir *et al.*, 1996; Kay and Hanley, 1994) but still escapes a fully convincing explanation. Initially, it was linked to the function observed in recall tasks, and considered to be due to the nature of spelling – a task that involves recalling the graphemes that comprise the written string (Wing and Baddeley, 1980). However, as stressed by Caramazza *et al.* (1987), this account is unsatisfactory: spelling is a serial recall task, and responses to serial recall, short-term memory tasks do not result in a reverse-U shaped curve. Thus, more recently it has been suggested that this error distribution may result from lower-than-normal activation of the target string, which would result in relative sparing of initial and final segments, and in greater vulnerability of middle segments, because initial and final segments may be learned better than middle segments

(Schiller *et al.*, 2001). In a different framework, the reverse-U shaped function observed in subjects with graphemic buffer damage has been successfully simulated by “competitive queuing” (CQ) models (Shallice *et al.*, 1995). These models include three layers of units: control nodes, grapheme nodes and a ‘competitive filter’. The grapheme nodes comprising a word are connected to two control nodes: an initiate (I) and an end (E) node. The graphemes in initial positions are characterized by strong connections to the I-node and weak connections to the E-node, whereas the reverse is true for letters in final positions. The I-node is maximally active at the beginning of a word, and its activation decreases with time; the reverse is true for the E-node. According to this approach, the reverse-U shaped error distribution would result from three features of the simulation: the lesser distinctiveness of letters in the middle of the to be-written sequence, the reduced opportunity for movement errors near the start and the end of a sequence, and the removal of competing graphemes from the pool of potential candidates for production (Glasspool, 2000).

The monotonic decline of spelling accuracy as a function of serial position, also documented in several dysgraphic subjects (Katz, 1991; Ward and Romani, 1998; Schiller *et al.*, 2001), has been attributed to graphemic buffer damage, i.e., to an impairment of the working memory system that holds orthographic representations active for further stages of the spelling process. Owing to the serial nature of spelling tasks, graphemes in initial positions remain in the buffer for a shorter time, while those in middle and final positions must be kept active in the buffer for a longer time (Schiller *et al.*, 2001). In the event of reduced capacity of the buffer, or of an abnormally fast decay of the information stored in the buffer, initial letters are produced correctly, and the error probability increases steadily for the following letters. This type of error distribution is problematic for CQ models. In this context, damage to the E-node might increase the error rate on final letters, as observed in these subjects. However, it predicts that repeated letters (e.g., the double *a* and the double *t* in *patate*, potatoes) should be particularly difficult to produce. This prediction was not borne out in the data reported for subjects BA (Ward and Romani, 1998), TH and PB (Schiller *et al.*, 2001).

The error distribution documented for GSI is clearly of the latter type, but it differs from previously reported cases in interesting respects. Its detailed analysis provides further evidence for the CV status distinction, and stimulates speculations on the mechanisms involved in processing orthographic representations in spelling.

The error distribution presented in Fig. 3 rules out a generalized working memory deficit as the cause of the impaired performance for our subject. Had this been the mechanism underlying GSI's spelling deficit, errors should have increased monotonically, as observed, but all types of letters should have been affected equally, as in other subjects in whom the same error distribution was demonstrated (Katz, 1991; Ward and Romani, 1998; Schiller *et al.*, 2001). In stark contrast with this pattern of performance, GSI only made errors on consonants, whose occurrence steadily increased with consonant position.

The interaction of serial error position by grapheme type (consonant/vowel) observed in GSI cannot be explained simply as the result of damage to a specific type of orthographic representations (consonants), either. In this case, we would have expected poor performance with consonants independently of their position within a word (i.e., the lines in Fig. 3 should have been flat, with the first consonant being as likely to result in an error as the second, third, etc.). A pattern of this type was reported for LiB (Cotelli *et al.*, 2003), who misspelled letters to essentially the same degree when they were in initial (27%), middle (19%) or final (23%) positions, and showed an analogous, albeit milder, selective disorder for vowels in reading aloud. This pattern of performance is consistent with the hypothesis that LiB suffers from selective damage to vowel representations. A substantially flat error distribution was reported also in the subjects with categorical disorders for vowels and consonants in speech (Caramazza *et al.*, 2000). GSI's performance offers an interesting contrast to the latter distribution of errors. He consistently produced the first consonant correctly, and only started making errors on the second consonant. This pattern of performance clearly rules out selective damage to a representational type (consonants), and locates the functional lesion at the level of the interaction of the orthographic information with working memory (the buffer mechanisms). Sparing of consonant representations in this subject also accounts for the fact that he reads aloud words, pseudowords and sentences essentially without errors (see Table 1). In these tasks, the stimulus remains visible to the subject, thus reducing error probability to a minimum.

Flawless performance on the first consonant and monotonic error increase on following consonants suggests that spelling errors in GSI arise at a stage of the spelling process in which a specific representational type (consonants) interacts with the working memory system that is necessary to maintain these types of information active during serial output. More specifically, spelling a word requires both that the consonants and vowels comprising the target string be activated, and that each grapheme be kept active until further stages of processing are completed. Poor performance in our subject might result from the combination of very mild damage to consonant representations (so mild that it does not affect correct spelling of the initial consonant) with pathological decay of the information stored in the working memory system. As a consequence of this association of deficits, a consonant in final within-word positions will no longer be active when it is time for production.

Several aspects of this subject's performance suggest that the spelling disorder cannot be attributed to a phonological deficit. Across speech production tasks, segmental errors were rare (and difficult to clearly distinguish from purely articulatory errors). In single-item production tasks, for example, GSI only produced segmental errors to 9/72 (12.5%) pseudowords in repetition, and 7/90 (7.8%) pseudowords in reading; and he produced segmental errors to 4/90 (4.6%) words in repetition, 3/184 (1.6%) in reading aloud, and 2/116 (1.7%) in picture naming. This contrasts with the very high error rate

observed in spelling tasks. In addition, the within-word distribution of errors in these tasks did not conform to that documented in spelling, since our subject mostly mispronounced letters in the initial part of the stimulus, but mostly misspelled letters in middle and final positions. As a further suggestion that the disorder in GSI is strictly orthographic, in the course of spelling tasks he often repeated the stimulus to himself correctly, while still being unable to spell it. Thus, the results reported for GSI complement the reverse clinical picture, namely, selective damage to the phonological working memory in the absence of comparable disorders of the orthographic working memory, documented in other brain-damaged subjects (Caramazza *et al.*, 1986; Shallice *et al.*, 2000).

The fact that orthographic processing can be affected independently of phonological processing suggests that the working memory systems are content-specific (Levy and Goldman-Rakic, 2000) – that is, distinct working memory systems are involved in processing different types of representational contents (e.g., visual vs. phonological vs. orthographic). Furthermore, the observed dissociation between consonants and vowels within the orthographic system is consistent with the possibility that the storage and “refreshing” components of the working memory systems function relatively autonomously (Smith and Jonides, 1998).

Be this as it may, the interaction between working memory and orthographic representations reveals that the process subsumed under the rubric “graphemic buffer” actually consists of a distributed set of mechanisms that can be damaged independently of each other.

(b) The independent representation of consonants and vowels

The most important fact that emerges from GSI's performance is the highly selective disorder in spelling consonants. Two sets of observations in the literature suggest that consonants and vowels are represented independently of each other. In the first place there is the well-known fact that, in subjects with graphemic buffer damage, substituted letters preserved the consonant-vowel status of the correct target (Caramazza and Miceli, 1990; McCloskey *et al.*, 1994; Jónsdóttir *et al.*, 1996; Kay and Hanley, 1994; Ward and Romani, 1998; Schiller *et al.*, 2001). Secondly, instances of disproportionate damage for one representational type have been reported in neuropsychological studies of spelling (Cubelli, 1991; Cotelli *et al.*, 2003) and of speech (Caramazza *et al.*, 2002). The evidence for spelling is highly suggestive, at least as concerns vowels. In one case (Cubelli, 1991), a complete but very short-lived dissociation was documented; whereas a disproportionate impairment of vowels over consonants was recorded in two further cases with a stable spelling disorder. Across a series of tasks, CW (Cubelli, 1991) and LiB (Cotelli *et al.*, 2003) misspelled vowels much more frequently than consonants (CW: 83% vs. 17%; LiB: 85% vs. 15%). In both cases, substitutions (83% of total errors in CW; 96% of total errors

in LiB) were by far the most frequent error type. The reverse, complementary dissociation was shown in subject John (Kay and Hanley, 1996), who produced significantly more errors on consonants (79.4%) than on vowels (20.6%).

The spelling behavior documented for GSI contrasts strikingly with that observed in CW and LiB. Regardless of task type (oral and written spelling, narrative writing, written picture naming) and of stimulus type (familiar or novel words), in our subject essentially all spelling errors (98.2%) involved consonants, and mostly resulted in letter omissions (78.4% of misspelled letters were omitted). GSI, then, completes the double dissociation between consonants and vowels in spelling disorders, and strengthens the argument for the separation of the two representational types.

The selective difficulty in spelling consonants cannot be attributed to a phonological deficit (see previous section) and it is not an effect of grapheme frequency. Although consonants are less frequent than vowels, and hence potentially more vulnerable to brain damage, nothing in the data collected from GSI suggests that grapheme frequency constrained his spelling performance: graphemes with comparable frequency of occurrence yielded disparate error rates, and similar error rates were observed on graphemes of disparate frequencies of occurrence.

To sum up, the observations reported for GSI demonstrate the selective inability to spell consonants, in the presence of spared ability to spell vowels and to produce both vowels and consonants in spoken output. Since the effect cannot be accounted for either in terms of a phonological effect or as a consequence of the distributional properties of Italian orthography, it most likely results from a categorical distinction between orthographic consonants and vowels.

The categorical nature of the distinction between consonants and vowels is further supported by the fine-grained analyses of the stimulus/error relationships carried out on the substitution errors produced by LB (Caramazza and Miceli, 1990) and HE (McCloskey *et al.*, 1994). In both subjects, substituted letters overwhelmingly preserved the CV status of the target (LB: 99.5%; HE: 95%). At the subsegmental level, incorrect letters were motorically and visually unrelated to the target (in 62% of the cases for LB, and in 63% of the cases in HE), and shared stroke features with the target only very rarely (LB: 2%; HE: 11%). These results contrast with those obtained from the same analyses in two other subjects with post-graphemic buffer damage (Rapp and Caramazza, 1997). These two subjects presented with a selective impairment (case JGE) and with a disproportionate, albeit not selective deficit (case HL) of written as opposed to oral spelling, and both produced many letter substitution errors. Unlike LB and HE, the latter patients' incorrectly written letters did not significantly preserve the CV status of the target (JGE: 73%; HL: 59%), and frequently bore a close subsegmental (motor) correlation with it (for example, E → F; this was true for 30% of the errors produced by JGE and for 37% of those produced by HL). The results documented for the two subjects with graphemic buffer damage support the contention that

their errors arise at an abstract level – one that specifies consonants and vowels as separate abstract categories.

These conclusions parallel those drawn on the basis of two case studies in the domain of phonology. In repetition tasks, subjects IFA and AS produced disproportionate numbers of errors to consonants and to vowels, respectively (Caramazza *et al.*, 2000). Also in these cases, detailed error analyses ruled out the possibility that subphonemic properties (sonority and articulatory features) were responsible for the observed double dissociation, thus strongly suggesting selective damage to categorical representations.

Two types of models have been proposed to account for normal and pathological spelling performance. Models of the type we have considered thus far propose that orthographic representations independently specify the identity of graphemes and their CV status (Caramazza and Miceli, 1990; McCloskey *et al.*, 1994). For example, the orthographic representation of *mare*, sea, codes at autonomous levels the facts that the string consists of a Consonant-Vowel-Consonant-Vowel sequence, and that the grapheme corresponding to the first consonant is <m>, the grapheme corresponding to the first vowel is <a>, and so on. Alternative models, such as the CQ (Competitive Queuing) models,³ do not distinguish CV status and grapheme identity, and do not assume an autonomous CV layer (Shallice *et al.*, 1995). Models of this latter type cannot accommodate the results presented for subjects like GSI and CF (Cubelli, 1991). Of course, one can imagine modifying a CQ-type model so as to include other independent levels of representation. For example, in one such model developed to implement serial output in speech, a syllabic structure layer was added in order to better fit the performance observed in normal subjects (Hartley and Houghton, 1996). It is difficult to anticipate what would happen if a CQ model of spelling were adjusted to incorporate (some or all of) the representational assumptions proposed in models of the first type (Caramazza and Miceli, 1990; McCloskey *et al.*, 1994). In a development of the original CQ model (Glasspool and Houghton, 1997), a CV constraint was built in the system, by adding a bias that favors the activation of all vowel graphemes in V positions and of all consonant graphemes in C positions. However, damage to the system only yields graded effects, as shown by Fig. 3 in Cotelli *et al.* (2003), where reduced activation of the set of vowels or of the set of consonants results in relatively greater impairment of vowels than of consonants, or *vice versa*, but never in exclusive damage to either grapheme type. In a more recent version of the model (Glasspool and Houghton, submitted, quoted in Cotelli *et al.*, 2003), a CV layer entirely autonomous from the grapheme layer has been included. For each letter position, the corresponding C or V node is activated, which then sends activation to the target grapheme. Depending on the node that is activated, only consonants or only vowels will compete for production. Since these models assume graded representations, it is unclear whether or not under conditions of damage they will still yield graded effects (i.e., consonants relatively more impaired than vowels, or *vice versa*), or the categorical-type

dissociations documented in subjects like GSI or CF (Cubelli, 1991). Interestingly, the more recent versions of the CQ model have progressively incorporated the representational assumptions proposed in our original model of the structure of orthographic representation (Caramazza and Miceli, 1990).

Anatomo-functional correlates

The lesion information in our subject – a left fronto-parietal lesion (Fig. 1) – is consistent with the conclusion that functional damage involves the interaction between representational types and working memory. It converges with three sets of observations. In the first place, neurophysiological studies in the monkey suggest that frontal and parietal structures (and in particular areas 8 and 7, whose equivalents were among those affected by GSI's lesion) behave as a functional unit (Andersen *et al.*, 1995; Chafee and Goldman-Rakic, 1998, 2000). In the second place, neuroimaging research (Paulesu *et al.*, 1993; Smith and Jonides, 1998) has implicated a left fronto-parietal circuit for the working memory system involved in language processing. Finally, neuropsychological evidence (Caramazza *et al.*, 1987; Katz, 1991; McCloskey *et al.*, 1994; Ward and Romani, 1998; Schiller *et al.*, 2001) shows that subjects with graphemic buffer damage usually present with lesions involving frontal structures, parietal structures, or both (the only exception so far is LiB (Cotelli *et al.*, 2003), whose pattern of performance might be accounted for without assuming graphemic buffer damage). Of course, any conclusion from our case must be cautious, because GSI's lesion is extensive, and individual lesion data are difficult to interpret with confidence. Even with these limitations, however, the anatomical correlates obtained in our subject confirm the involvement of the fronto-parietal structures in the stages of the spelling process that take place at the level of the graphemic buffer.

Conclusions

The results reported here provide the strongest confirmation yet, in the area of orthography, of the suggestion that consonants and vowels are represented separately, since they show that the selective difficulty in producing consonants is not associated with a generalized impairment in processing all types of information. The total sparing of vowels is a clear indication that consonants and vowels are represented independently of each other. Independent evidence for the separability of consonants and vowels has been provided for speech production as well (Caramazza *et al.*, 2000). Taken together, segmental disorders of written and of spoken production show that consonants and vowels can be separately impaired, and that damage to representational types can independently affect speech and spelling. In other words, data from aphasia converge in suggesting that phonological and orthographic vowels and consonants are represented categorically, in distinct neural networks. The functional reason for the distinction between the two representational types probably resides in the very different

role they play in production, and in particular in determining the syllabic structure of the target: vowels occupy the nucleus position, consonants occupy non-nucleus positions.

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Notes

¹Visual extinctions notwithstanding, no evidence of neglect phenomena emerged from standard visuo-spatial tasks, such as line cancellation, line bisection, visual search tasks, spontaneous drawing and copy of complex drawings.

²The word length effect in this subject's performance is very clear (Table 2). However, since GSI's error rate is carried entirely by misspelled consonants (see later), and since stimuli were not matched for CV structure, the length effect *per se* is uninformative. For a more accurate measure, the error probability in a word was scaled by the number of consonants in that word. We considered the probability of misspelling one of the consonants in the target string as a function of the number of consonants in the target. In words with 1, 2, 3, 4 and 5 consonants, the average number of consonants misspelled by GSI rose from 0%, to 13.4%, 18.7%, 28.5% and 32.7%, respectively. Arbitrarily setting 1.5 consonants as unity and scaling the probability of an error by the discrepancy of word length from unity (error probability $\times 1.5$: number of consonants), the scaled error probabilities were 0%, 10%, 9.4%, 10.7% and 9.8%, respectively. Thus, the length effect would seem to result from the linear increase of error probability with the number of consonants in the word. However, this analysis is also not very informative – it measures a complex effect, resulting from length and serial position. In fact, systematic sparing of the first consonant and the substantial position effect (see later) suggest that consonant position in a string is at least as relevant as the number of consonants in constraining GSI's performance.

³Although the CQ model in its various versions is often discussed as a connectionist model, it is really a localist representation model, as it postulates discrete representations for graphemes as well as for geminate features.

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