

Qualitatively different forms of pure alexia

Cristina Rosazza

Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste, Italy

Ildebrando Appollonio and Valeria Isella

Neurology Section, Department of Neurosciences, University Milano Bicocca, San Gerardo Hospital, Monza, Italy

Tim Shallice

International School for Advanced Studies (SISSA-ISAS), Trieste, Italy, and Institute of Cognitive Neuroscience, London, UK

In this study we investigated two patients with pure alexia, F.C. and L.D.S., in order to make inferences about how processes and levels involved in the early stage of visual word recognition are organized and how they can be selectively damaged. Moreover, we investigated whether pure alexia can be caused by different functional deficits. F.C. and L.D.S. were presented with tasks of letter processing and tasks of orthographic integration. There was a clear double dissociation between the pattern of performance of F.C. and L.D.S. F.C. was able to process single letters rapidly and accurately, but was unable to group together the letters that he had correctly identified. By contrast, L.D.S. was slower and more impaired at letter identification, but she could use letter groups to assist reading. Thus, two different forms of pure alexia emerged: F.C. has a higher level deficit in integrating letters, whereas L.D.S. has a lower level deficit in letter processing. The results support the assumption of a functional organization of the reading process that involves a series of orthographic units (i.e., single letters, sub-lexical letter groups, and the lexical unit), which can be selectively damaged. Finally, our data present difficulties for models of pure alexia that assume all patients to have a low-level processing deficit.

Acquired disorders of the reading process can throw light on at least three types of issue. The first relates to the separability in the normal brain of the processes underlying reading from those relating to other cognitive processes such as object recognition (Cohen & Dehaene, 2004; Price & Devlin, 2004). The second issue

concerns the detailed functional architecture of the reading process itself. The third relates to how that functional architecture can be impaired. This study concerns the second and third of these issues.

The investigation of acquired dyslexia has made many contributions to our knowledge of the

Correspondence should be addressed to Tim Shallice (E-mail: shallice@sissa.it) or to Cristina Rosazza (E-mail: rosazza@sissa.it), Scuola Internazionale Superiore di Studi Avanzati (SISSA), Via Beirut n. 2–4, 34014 Trieste, Italy.

We are grateful to F.C. and L.D.S. and their matched controls for their active cooperation and patience over many hours of testing. We wish to thank Dr. Lucia Tedesco for enabling us to make contact with F.C. and the neuroradiologists Dr. Marco Grimaldi and Dr. Andrea Falini for their assistance with MRI scans. We should also thank Prof. Rick Hanley and two anonymous referees for their helpful comments on early drafts of the paper.

functional architecture of the reading system (Coltheart, 1985; Coltheart, Patterson, & Marshall, 1980; Ellis, 1993). However, earlier studies were mainly concerned with separating orthographic from subsequent processing and with specifying the processes that follow the orthographical analysis of words. In general, theoretical accounts of patterns of acquired dyslexic disorders have found it sufficient to assume that the organization of orthographic processing merely involves direct feed forward processing between a level of letter analysis and units corresponding to words (e.g., Behrmann, Plaut, & Nelson, 1998). In this respect accounts of the performance of patients merely reflect most computational models of the reading process (e.g., Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001; McClelland & Rumelhart, 1981; Plaut, McClelland, Seidenberg, & Patterson, 1996). Exceptions in the patient literature include analyses of attentional dyslexia (Shallice & Warrington, 1977) and of neglect dyslexia (e.g., Caramazza & Hillis, 1990; Ellis, Flude, & Young, 1987; Mozer & Behrmann, 1990). Most critically, Miozzo and Caramazza (1998) reported the case of a patient who showed a clear dissociation between her ability to access the visual shape of letters but not their abstract, graphemic identity. Their results support the position that abstract graphemic identities mediate access to the orthographic lexicon (McClelland, 1976) and the finding helps to constrain the architecture of the early stages of visual word recognition.

However, a variety of additional theoretical possibilities about the organization of orthographic processing has been mooted to account for the results of applying human experimental psychology methods to the study of the normal reading (Rouibah & Taft, 2001). For instance, Prinzmetal and colleagues (Prinzmetal, Hoffman, & Vest, 1991; Prinzmetal, Treiman, & Rho, 1986) used the illusory conjunction paradigm to determine the nature of the sublexical units that are automatically perceived at a perceptual level of word processing. In a series of experiments where subjects were briefly presented words composed of

colour letters, they showed that illusory conjunctions were more likely to occur between letters within syllables than between letters in different syllables: For instance, with a word like VODKA, subjects were two or three times more likely to incorrectly respond that the D was the colour of the V or O than the colour of the K or A. Rapp (1992) provided further supporting evidence using another illusory conjunction paradigm: Participants made more illusory conjunctions that preserved syllable units than illusory conjunctions that broke syllable units. These findings suggest that printed words have an internal organization based on orthographic units, with no influence of purely phonological structure. More importantly, these results argue for the existence of syllables as sublexical reading units.

There are other empirical observations supporting the hypothesis that syllables are processing units for visual word identification (Carreiras, Alvarez, & de Vega, 1993; Ferrand, Segui, & Grainger, 1996). For instance in a study with event-related potentials (ERPs), Carreiras, Vergara, and Barber (2005) found with bisyllabic words and pseudowords that when there was a match between syllable boundaries and colour boundaries, a different type of evoked response occurred than when there was a mismatch (see Experiment 5). This suggests first that, at least in languages with clear syllabic boundaries such as Italian, French, or Spanish, the syllable has a role in word processing, with respect to orthographic as well as phonological representation (see also Caramazza & Miceli, 1990); in addition it also suggests that there may be intermediate levels of orthographic units between letters and words.

One model that makes this second assumption but does not actually assume the existence of orthographic syllables per se is the "open bigrams" scheme (Grainger & Whitney, 2004; Whitney, 2001). This scheme, comprises five layers: a retinal level, a feature level, a letter level, and then a bigram level before the final, word level; therefore letter and word levels are not directly connected. On this account, word coding

is based on ordered letter pairs, the bigrams, which do not contain precise information about letter position.¹ Another recent study (Dehaene, Cohen, Sigman, & Vinckier, 2005) also supports the importance of bigrams in visual word recognition, although in the context of a different theoretical account. Dehaene et al. (2005) have developed the word-form model of word processing, which is derived generally from the neuropsychological literature on pure alexia (e.g., Cohen et al., 2003; Warrington & Shallice, 1980) and which is inspired from neurophysiological models of invariant object recognition. In this model local combination detectors become sensitive to increasingly larger fragments of words, from (abstract) letters to bigrams, morphemes, and finally words (see also Shallice & McCarthy, 1985, for an analogous more symbolic model). Cohen, Dehaene, and colleagues (Cohen & Dehaene, 2004; Dehaene et al., 2005) localized the system in the occipitotemporal area, in the so-called visual word-form area (VWFA; see also Kinsbourne & Warrington, 1963). Thus, in the current study we investigated whether there can be neuropsychological evidence for the existence of a sublexical level that lies between the letter and the lexical levels and whether this integrative process of letters into higher level units can be selectively damaged in patients with an acquired reading disorder.

The one neuropsychological study that relates to these hypothetical levels of processing between the abstract letter and word levels is that of Osswald, Humphreys, and Olson (2002). They investigated whether the alexic patient D.M. was able to use information coded at a supraletter level to help her reading. Functional spelling units (FSUs) that are visual units corresponding to a single phoneme were used (e.g., b-r-ai-n: four FSUs; th-r-ough: three FSUs). Results showed shorter naming latencies for words presented FSU by FSU than for whole words (and than for four-letter words presented 2×2 and

six-letter words presented 2×3). Osswald et al. (2002) hypothesized that although D.M. was generally impaired with supraletter reading, D.M. was strongly facilitated when subparts of words presented formed “functional spelling units”.

The third issue concerns the processes that can be separately impaired. If one considers the cases of pure alexia or letter-by-letter (LBL) reading described in the literature, given the hypothesized complexity of the orthographic processing system, it is natural to presuppose that this is a broad clinical category covering a set of functionally distinct conditions. Indeed a number of researchers have explicitly argued and given evidence for such a position (Chialant & Caramazza, 1998; Hanley & Kay, 1996; Miozzo & Caramazza, 1998; Patterson & Kay, 1982; Price & Humphreys, 1992). However, the issue interacts with that of how to provide a more detailed implementation of a model of the reading process. Thus, Behrmann et al. (1998) used the interactive activation model of letter and word perception (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982) as a framework to explain letter-by-letter reading. Their assumptions relating to the cascade nature of information transmission provided them with the conceptual possibility of attempting to explain deficits at multiple levels of the reading process in terms of a single common impairment. They assumed that there can be general perceptual deficit that prevents the identification of words. Yet weak activation can propagate in a cascaded and interactive way to higher levels to engage lexical and semantic representations, which in turn can provide top-down support to letter and word identification. They went much further and speculated that “a deficit in letter processing (perhaps attributable to an even more fundamental perceptual impairment) is *common to all LBL readers*” (pp. 45–46). A somewhat similar position holding letter processing to be the critical stage is advocated by Arguin, Bub, and colleagues (Arguin & Bub, 2005; Arguin, Fiset, & Bub, 2002).

¹ For example the word “take” is represented by activation of units (bigrams) representing TA, TK, TE, AK, AE, and KE.

The potential power of the cascade hypothesis and our lack of knowledge of how specific tasks map on to the hypothetical reading model mean that this position cannot be easily refuted. Thus, one can attempt to explain away striking dissociations that have been observed between impaired reading and intact performance on other tasks involving written letters or words. For instance, the pure alexic patient G.V. (Miozzo & Caramazza, 1998) showed an excellent performance in discriminating letters from mirror images on the Cooper and Shepard (1973) letter rotation task, but was unable to access graphemic representations.

It may be argued that well-performed tasks that clearly involve the main online processing systems involved in reading are not themselves sufficiently resource demanding in the sense of Shallice (1979). For instance, as claimed by Chialant and Caramazza (1998, pp. 197) concerning their pure alexic patient M.J. "we have taken M.J.'s perfect performance in letter naming at 16-ms exposure as an indication of preserved single-letter processing. We agree...that even in those cases in whom individual letter recognition is considered to be accurate, identification may well be slowed". Here *recognition* and *identification* refer to the highest levels of explicit letter categorization available in the orthographic system. Chialant and Caramazza are basically pointing out that 100% performance on this type of letter identification task does not demonstrate that the lower levels of the processing system are operating in a completely unimpaired fashion. Thus, on the Behrmann et al. (1998) interactive activation cascade account where the critical impairment is at a lower level, tasks that depend on selection of one from thousands of alternatives at a higher level of the system (e.g., word identification) could be more resource demanding than two-choice letter decision tasks and so give rise to poorer performance. The Behrmann et al. (1998) position cannot be easily dismissed.

The present study considers two pure alexic patients, L.D.S. and F.C., who have contrasting patterns of difficulty in single-letter and multiletter unit processing. They therefore speak to what we

have described as *Issue 2*—that is, the functional organization of the reading process and in particular the existence of different stages of processing involving single and multiple letters. With respect to *Issue 3*—that is, whether there are qualitative differences in how the early stages of the reading process can be impaired—the performance of the patients is relevant because they present a double dissociation across tasks. This pattern cannot be easily explained in terms of the account of pure alexia as a *single basic deficit* that results from impairment early in the cascade of visual/orthographic processes (Behrmann et al., 1998; Farah & Wallace, 1991; Saffran & Coslett, 1998).

PARTICIPANTS

Case report on F.C.

F.C. is an 85-year-old man with 8 years of schooling (starting with normal day-time school for 5 years and after at evening school) who worked as a draughtsman and mechanic. Despite his low educational level, he read books and newspapers extensively, being very interested in politics. In April 2001 he suffered an ischaemic stroke in the left occipital lobe, confirmed by magnetic resonance imaging (MRI) scans, and neurological examinations revealed a right homonymous hemianopia. MRI examination revealed a stabilized left occipital lobe and subcortical focal ischaemic lesion (see Figure 1a). His left inferior and medial occipital lesion involved the occipital pole (area 17), the lingual gyrus (area 18) with anterior and medial extension to the posterior parahippocampal gyrus and the occipital fusiform gyrus encompassing part of the collateral gyrus. Multiple, diffuse foci of chronic ischaemic encephalopathy were also present, mainly in the periventricular white matter and in the basal ganglia. More specifically, there was a primary white-matter lesion that involved the medial-posterior side of the occipital horn and the ventro-medial paraventricular white matter beneath it. The area over the occipital horn was likely to be intact. The splenium of

the corpus callosum was spared. A small right occipital lesion was also present in the lateral occipital gyrus (areas 18 and 19) and possibly extending into the posterior occipito-temporal sulcus bordering the occipital fusiform gyrus (area 19). A further MRI examination carried out in March 2004 confirmed the previous lesions and revealed a new one in the cortical and subcortical left parietal area involving the supramarginal gyrus and the angular gyrus. Three different neuroradiologists confirmed that the 2001 MRI examination did not show the left parietal lesion. The lesion did not cause any evident symptoms since the subsequent neurological examinations as well as his neuropsychological assessment repeated in 2004 did not show any change. In particular no change was apparent in his reading performance. At the time of testing F.C. (from February 2002) was able to write

normally and to read letters and digits. When he was asked to read words, he used a letter-by-letter strategy. He is alert, well oriented in time and place, and cooperative. He did not show other language, apraxic, or memory deficits; his main complaint is his inability to read newspaper and books.

Neuropsychological assessment

A general assessment revealed that F.C. was of normal intelligence (see Table 1) performing well on the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1986). He had good language abilities except for reading, with spontaneous speech being normal. F.C. had good spelling abilities on tasks of oral spelling with words and non-words from four to eight letters in length as well as on tasks of written spelling (see *Writing* below). His memory as assessed with the Story Recall

Table 1. *The performance of the patients on general neuropsychological assessment*

	<i>F.C.</i>	<i>L.D.S.</i>
MMSE	—	29
Token Test (Spinnler & Tognoni, 1987) ^a	32 (31.05 ± 2.93)	33 (33.6 ± 2.11)
Verbal Fluency (FAS) ^a	16; 13 ^b (22.5 ± 10.11)	28 (30.19 ± 9.64)
Raven Progressive Coloured Matrices (Raven, 1962)	25; 27 ^b (21.50 ± 6.95)	19.5* (26.75 ± 5.13)
WAIS (Wechsler, 1986) ^{a,c}		
Information	11	10
Digit Span	8; 7 ^b	7
Vocabulary	9	11
Arithmetic	9; 8 ^b	5 ^c
Comprehension	—	13
Similarities	11	13
Picture Completion	12	8
Picture Arrangement	—	9
Block Design	9	6 ^c
Object Assembly	5 ^c	6 ^c
Digit Symbol	—	7 ^c
Story Recall (Spinnler & Tognoni, 1987) ^a	7.7 (10.86 ± 3.17)	13.7 (12.37 ± 3.73)
Rey Figure Copy		11 ^f (32.44 ± 3.5)
Attentional matrices (Spinnler & Tognoni, 1987) ^a	30 ^c (39.68 ± 8.03)	53 (50.41 ± 8.78)
Test of ideomotor apraxia (De Renzi et al., 1980) ^d	68 ^b	

Note: Mean and standard deviation prorated by age are given in parentheses. MMSE = Mini-Mental State Examination. WAIS = Wechsler Adult Intelligence Scale.

^aThe scores are prorated by age. ^bThe score refers to retesting in 2004, carried out after the last MRI examination. ^cMean = 10 and *SD* = 3 for each subset according to the Italian correction (Wechsler Adult Intelligence Scale-Revised, WAIS-R, Contribution to the Italian scoring; age: 55–64 years). ^dCut-off: 53; borderline: 54–62. ^eScore <1 standard deviation below normal mean.

^fScore <2 standard deviations below normal mean.

(Spinnler & Tognoni, 1987) indicated a performance within the average range (see Table 1). After the second MRI examination, F.C. was also tested with the ideomotor apraxia test (De Renzi, Motti, & Nichelli, 1980): his performance was completely normal. When assessed on standardized perceptual tests (see Table 2), F.C. achieved normal scores on all the subsets of the Visual Object and Space Perception Battery (VOSP; Warrington & James, 1991) except on Silhouettes, although his performance was

impaired on the Object Decision and the Association Match of the Birmingham Object Recognition Battery (BORB; Riddoch & Humphreys, 1993). In another perceptual test, the Cortical Vision Screening Test (CORVIST; James, Plant, & Warrington, 2001), he scored well on all the subsets except those tapping colours. F.C. had slight colour agnosic or anomic difficulties on the colour-naming task (7/10) included in the Aachen Aphasia Test (AAT; Luzzatti, Willmes, & De Bleser, 1996). Brown

Table 2. *The performance of the patients on visual perception tasks*

	F.C.	L.D.S.
CORVIST (James et al., 2001)		
Symbol acuity test	24/24	36/36
Shape discrimination test	8/8	7/8
Size discrimination test	1/2	2/2
Shape detection test	8/8	8/8
Hue discrimination test	1/4	4/4
Word reading test	Normal, but slow	Normal but slow
Fragmented numbers test	7/8	8/8
Face perception test	5/8	8/8
BORB (Riddoch & Humphreys, 1993)		
Minimal features	—	22/25
Foreshortened view	—	24/25
Association match	25/30 ^c	27/30
Item Match	31/32	30/32
Object Decision		
A&B hard version	20/32 ^f & 25/32 ^c	23/32 ^f & 22/32 ^c
A&B easy version	26/32 ^c & 26/32 ^{c,f}	28/32 & 26/32 ^{c,f}
VOSP (Warrington & James, 1991) ^a		
Screening test	20/20	19/20
Incomplete Letters	17/20	17/20
Silhouettes	11/30 ^b	15/30 ^b
Object Decision	20/20	18/20
Progressive Silhouettes	10	6
Dot Counting	10/10	10/10
Position Discrimination	19/20	19/20
Number Location	10/10	10/10
Cube Analysis	10/10	10/10
Colour Naming (Luzzatti et al., 1996)	7/10	10/10
Ishihara's test	25/25	—
Benton test (Benton et al., 1992) ^d	41	42

Note: CORVIST = Cortical Vision Screening Test. BORB = Birmingham Object Recognition Battery. VOSP = Visual Object and Space Perception Battery.

^aThe scores are scaled by age. ^bScore below 5% cut-off score. ^cThe two measures reported in a cell are based on different pictures and therefore have different control values. ^dThe scores are prorated by age and education. ^eScore <1 standard deviation below normal mean. ^fScore <2 standard deviations below normal mean.

was named as orange, looking at orange he said: “*It is not brown, not orange, I don’t know*”, and violet was not recognized. However, his performance on the Ishihara test was flawless (25/25). F.C. was given the Benton Faces Recognition Test (Benton, Silvan, Hamsher, Varney, & Spreen, 1992) where his performance was borderline (see Table 2). A series of tasks tapping general abilities (Raven and Verbal Fluency) and arithmetic-related skills (Digit Span and Arithmetic subsets of the WAIS) in addition to tests of ideomotor apraxia (see above) was carried out again after his second MRI examination to reveal any difficulty associated with his left parietal lesion. The results did not show any significant change (see Table 1).

Case report on L.D.S.

L.D.S. is a 56-year-old right-handed woman with 13 years of schooling who had worked as an agent for a pharmaceutical company. In February 1998 she noted the sudden onset of an inability to read. This was due to an ischaemic stroke. A computed tomography (CT) scan (February 1998) demonstrated an infarction in the left posterior temporal lobe and a small right posterior frontal subcortical ischaemic area. The result was confirmed by an MRI carried out in June 2000 (see Figure 1b), which indicated a lesion in the left occipito-temporal part of the inferior temporal gyrus and in the left temporo-occipital fusiform gyrus encompassing the occipito-temporal sulcus (area 37). The lesion also involved the occipital fusiform gyrus (area 19) with no apparent involvement of the subcortical white matter. The corpus callosum was intact. Another lesion involved the subcortical white matter of both hemispheres in the fronto-central and posterior frontal regions and in the right hemisphere the subcortical white matter of the precentral gyrus. She had a right homonymous hemianopia. L.D.S. is clinically a “pure alexic patient”: She is able to write normally and to read letters and digits, but she uses a letter-by-letter strategy to read words. She is alert, well oriented in time and place, and cooperative.

Neuropsychological assessment

When tested in April 2002, L.D.S. performed within normal limits on the Vocabulary, Digit Span, and Similarities subsets of the WAIS (Wechsler, 1986), but had weak performance on the Arithmetic subset. She also performed weakly on the WAIS Performance IQ subsets (Block Design, Object Assembly, and Digit Symbol). She showed impaired performance on the Rey Figure copy test. These problems may be related to her right frontal lesion. Her spontaneous speech was fluent and well formed, and her comprehension abilities were good; like those of F.C., L.D.S.’s spelling abilities were intact on tasks of oral and written spelling (see *Writing* below). Moreover, her memory abilities were good (see the standardized tests in Table 1). On visual perceptual tasks her performance was normal, for the VOSP (Warrington & James, 1991) on all the subsets except for the Silhouettes task and for the BORB (Riddoch & Humphreys, 1993) again all the subsets, except for the Object decision test (see Table 2). Moreover she had no difficulties with the CORVIST test (James et al., 2001), and her performance was flawless on the colour-naming test (10/10) included in the AAT (Luzzatti et al., 1996). Finally her performance was normal on the Benton Faces Recognition Test (Benton et al., 1992).

Control group

Control participants participated in the study: A total of 7 (from C1 to C7) were matched to F.C. for age (mean age = 84.4 years; $SD = 3.4$) with 4 men and 3 women. The comparison is a conservative one as all the controls except one had a higher education level (mean schooling = 11.7, $SD = 2.4$, almost 4 years more than F.C.). The other 8 controls (from C8 to C16) were matched to L.D.S. for age (mean age = 58.75 years, $SD = 2.71$), gender, and education level (C10 had 8 years of schooling, the other controls 13 years of schooling). A key contrast will be of the direct comparison between F.C. and L.D.S.’s performance. However as they are different in age, interpretations must also be supported by comparisons of each with their controls.

DOCUMENTATION OF READING AND WRITING SKILLS

Prose reading

Patients and control participants were presented with a text to read taken from a battery of 325 words (Cornoldi & Colpo, 1995) used to assess reading abilities in young students with possible developmental dyslexia. The text comprised 325 words. Participants were asked to read at their own speed. Text reading was recorded with a microphone connected to a PC via a Cool Edit program (Syntrillium Software Corporation, 2002) for each patient and control participant.

F.C. took 9 min 49 s to read the text and made two errors. L.D.S. took 10 min 38 s to read and made five errors. Control participants C1 and C2, matched to F.C., took 3 min and 2 min 38 s and made six and zero errors, respectively. C8 and C9, matched to L.D.S., took 3 min 7 s and 2 min 21 s and made one and zero errors, respectively.

Word reading

A total of 120 words, 30 each of 4, 6, 8, and 10 letters in length, were presented in random order on a PC monitor using an E-prime program (Schneider, Eschman, & Zuccolotto, 2002). Words, taken from the *Corpus of contemporary written Italian CNR* (Istituto di Linguistica Computazionale del CNR di Pisa, 1989), were divided into abstract and concrete, and each of the two subgroups was matched for length, $F(1, 117) = 0.005$, $p = .941$, and frequency, $F(1, 117) = 0.359$, $p = .55$. Words were printed in lower case 30-point Arial font, and the microphone connected to the PC started measuring at the beginning of the vocal response. Responses in which an initial response phonologically related to the stimulus was immediately corrected (e.g., caccia...cacciatore) were removed as well as trials in which participants produced an explicit breath close to the response. Moreover if the microphone did not "hear" the voice, the E-prime program did not move to the next trial. These criteria were applied in all experiments.

By performing an analysis of variance, a clear word length effect emerged for both F.C., $F(1, 113) = 41.14$, $p < .0001$, and L.D.S., $F(1, 115) = 34.3$, $p < .0001$, whose increments in reading speed per letter were 90 ms and 160 ms, respectively (see Figure 2). They showed neither effects of imageability nor effects of frequency. They each made one error. Control participants (from C1 to C9, C12, C13, and C14) showed little increment in reading speed (ms) per letter ($-11 < B < 10$) with the effect of word length being completely insignificant. C1, C6, C7, C8, C12, and C13 made no errors, and C2, C3, C4, C5, and C9 only one error each. F.C. was asked to read the same set of words in 2004 after his last MRI examination. His performance, if anything, showed a slight improvement. In fact despite an evident word length effect, $F(1, 106) = 27.27$, $p < .0001$, the increment in reading speed per letter was slightly less than before—namely, 70 ms. He made two errors and three conduites d'approches (e.g., meta → me...meta; fantasia → fanta...fantasia; termometro → ter...termore...termometro).

The results indicated that F.C. was quicker than L.D.S. Qualitatively their performance is that of relatively mild LBL readers since they are accurate and not so slow at word reading. In fact regarding the word reading speed, F.C. and

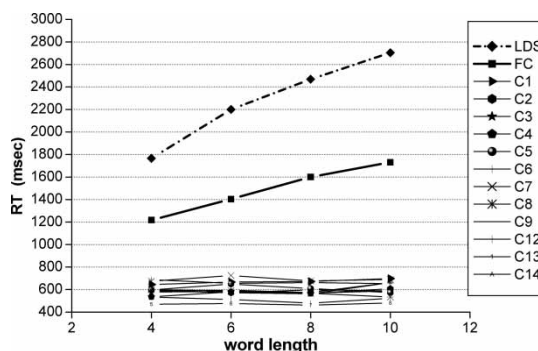


Figure 2. Word-reading task. Response times (ms) of F.C., L.D.S., and their matched controls as a function of word length. The voice onset time was measured, and errors and conduites d'approches were removed from the analysis.

L.D.S. take an average of 1.6 s and 2.5 s, respectively, to name eight-letter words. If their performance is compared to that of the 4 patients described by Patterson and Kay (1982) and the 7 reported in Behrmann et al. (1998) one sees that only 3 patients out of the 11 mentioned showed a similar reading pattern, taking about 1.3 s, 2.3 s, and 2.3 s on average to read seven-letter words.

Writing

Both the patients were asked to write to dictation three prose passages from the MT battery (Cornoldi & Colpo, 1995), a reading test for teenagers with probable developmental dyslexia. The passages had a total of 101 words. Patients were also asked to write 50 words of 4, 5, 6, 7, and 8 letters in length.

F.C. made seven mistakes writing the prose passages, six of which were grammatical—for example, *un attimo* (*an instant*) → *un'attimo*; *l'integrità* (*integrity*) → *lintegrità*; *ha cominciato* (*has begun*) → *a cominciato*—and one was morphological—*viaggiare* (*to travel*) → *guardare* (*to look*). The grammatical errors could well be due to his low education level. His performance was fairly good with the 50 words to write, since he made four mistakes—for example, *ciliegia* (*cherry*) → *cigliegia*. L.D.S. made just one mistake—*inurbarsi* (*to move into urban areas*) → *inerbarsi*—and two errors (out of 50 words) with single words—for example, *carriola* (*wheelbarrow*) → *cariola*, a common error made also by F.C.

EXPERIMENTAL PROCEDURES: LETTER AND DIGIT PROCESSING

EXPERIMENT 1A: LETTER NAMING

Method

In this task we investigated the time taken to name each single letter. We were interested to see whether patients performed within the normal range.

Materials and procedure

All the 21 letters of the Italian alphabet were presented 10 times each in a random order on a computer screen by means of an E-prime program for a total of 210 stimuli. Letters were printed in uppercase, in Arial font size 30, displayed in black on a white background. Patients and 14 controls (from C1 to C7 matched to F.C. and from C8 to C14 matched to L.D.S.) were asked to name each letter; the patients performed the task three times. Mean and median response times (RTs) were measured for each participant (starting from the beginning of the vocal response).

Results

The distribution of correct response times for both the patients and controls are illustrated in Figure 3a. On average F.C. took 682 ms ($SD = 133$) whereas L.D.S. took 914 ms ($SD = 284$) to same single letters. The results show that F.C.'s performance was well within the normal range ($t = 0.835$, one-tailed $p = .22$ [Crawford & Garthwaite, 2002]), whereas L.D.S. was significant slower in identifying letters than were her matched controls ($t = 8.3$, one-tailed $p < .0001$ [Crawford & Garthwaite, 2002]). Finally a direct comparison between F.C. and L.D.S. showed a significant difference in RT (Wilcoxon test, $z = -17.85$, $p < .0001$).

Regarding F.C., the letters that resulted in the slowest RT were H and I, with RTs of 166 ms and 126 ms above the average, respectively. However, this RT difference is well within the range of the difference shown by the controls matched to F.C. for some letters: letter Q being 190 ms above the average (C2); letter V being 100 ms, 140 ms, and 140 ms above the average (C4, C5, and C7, respectively); letter O being 110 ms above the average (C6). By contrast, L.D.S. was particularly slower with Q (500 ms more than the average) and H (250 ms more than the average) and became confused four times with Q, which she read as H. Unlike F.C. and his controls, the RT difference for L.D.S. of 506 ms and 264 ms was much greater than the difference showed by her matched controls: maximum of

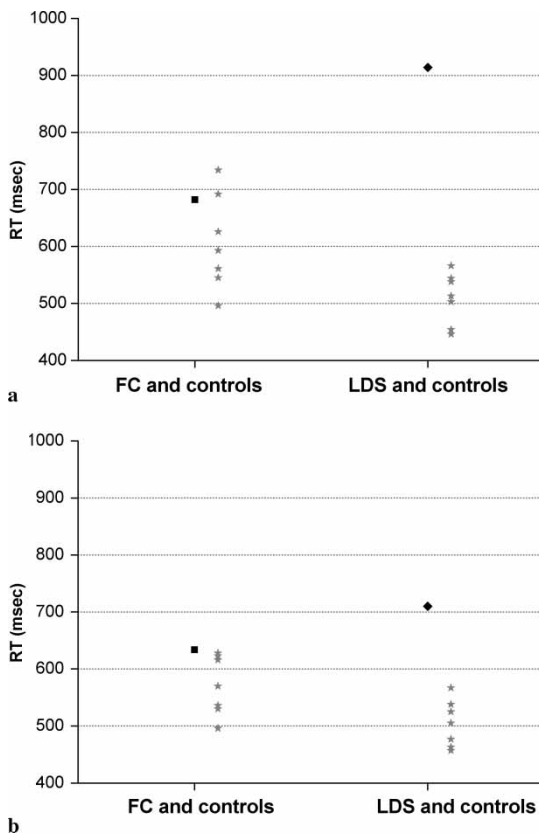


Figure 3. (a) Letter-naming task. Response times for F.C. and L.D.S. and their relative matched controls. (b) Digit-naming task. Response times for F.C. and L.D.S. and their relative matched controls.

100 ms above the average for letter V (C8, C10, and C12) and O (C11). L.D.S. is therefore qualitatively worse than her controls for particular letters. This is not the case for F.C.

EXPERIMENT 1B: DIGIT NAMING

Method

This task was carried out with digits instead of letters, for the same purpose as the previous one. Digits from 0 to 9 were presented 10 times in a randomized order using E-prime. Patients and 14 control participants (F.C., L.D.S., and from

C1 to C14) were asked to name each digit written in black (Arial 30) on a white background. The patients performed the task twice. Mean and median RTs were measured for each participant.

Results

The correct response times for both the patients and controls are illustrated in Figure 3b. On average F.C. took 634 ms ($SD = 84$), and L.D.S. took 710 ms ($SD = 105$) to name single digits. The results show that F.C.'s performance was within the range of the other 7 matched controls ($t = 1.13$, one-tailed $p = .15$ [Crawford & Garthwaite, 2002]). By contrast, L.D.S.'s performance was worse than that of her matched controls ($t = 4.68$, one-tailed $p < .005$ [Crawford & Garthwaite, 2002]). The difference between the performance of F.C. and that of L.D.S. is still significant (Wilcoxon test, $z = -9.1$, $p < .0001$).

EXPERIMENT 2: RAPID LETTER RECOGNITION

Method

We replicated a letter recognition task developed by Warrington and Langdon (2002), in which strings of six letters were presented serially in the same spatial location for brief exposure durations. Participants were asked to say whether a target letter verbally given prior to the string was present or absent in the six-letter string. This experiment is assumed to assess the early stage of letter processing, when prior to identification of a letter, a letter-form or structural description is activated. Normal performance would indicate that the ability to detect letter-forms (letter-form categorization) is adequate and that damage is likely to be at higher levels.

Materials and procedure

Strings of six letters were presented serially, in the same spatial position without an interval between successive letters and with three different exposure durations (60, 80, 100 ms). Prior to the

presentation of each letter string, a letter was named (e.g., "L"). Patients and controls (F.C., from C1 to C7; L.D.S., C8, C9, C12, C13, C14) had been instructed to say whether that letter was present or absent in the subsequent string (e.g., T S L A C V). Participants were tested in nine blocks of 10 strings, three blocks at each of the three exposure durations in a Latin square design. Stimuli were printed in upper-case letters (Arial 30) and appeared black on a white background in the centre of the PC screen using the E-prime program. The target letter could occupy any of the positions 2–5 in the six-item strings, and there were an equal number of "Yes" and "No" responses.

Results

As reported in Table 3, F.C.'s accuracy was very good (93%), very comparable to his controls. In contrast L.D.S.'s performance was impaired with respect to her matched control participants, C8, C9, C12, C13, and C14, $\chi^2(1) = 7.1$, $p < .007$; $\chi^2(1) = 13.4$, $p < .0001$; $\chi^2(1) =$

10.98, $p < .001$; $\chi^2(1) = 16.2$, $p < .0001$, $\chi^2(1) = 7.1$, $p < .008$, respectively; in combination $t = -10.84$, one-tailed $p < .0001$ (Crawford & Garthwaite, 2002). A direct comparison between F.C. and L.D.S. showed that F.C. performed significantly better, $\chi^2(1) = 4.3$, $p < .05$. The finding indicates that F.C. appears to have preserved letter-form activation, and L.D.S. has impairment at the level of letter-form processing.

EXPERIMENT 3: TASK INVOLVING 13 DIGITS AND 2 LETTERS

Method

The previous task presumably tapped letter-form activation. To assess whether letter identification is slowed in pure alexic patients, Behrmann and Shallice (1995) presented their patient D.S. with two letters to report. The first and second letter appeared in the same spatial location but with different temporal intervals between them. The idea was that if single letter identification is slowed, then additional time will be required to process the first letter satisfactorily; this in turn will interfere with the processing of the second letter presented later. Thus, when the two letters are presented in a temporally adjacent fashion, the task is more difficult than if there is a gap between them. With respect to the previous experiment, this task requires not only letter-form activation, but also letter identification under conditions where stimuli are briefly presented and must be processed very quickly.

Materials and procedure

A trial consisted of a string of 15 symbols (2 letters and 13 digits), which were displayed individually for 100 ms under conditions of rapid serial visual presentation (RSVP). The 60 trials were divided into three conditions: when the 2 letters appeared either near to each other with no digit between them (e.g., 3942PL785134096), with 3 digits between them (e.g., 2045T327A069735), and with 7 digits between them (136G0754236D198).

Table 3. Rapid letter recognition task

Participant	Performance at different durations			Total score	Total % correct
	60 ms	80 ms	100 ms		
F.C.	25/29	28/30	30/30	83/89	93
C1	27/30	29/30	29/30	85/90	94
C2	25/30	29/30	28/30	82/90	91
C3	27/30	24/30	30/30	81/90	90
C4	30/30	29/30	29/30	88/90	98
C5	29/30	29/30	30/30	88/90	98
C6	30/30	30/30	24/30	84/90	93
C7	24/30	28/30	29/30	81/90	90
L.D.S.	21/30	28/30	26/30	75/90	83
C8	29/30	29/30	28/30	86/90	95
C9	30/30	30/30	29/30	89/90	99
C12	28/30	30/30	30/30	88/90	98
C13	30/30	29/29	30/30	89/89	100
C14	30/30	28/30	29/30	87/90	97

Rapid letter recognition task. Number of correct responses for each patient and controls: controls for C1 to C7 are matched to FC, controls from C8 to C14 are matched to LDS.

Letters were not presented in either the first or the final three positions of the string to avoid primacy and recency effects, and there were no letters O and I because of possible interference with digits 0 and 1. Letters were all capitals, in Arial font size 30, as were the digits; the stimuli were displayed centred in black on a white background using the software E-prime. Patients and 13 controls (F.C., from C1 to C7; L.D.S., C8, C9, C12, C13, C14, C15) were asked to report both the letters. This task was given three times to each patient (for a total of about 180 trials), but just once to control participants.

Results

As shown in Table 4, F.C.'s performance is clearly normal given the comparison with his 7 matched controls in the three conditions: with no digit, with 3 digits, and with 7 digits between the two letters. Although there is some variability among controls, F.C. was roughly at the mean of

normal controls of his age. This finding suggests that single-letter identification operates at normal speed in F.C. In contrast, L.D.S. performed very much worse than her controls at all size gaps, even when the interval between the two letters increased.

Again in this task F.C. had no difficulties in letter processing while L.D.S. was slower in identifying letters; her performance indicates a letter identification deficit.

SUMMARY OF THE LETTER AND DIGIT EXPERIMENTS

The results from Experiments 1–4 suggested that F.C. had no difficulty in single-letter recognition and in single-letter identification (letter naming; rapid letter recognition), and he processed letters very rapidly (13 digits and 2 letters). In contrast, L.D.S. was slower in rapid letter recognition and much more impaired than F.C. in letter processing (letter naming; 13 digits and 2 letters). Overall L.D.S. had clear letter identification problems, and F.C. was essentially normal in letter processing when compared with controls of his age.

Table 4. *Task involving 13 digits and 2 letters*

Participant	Size gap ^a	Performance		
		++	+-	-+
F.C.	0	49 (29/59)	17 (10/59)	25 (15/59)
	3	69 (42/61)	20 (12/61)	10 (6/61)
	7	74 (42/57)	12 (7/57)	9 (5/57)
From C1 to C7	0	52 (23)	17 (16)	30 (9)
	3	63 (27)	26 (24)	6 (5)
	7	69 (10)	11 (8)	16 (3)
L.D.S.	0	8 (5/60)	43 (26/60)	32 (19/60)
	3	23 (14/60)	33 (20/60)	27 (16/60)
	7	12 (7/59)	22 (13/59)	59 (35/59)
From C8 to C15	0	78 (18)	5 (5)	15 (97)
	3	82 (24)	16 (22)	3 (4)
	7	91 (9)	2 (3)	6 (6)

Task including 13 digits and 2 letters. Values are percentage of times in which patients and controls reported both letters correctly (++), just the first letter (+-) and just the second letter (-+); mean values (and standard deviation in parentheses) are shown for controls. Actual scores are given in parentheses for patients. Controls from C1 to C7 are matched to FC, controls from C8 to C15 are matched to LDS.

^aNo. of digits between the 2 letters.

EXPERIMENTAL PROCEDURES: ORTHOGRAPHIC INTEGRATION

EXPERIMENT 4: CUMULATIVE AND SUCCESSIVE PRESENTATION OF WORDS

Method

This task, taken from Warrington and Langdon (2002), was designed to investigate whether purely serial processing of letters was all that was used by letter-by-letter readers. Two types of presentation were used. In the *cumulative* condition a letter was added one at a time to the letter string until the word was complete (e.g., G GE GEL GELA GELAT GELATO); in the *successive* condition each letter appeared one at a time in

the appropriate spatial position but the preceding letter was removed when a letter was presented. In these two different presentation conditions there is a critical difference in the processing of letters in their spatial relation to other letters that are simultaneously present. Thus, single letters appeared in the correct spatial position in the successive condition, while in the cumulative condition letters were added one at a time, and spatial letter integration was possible with nearby letters. The LBL reader R.O.C. studied by Warrington and Langdon (2002) showed a very similar type of performance on the cumulative and successive presentations: His accuracy was about 10% at 200-ms exposure duration per letter, about 50% at 300 ms, and about 80% at 500 ms in both conditions.

Materials and procedure

The stimuli consisted of 80 midfrequency six-letter words taken from the set of Burani, Barca, and Arduino (2001); words were presented in two different conditions as described above, following the procedures of Warrington and Langdon (2002). Half of the words were presented in the cumulative condition and the other half in the successive one in an ABBA design; in another session the BAAB version was administered, so that all the 80 words were presented in both the conditions. The word stimuli were presented individually on a PC screen on the left of a central fixation point using the E-prime program. Stimuli were black on a white screen printed in capitals (Arial 30). Words appeared for 100-, 200-, 300-, or 500-ms exposure duration per letter, so that words lasted for 600, 1,200, 1,800, or 3,000 ms. Four blocks of 20 words were presented in four increasing exposure durations in an ABBA BAAB design, so that the first 20 words displayed in the cumulative condition at each exposure duration were followed by two successive presentation blocks and so on. The task was given three times to both F.C. and L.D.S. and twice to C3, C4, C5, C6, C7, C9, C12, C13, and C14; participants were encouraged to guess the whole word.

Results

Control participants performed perfectly on the cumulative condition. This was very easy for competent readers, while in the successive condition they made errors at the brief time durations that they found rather difficult.

As shown in Figures 4a and 4b, the cumulative condition was easier than the successive one for the patients too. If we consider the successive condition, it is evident that L.D.S.'s performance was highly impaired; F.C.'s performance is better than hers but not significantly in this condition. By contrast in the cumulative condition when letters were added one at a time until the word was complete, L.D.S.'s performance improved strongly and was much better than that of F.C.

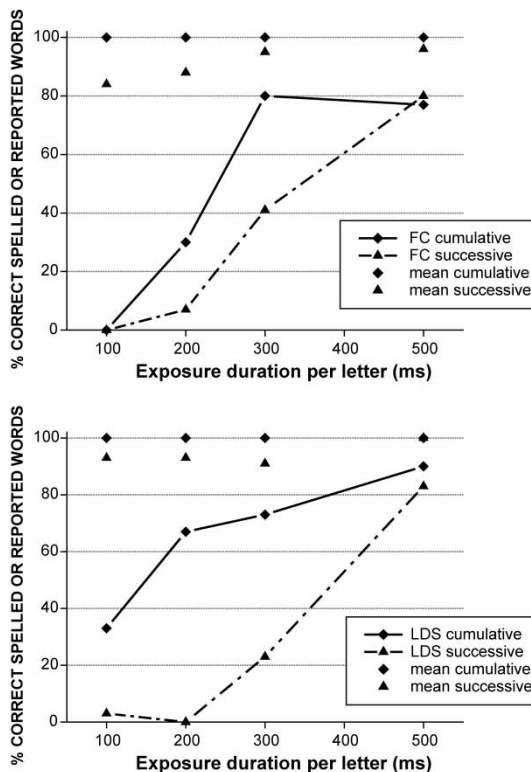


Figure 4. Cumulative and successive task. (a) Performance of F.C. and his matched controls. (b) Performance of L.D.S. and her matched controls. Words were considered correct if they were either reported or spelled correctly.

especially for short exposures: The difference in performance between L.D.S. and F.C. was significant at 100 ms of exposure duration (McNemar, $p < .002$), as well as at 200 ms (McNemar, $p < .01$). In other words, F.C.'s performance improved in a rather similar fashion in the cumulative and successive presentations as exposure duration increased, while L.D.S. performed very differently in the two conditions.

It is worth noting that F.C. gave some unusual answers in the successive condition with longer exposure durations, when he could identify all the letters. For example, with the word *GIGLIO* (lily; at 500 ms per letter), he said "G...I...G...L...I...O . . . GIUGLIO" (which does not exist); *MOGLIE* (wife; 500 ms) → "M...O...G...L...I...E... I don't know the word!"; *CODICE* (code; 500 ms) → "C...O...D...I...C...E... don't know!"; *LUMACA* (snail; 500 ms) → "L...U...M...A...C...A... MUCCA (cow)!"; *ESTATE* (summer; 300 ms) → "E...S...T...A...T...E... I don't know the word!"; *SANGUE* (blood; 300 ms) → "S...A...N...G...U...E... I don't know the word!" These errors revealed that although F.C. was able to recognize the single letters of a word, he often failed to integrate them together correctly to read the word. Words were considered correct if they were either reported or spelled correctly. Similar types of mistakes have already been reported before in pure alexia: for instance, by Patterson and Kay (1982). It should be noted that these types of explicit letter-naming responses did not occur when F.C. was attempting to read normally presented words. However, LBL reading can be mediated by different strategies. In pure alexia LBL reading is possible after naming each letter either covertly or explicitly (Shallice, 1988; Warrington & Langdon, 2002); another possibility is the use of a visual strategy, based on a residual contribution of the word-form system (related to the position of Hanley & Kay, 1992). It is possible that F.C. could use more than one strategy; however, this task might have encouraged a more explicit letter-naming procedure, since it would stress further an already impaired letter integration process that a visual strategy, say, would require.

F.C.'s performance was similar to the performance of the patient R.O.C. (Warrington & Langdon, 2002) since the difference between the two conditions was not significant; similarly, the authors claimed that the deficit of ROC was at the word-form system. In this experiment, the performance and the type of errors made by F.C. provides further evidence that F.C. was not able to make effective use of any letter integration in order to read, while L.D.S. was able to do so.

EXPERIMENT 5: SYLLABLE TASK

Method

In this experiment our aim was to obtain further evidence as to whether the patients were able to integrate information across letters present simultaneously. We aimed to assess whether they could use information from syllabic structure, an intermediate level between letters and words. Evidence in favour of syllabic processing in reading words has been mostly obtained in languages such as Italian, French, and Spanish with clear syllabic boundaries (e.g., French: Ferrand & New, 2003; Ferrand et al., 1996; Rouibah & Taft, 2001; Spanish: Alvarez, Carreiras, & Taft, 2001; Carreiras et al., 1993; Carreiras & Perea, 2002). As regards syllabic structure, the debate is still open whether it is phonological or visual in word recognition. The fact that syllables are phonological units in speech does not necessarily imply that any syllabic effects observed in visual word recognition experiments are due to the activation of phonological codes. Support has been presented for both positions—namely, that syllabic effects arise from a sublexical phonological level (e.g., Alvarez, Carreiras, & Perea, 2004) and that they arise from a sublexical orthographic level (e.g., Prinzmetal et al., 1991; Rapp, 1992; Rouibah & Taft, 2001; Taft, 1979). For instance, in the study of Carreiras et al. (2005) colour changes coinciding with syllable boundaries led to different evoked responses from those that did not coincide;

in particular, the event-related potential (ERP) effect of colour-syllable congruency for both words and pseudowords was very early—namely, in the P200 time window. The onset latency of this effect was earlier than that of lexical variables that modulated the N400 component. The results support the existence of syllables as sublexical reading units and suggest that in the orthographic as well as in the phonological system there are syllable-level representations.

In the present experiment we investigated the ability to integrate letters into orthographic syllables by comparing different conditions: when patients and controls were supposed to be able to process letters together, in syllables, compared to those where this was more difficult, with nonsyllables (Condition A). The condition A has also been compared to the condition B (which comprised only syllables), where the ability to integrate letters into syllables was explicitly required.

Materials and procedure

A total of 80 triplets of letters were created, and an ABBA design was used. In Condition A, half of the set were orthographic syllables (e.g., *por, man, dre, gri*) and the other half nonsyllables—namely, not orthographically plausible syllables (e.g., *gme, etm, igf, qco*); items were randomly presented. Patients were asked to report the triplets as three single letters. In Condition B, all the triplets were orthographic syllables, patients were told that the three letters were pronounceable syllables, and they were asked to report the triplet as a syllable. The criterion according to which triplets have been divided into orthographic syllables and nonsyllables is consistent with the database of the orthographic syllables in written Italian (Stella & Job, 2001). The three letters were presented for 165 ms on a PC screen using the E-prime program; at the beginning of each trial a central fixation point appeared for 1,000 ms, and, following a 150-ms interstimulus interval (ISI), the triplet was presented centrally in the screen in lower-case letters, in 35-point Arial font. The task was presented to the patients and to the controls (C1, C2, C7, C8, C9, C13, and C14), and

the instruction was to report the triplet as three single letters in Condition A and as a syllable in Condition B.

Results

All the 7 control participants performed the task perfectly. F.C. and also L.D.S. were distracted in one trial, so the trial was excluded from each respective analyses. One triplet was not consistent with the database of orthographic syllables in written Italian (Stella & Job, 2001) and therefore it was excluded from the analysis. The answer was considered as an ordinal variable (which can be 0, 1, 2, or 3), and the Mann-Whitney test was used to analyse the data; data have been analysed also with the χ^2 , using the number of syllables reported by the patient as dependent variable. As shown in Table 5, F.C. did not show a significant difference between Conditions A and B in terms of either the number of letters reported ($z = -1.63$, $p = .10$) or the syllables reported ($z = 0.695$, $p = .49$; $\chi^2 = 0.25$, $p = .381$). In addition, there was no significant difference for F.C. between performance on syllables and that on nonsyllables in Condition A ($z = -1.02$, $p = .31$) in terms of the number of letters reported. These results indicate that his performance was not sensitive to the presence of pronounceable units.

By contrast, L.D.S. showed a significant improvement between Conditions A and B in terms of the number of letters ($z = -3.84$, $p < .0001$) and the number of syllables ($z = -2.03$, $p < .05$; $\chi^2 = 3.83$, $p < .05$): This suggests that the explicit request to conjoin letters into syllables enhances her ability to put them together by inducing a broader attentional window. Moreover, there is a significant difference between L.D.S.'s performance on syllables and nonsyllables in Condition A ($z = -2.05$, $p < .05$) in terms of the number of letters reported and a strong trend for the number of triplets reported ($\chi^2 = 3.3$, $p = .057$). This suggests that the presence of pronounceable units facilitate L.D.S.'s performance, unlike F.C.'s.

Table 5. *Syllable task*

Participant	<i>Condition A</i>						<i>Condition B</i>			
	<i>Letters</i>		<i>Syllables</i>		<i>Nonsyllables</i>		<i>Letters</i>		<i>Syllables</i>	
	Score	%	Score	%	Score	%	Score	%	Score	%
F.C.	187/234	80	20/38	53	16/40	40	199/237	84	46/79	58
L.D.S.	178/231	77	18/38	47	11/39	28	213/240	89	53/80	66

Syllable task. Performance of FC and LDS with orthographic syllables and nonsyllables, subjects are asked to report the triplet as 3 single letters in condition A and as a syllable in condition B. The table shows the number of letters and triplets (syllables and nonsyllables, with percentages) reported in both the conditions. Control performance is at ceiling.

This result fits with the previous finding that F.C. does not benefit from a possible integration of letters, while L.D.S. can integrate letters into orthographic syllables. This capacity improves her letter identification and so in part compensates for her letter identification problems. These results show that although the performance of the patients is more impaired than that of their matched controls, L.D.S. retains the capacity to conjoin letters together and that her ability in this request is apparently more effective than F.C.'s even though L.D.S. is slower than F.C. in letter naming.

SUMMARY OF THE ORTHOGRAPHIC INTEGRATION EXPERIMENTS

F.C., who is quick and accurate with single letters (Section 1), has difficulty in conjoining letters into syllables and words (cumulative and successive task; syllable task). His deficit involves higher levels of the reading process, starting from letter groups and leaving intact single letter identification. On the contrary, having letters presented together in a typical arrangement facilitates L.D.S.'s performance considerably. L.D.S. is able to use information from the syllable structure, an intermediate level between letters and words. Despite the fact that L.D.S. has a deficit at letter processing, she performed significantly better than F.C. in the cumulative presentation at the shortest exposure durations. L.D.S.'s deficit, although involving lower level letter processing,

still allows a partial ability to integrate letters together in larger fragments of words.

We can draw an important conclusion from this section: The difference between the performance of F.C. and that of L.D.S. fits with the hypothesis of two qualitatively different forms of impairments giving rise to the letter-by-letter reading pattern typical of pure alexia.

WORD PROCESSING

EXPERIMENT 6: VISUAL IMAGERY OF WORDS

Method

In pure alexia an impairment in the visual identification of letters or words might suggest an impairment of mental representation of the same stimuli (Bartolomeo, 2002; Bartolomeo, Bachoud-Lévi, Chokron, & Degos, 2002). In the few cases of pure alexia where identification of letters and words was difficult, and imagery of letters was assessed, visual imagery has often been found intact (Behrmann, Moscovitch, & Winocur, 1994; Goldenberg, 1992; Perri, Bartolomeo, & Silveri, 1996). Recent cases of patients showing double dissociations between perception and imagery suggest that from an anatomical point of view occipital damage is neither necessary nor sufficient to produce imagery deficits (Bartolomeo, 2002; Goldenberg, 1998), and

imagery deficits are often accompanied by extensive left temporal damage.

This task was carried out to explore whether F.C. and L.D.S. were able to access the orthographic representation of words—namely, the word-form unit—though not through visual input but through the use of visual imagery. We investigated the accuracy of the visual imagery, as well as the time taken to perform the task. A deficit in the imagery task that requires revisualizing the visual form of a given word from memory would suggest that the word-form unit itself is damaged. On the contrary, if the patients are able to carry out the task, the word-form system might be partially or totally preserved, depending on the performance.

Materials and procedure

Participants were presented auditorily with a list of 39 words, which were of four to nine letters in length, matched for frequency. Words were divided into three groups, according to how they are written in lower case: physically higher at the beginning than at the end, physically higher at the end than at the beginning, or with physically equal size beginning and end (“beginning” and

“end” refer to the first and the last two letters of words). Examples of words that are higher at the beginning are *chiesa*, *clero*, *lupo*; examples of higher words at the end are *eredo*, *usignolo*, *patata*; and examples of “similar words” are *cratere*, *zebra*, *ragno*. Controls and patients (F.C., C1, C2, C3, C4, and C7; L.D.S., C8, C9, C12, and C14) listened to the words and had to revisualize the visual form of a given word from memory, focusing in particular to the beginning and to the end. The task was to report whether the beginning and the end of the word were equal, or the beginning was higher or the end was higher. Six words were presented orally as practice trials. Participants’ answers were recorded with a microphone connected to a PC via a Cool Edit program. At the end of the task, participants were asked to say whether they relied on the visual word-form to accomplish the task.

Results

At the end of the task all the participants said that they thought about the visual word-form to answer. As shown in Table 6, F.C.’s performance was comparable to that of his matched control

Table 6. *Visual imagery task for words*

<i>Participant</i>	<i>Performance</i>		<i>RT(s)</i>			
	<i>Score</i>	<i>%</i>	<i>M</i>	<i>SD</i>	<i>Errors</i>	<i>Autocorrections</i>
F.C.	35/38	92	5.7	1.9	3	4
C1	32/35	91	5.3	2.1	3	2
C2	32/37	86	6.8	3.7	5	1
C3	37/38	97	3.9	2.5	1	0
C4	35/39	90	4.1	1.4	4	0
C7	33/38	87	4.9	2.3	5	1
L.D.S.	28/37	76	7.3	2.4	9	0
C8	38/38	100	3.4	1	0	1
C9	37/39	94	3.7	1.5	2	3
C12	36/38	95	3.3	1.6	2	1
C14	36/39	92	3.4	1.15	3	1

Visual imagery task for words. Performance of patients and their matched controls: they are asked to visualize the visual form of a given word from memory. Words which resulted in either doubt or unclear answers were eliminated; answers with autocorrections were eliminated from the analyses of RTs.

participants in terms of the percentage of correct answers and of the time taken to answer ($t = 0.99$, one-tailed $p = .189$ [Crawford & Garthwaite, 2002]). Although L.D.S. was able to answer well above chance, her answers were significantly slower than those of her matched controls ($t = 10.852$, one-tailed $p = .001$ [Crawford & Garthwaite, 2002]). A direct comparison between F.C. and L.D.S. indicated a pattern of performance not significantly different, $\chi^2(1) = 3.03$, $p = .076$, regarding the number of mistakes made, but significantly different, $t(23) = -2.94$, $p < .01$, regarding the time taken to accomplish the task. The mistakes made by L.D.S. included one word with a physically higher beginning (abisso), seven with equal size beginning and end (sedia, capra, brivido, zebra, vetro, ragno, tromba), and one word with physically higher end (custode).

This task replicates findings by Miozzo and Caramazza (1998) who showed that their patient G.V., unable to read letters and words, could recognize orally spelled words, "suggesting that graphemic information is preserved but not accessible through the visual modality" (p. 206).

Our results indicate that F.C. can easily process the word-form information, suggesting that at least the higher levels of the word-form system are preserved and are accessible through the visual imagery. On the other hand, while L.D.S. is able to perform the visual mental imagery task with words better than chance, she is slower and makes more errors than her matched controls. This finding suggests that she has a partial ability to access the orthographic representation of words. Overall, the results from the imagery task suggest that the word-form system is intact (at least its higher levels) for F.C. and is accessible to L.D.S.

GENERAL DISCUSSION

In our investigation we have described two cases of pure alexia who show normal language abilities (preserved writing, speech, and comprehension), generally spared visuo-perceptual and

visuo-spatial functions, and normal memory skills but who are unable to read normally. They are mild LBL readers, showing a length effect in word reading, impaired performance under tachistoscopic presentation, and difficulties with script (Warrington & Shallice, 1980). In this study we investigated the functional organization of the early stage of word recognition (Issue 2), whether different types of orthographic units such as single letters, supraletter units and words are involved. Moreover, as regards Issue 3, we investigated whether these orthographic units, hierarchically organized, can be differently damaged in our patients. This relates to the issue of whether there is a single primary deficit common to both patients as would be expected on the position of Behrmann et al. (1998) or whether the two patients have different functional deficits from a neuropsychological point of view (Patterson & Kay, 1982; Price & Humphreys, 1992).

At a gross level the reading performance of F.C. and that of L.D.S. have similar characteristics: They both perform accurately with single letters and digits, their reading speeds are similar, and neither patient is able to access semantic representations from briefly presented words. However, on more detailed investigation major qualitative differences between their impairments emerged, and there is a clear double dissociation between the patterns of deficits shown by the two patients. Of course F.C. and L.D.S. differ considerably in age and educational level. However, this alone cannot explain the difference in pattern, as the contrasts that they show with each other also occur when their performance is compared with the appropriate 7 controls.

In the first set of experiments we assessed the abilities of the patients to identify and process letters independently of each other. F.C. performs well on letter recognition (rapid letter recognition) and on letter identification (letter naming), and he is able to process single letters very rapidly and accurately in a RSVP task (13 digits and 2 letters). Overall he is generally as accurate and fast on such tasks as are his 7

matched control participants. By contrast, L.D.S. has difficulties in a task that required rapid letter recognition; she is very slow at naming letters and to a lesser extent also digits and, unlike F.C., has special difficulty with particular letters. She is impaired when letter identification is required at speed using the RSVP task. In these tasks L.D.S. performs worse than both F.C. and her own matched controls.

In a complementary set of experiments we investigated the patients' ability in orthographic integration tasks, which come into play once letter-form (letter structural description on the model of Miozzo & Caramazza, 1998) units and then individual abstract letter identities have been accessed. Performance of L.D.S., with a slowed letter activation, is facilitated when groups of letters are presented together in space; she performs significantly better with cumulative than with successive presentation of the letters in a word. In addition, it is evident from the syllable task that L.D.S.'s reading performance improves if supraletter units are simultaneously available (see Osswald et al., 2002, for a related phenomenon). By contrast, F.C. appears to be unable to conjoin letters into syllabic units, as he shows no superiority in identifying the constituent letters of syllables compared with random letters (syllable task). Moreover, he is unable to use spatial information to group together the letters that he was correctly identifying individually; he gains no advantage in the cumulative over the successive presentation condition.

It is not plausible to give an interpretation of F.C.'s results in this paradigm in terms of visual interference. A visual span task was also administered to the patients, where triplets of letters (e.g., A L R) and digits (e.g., 3 8 1) were displayed briefly, and patients were asked to report all the three items. The performance of L.D.S. was more impaired than that of F.C. with both letters (Wilcoxon test, $z = -4.4$, $p < .0001$) and digits (Wilcoxon test, $z = -4.6$, $p < .0001$). If F.C. had suffered from a problem of visual interference, then in this task where three items have to be reported, he would be expected to perform worse than L.D.S. On the contrary, he performed

better when he did not have to integrate letters into orthographic units.

Finally, for a task requiring visual mental imagery of words, F.C. is able to perform as well as controls in assessing the visual forms of words: This suggests that the word-form system is intact at its higher levels and is accessible through visual imagery, but it is not accessible through the visual modality because of his lesion. L.D.S. is significantly slower than F.C. on this task and somewhat less accurate: This would confirm that her word-form system is not totally damaged.

In particular, F.C. and L.D.S. present with a double dissociation. If one looks at it in more detail, the tasks where F.C. performed better than L.D.S. give rise to a *classical* dissociation in the sense of Shallice (1988) in that F.C.'s performance is as good on the letter-processing tasks and on the imagery task as that of the matched controls. By contrast, where L.D.S. performs much better than F.C. (orthographic integration tasks), one has a *strong* dissociation in that she still performed worse than her matched controls. We take the observed pattern as providing powerful evidence that the impairments of the two patients are two different parts of a complex whole. Given that in the reading system the stage of abstract letter identification occurs before letter integration, impaired letter processing will result in a less efficient input to the letter integration process, even if this process is not itself damaged. With this serial organization of the system, one could never observe two classical dissociations. The occurrence of complementary classical and strong dissociations is the most powerful combination that can be observed.

What inferences can one draw about the nature of the underlying system and how a damage to it would produce the patterns of performance of the two patients? Consider first the model of Patterson and Kay (1982), which they derived from Shallice (1981). They argue that different forms of pure alexia exist—one (Type 1) with a lesion to the connection between the letter-form analysis and the word-form system and the other (Type 2) with, in addition, a lesion to the

word-form system. Hanley and Kay (1996) took a similar approach except that they appear to move the Type 1 impairment earlier in the system and assume it involves the letter-form analysis system itself, but they retain the assumption that Type 2 has an additional impairment to the word-form system. F.C.'s results are not compatible with the Patterson and Kay (1982) disconnection account, nor with the Hanley–Kay modification (Hanley & Kay, 1996), because in those models a primary letter-processing problem is always assumed. In fact we provided evidence that F.C.'s single-letter recognition and identification skills are normal, unlike the Type 1 patients M.W. and C.H. (Patterson & Kay, 1982),² patient P.D. (Hanley & Kay, 1996), D.S. (Behrmann & Shallice, 1995), W.L. (Reuter-Lorenz & Brunn, 1990), and those reported in the review by Behrmann et al. (1998).³

Moreover, there is an additional consideration. F.C. has problems when integrating letters into syllables as well as into words and traditional models of word recognition do not include sublexical orthographic units in the reading process (e.g., Coltheart et al., 2001; McClelland & Rumelhart, 1981). A straightforward implication that follows from our data and in particular the double dissociation between F.C. and L.D.S. is that in models of normal reading it is likely we have hierarchical series of orthographic units, which integrate information from lower level units, as proposed by Dehaene et al. (2005).

In light of these considerations we have hypothesized a theoretical explanation that identifies the processes and levels that are involved in the early stage of visual word recognition and that are damaged in our alexic patients. Considering the development of the word-form model (Dehaene et al., 2004; Shallice & McCarthy, 1985): The initial stage of processing involves activation of case-specific letter-form units in particular retinal locations. Then, as in

the model of Miozzo and Caramazza (1998), one has a set of units each corresponding to an abstract letter identity, related to position within the word. Finally, following McClelland and Rumelhart (1981), letters are assumed to be integrated in a series of stages to produce the activation of larger and larger orthographic units like bigrams and syllables. As the subunits of the representation of a word like “albero” (tree) are built, they can be utilized by phonological reading procedures, and the ultimate orthographic representation of the morpheme or word can be used by the semantic route (see Figure 5). In addition we assume that an attentional control system (Ladavas, Shallice, & Zanella, 1997) controls what portion of the letter string is admitted to the word-form system.

Critically, the functional MRI study of Dehaene et al. (2004) showed that the lower stages of the visual word-form system were bilaterally represented; paradigms that relied on priming of letter processing produced activation bilaterally in the left VWFA and also, less strongly, in the right VWFA. However, paradigms that depended on higher levels of the system, such as bigrams and words themselves, produced only left hemisphere activation of the VWFA. The contribution of the right hemisphere with respect to abstract letter identification is not clear but the data available do not rule it out; they show a strong trend ($p = .066$). According to Dehaene et al. (2004, p. 310). “The results indicate case invariance in the left fusiform gyrus and merely suggest but not prove that the right fusiform [...] may not show genuine case invariance.” According to the models presented by Ellis (2004) and Dehaene et al. (2005), abstract letter identities are bilaterally represented. Thus, we assume that up until the level of letter processing, the visual word-form system is bilaterally organized, but above that level processing is limited to the left hemisphere.

²Type 1 patients who had a disconnection deficit (Patterson & Kay, 1982) showed a high proportion of “clear misidentification errors” (M.W. 40%, C.H. 69%).

³In particular, Behrmann et al. (1998) wrote (p. 23): “The findings from the review [of 57 published cases of LBL reading] suggests that there is no single participant for whom letter recognition is definitely normal.”

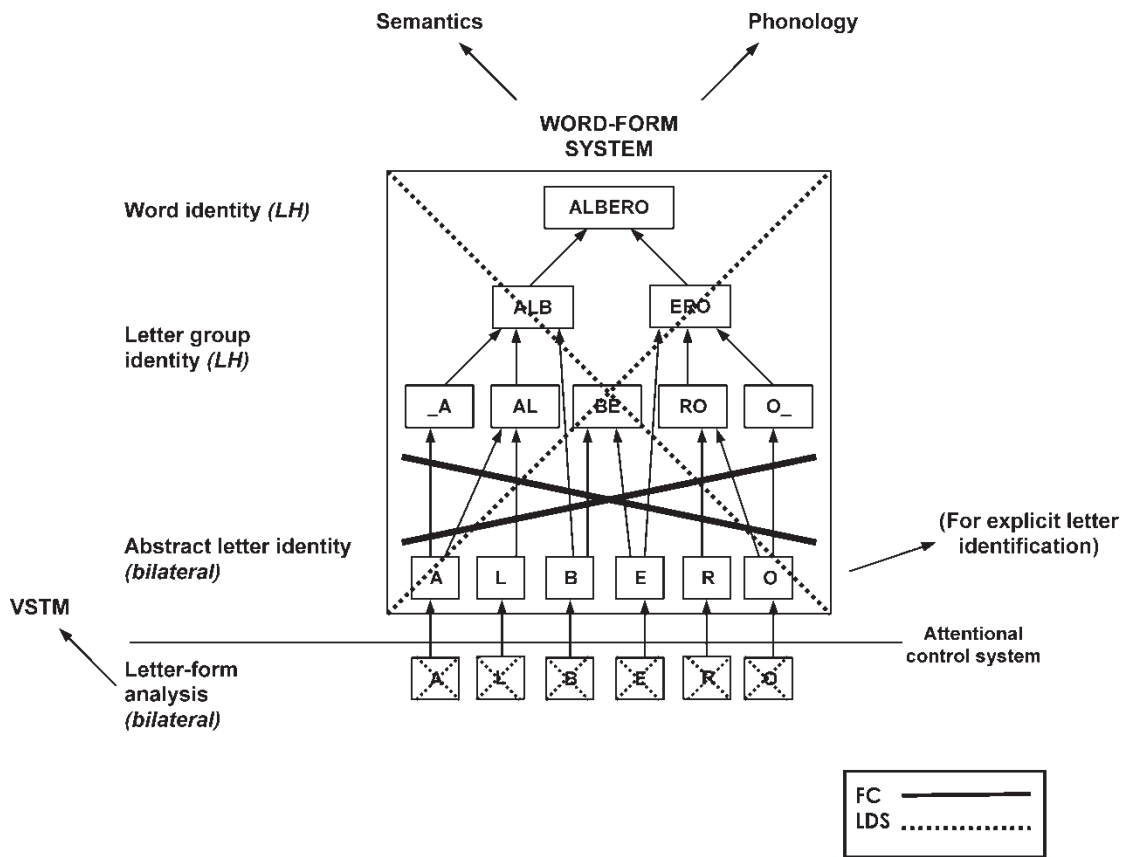


Figure 5. The explanation of the double dissociation. F.C. (solid line) would have the “abstract letter identity level” intact, but an impairment in accessing the higher levels of the word-form system. By contrast, L.D.S. (dashed line) would have a deficit in letter processing, and she would have a partially damaged word-form system.

As far as F.C. is concerned, his preserved visual imagery of the forms of words would imply that at least the higher level processes of the visual word-form system are undamaged, since the overall visual form of a word can be represented. F.C.’s inability to read implies that these higher level processes must be disconnected from earlier stages. The site of his lesion, in the left occipital lobe and in the left paraventricular white matter, fits reasonably well with a disconnection of the processing of the larger fragments of words (like syllables and words themselves) from the lower, abstract letter level within the word-form system. In Figure 5, F.C. has an intact “abstract letter identity level”. To explain why his word reading

is no worse than that of L.D.S., it can be hypothesized that it can be carried out in the left hemisphere because the disconnection is not “all or none”, and so some words can be read through the word-form system. Alternatively, a procedure by-passing the word-form system could be used, based on the processing of individual letters (Cohen et al., 2004); possibly this procedure could involve “reverse spelling” (Shallice, 1988; Warrington & Langdon, 2002) or, more likely, a strategy based on visual imagery (Hanley & Kay, 1992), using a top-down input to the left visual word-form system.

In contrast to F.C., L.D.S. has a deficit in letter processing, and she would have a partially damaged

word-form system (see Figure 5), but would still use it for tasks involving letters, presumably because of strategic functional fixedness, frequently found in letter-by-letter readers (see Coslett & Saffran, 1993). It is possible that a letter-processing impairment could in itself account for her reading deficit, but we cannot rule out the presence of concomitant damage to the visual word-form system. The lesion of L.D.S. is located where Cohen, Dehaene and colleagues (Cohen & Dehaene, 2004; Cohen et al., 2003) argue the VWFA to be. However, the results of the two orthographic integration tasks together with her partial ability to carry out the imagery task, albeit more slowly and with more mistakes than controls, suggest that her VWFA is not totally damaged. It can be hypothesized that the VWFA is partially spared although closely surrounded by lesioned cerebral tissue, as has been shown in patient F described by Cohen et al. (2003). Interestingly, patient F had an occipito-temporal lesion as had L.D.S., and his pattern of reading was very similar to that of L.D.S.; critically, in a brain imaging study that compared alphabetic stimuli with checkerboards, residual activation was present in the left VWFA of patient F. Therefore it is possible that the left VWFA might have contributed, at least in the case of L.D.S., to a limited ability to integrate letters.

A secondary aim of our study was to investigate whether these two cases of pure alexia could be explained by a single functional cause. The findings indicate that the nature of the deficit in pure alexia differs qualitatively across the two patients and support positions such as those of Price and Humphreys (1992), Kay and colleagues (Hanley & Kay, 1996; Patterson & Kay, 1982), and Miozzo and Caramazza (1998) that there is not just a single basic type of impairment common to all LBL readers.

In conclusion, F.C. and L.D.S. show complementary classical and strong dissociations. We interpreted this in terms of L.D.S. having a lower level deficit in letter processing, with F.C. having a higher level deficit in integrating into higher level units the letters that he can correctly and rapidly identify. These findings support

characterizations of the functional architecture of the early stage of visual word recognition in which a series of orthographic units is hierarchically organized with intermediate stages between a level of letter analysis and units corresponding to words.

Manuscript received 11 May 2004

Revised manuscript received 8 March 2007

Revised manuscript accepted 2 April 2007

REFERENCES

- Alvarez, C. J., Carreiras, M., & Perea, M. (2004). Are syllables phonological units in visual word recognition? *Language and Cognitive Processes*, *19*, 427–452.
- Alvarez, C. J., Carreiras, M., & Taff, M. (2001). Syllables and morphemes: Contrasting frequency effects in Spanish. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *27*, 545–555.
- Arguin, M., & Bub, D. (2005). Parallel processing blocked by letter similarity in letter-by-letter dyslexia: A replication. *Cognitive Neuropsychology*, *22*, 589–602.
- Arguin, M., Fiset, S., & Bub, D. (2002). Sequential and parallel letter processing in letter-by-letter dyslexia. *Cognitive Neuropsychology*, *19*, 535–555.
- Bartolomeo, P. (2002). The relationship between visual perception and visual mental imagery: A reappraisal of the neuropsychological evidence. *Cortex*, *38*, 357–378.
- Bartolomeo, P., Bachoud-Lévi, A. C., Chokron, S., & Degos, J. D. (2002). Visually- and motor-based knowledge of letters: Evidence from a pure alexic patient. *Neuropsychologia*, *40*, 1363–1371.
- Behrmann, M., Moscovitch, M., & Winocur, G. (1994). Intact visual imagery and impaired visual perception in a patient with visual agnosia. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1068–1087.
- Behrmann, M., Plaut, D. C., & Nelson, J. (1998). A literature review and new data supporting an interactive account of letter-by-letter reading. *Cognitive Neuropsychology*, *15*, 7–51.
- Behrmann, M., & Shallice, T. (1995). Pure alexia: An orthographic not spatial disorder. *Cognitive Neuropsychology*, *12*, 409–454.

- Benton, A. L., Silvan, A. B., Hamsher, K. de S., Varney, N. R., & Spreen, O. (1992). *Facial recognition*. Firenze, Italy: Organizzazioni Speciali.
- Burani, C., Barca, L., & Arduino, L. S. (2001). Una base di dati sui valori di età di acquisizione, frequenza, familiarità, immaginabilità, concretezza, e altre variabili lessicali e sub-lessicali per 626 nomi dell'italiano [Set of data on age of acquisition, frequency, familiarity, imageability, concreteness, and other lexical and sublexical variables for 626 Italian words]. *Giornale Italiano di Psicologia*, 4, 839–854.
- Caramazza, A., & Hillis, A. E. (1990). Levels of representation, coordinate frames, and unilateral neglect. *Cognitive Neuropsychology*, 7, 391–445.
- Caramazza, A., & Miceli, G. (1990). The structure of graphemic representations. *Cognition*, 37, 243–297.
- Carreiras, M., Alvarez, C., & de Vega, M. (1993). Syllable frequency and visual word recognition in Spanish. *Journal of Memory and Language*, 32, 766–780.
- Carreiras, M., & Perea, M. (2002). Masked priming effects with syllabic neighbors in a lexical decision task. *Journal of Experimental Psychology: Human Perception and Performance*, 28, 1228–1242.
- Carreiras, M., Vergara, M., & Barber, H. (2005). Early ERP effects of syllabic processing during visual word recognition. *Journal of Cognitive Neuroscience*, 17, 1803–1817.
- Chialant, D., & Caramazza, A. (1998). Perceptual and lexical factors in a case of letter-by-letter reading. *Cognitive Neuropsychology*, 15, 167–201.
- Cohen, L., & Dehaene, S. (2004). Specialization within the ventral stream: The case for the visual word form area. *NeuroImage*, 22, 466–476.
- Cohen, L., Henry, C., Dehaene, S., Martinaud, O., Lehericy, S., Lemer, C., et al. (2004). The pathophysiology of letter-by-letter reading. *Neuropsychologia*, 42, 1768–1780.
- Cohen, L., Martinaud, O., Lemer, C., Lehericy, S., Samson, Y., Obadia, M., et al. (2003). Visual word recognition in the left and right hemispheres: Anatomical and functional correlates of peripheral alexias. *Cerebral Cortex*, 13, 1313–1333.
- Coltheart, M. (1985). Right-hemisphere reading revisited. *Behavioral and Brain Sciences*, 8, 363–379.
- Coltheart, M., Patterson, K., & Marshall, J. C. (1980). *Deep dyslexia*. London: Routledge.
- Coltheart, M., Rastle, K., Perry, C., Ziegler, J., & Langdon, R. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, 108, 204–256.
- Cooper, L. A., & Shepard, R. N. (1973). Chronometric studies of the rotation of mental images. In W. G. Chase (Ed.), *Visual information processing* (pp. 75–175). New York: Academic Press.
- Cornoldi, C., & Colpo, G. (1995). *Nuove prove di lettura MT per la scuola media inferiore* [New reading tests of the MT group for junior high school]. Firenze, Italy: Organizzazioni speciali.
- Coslett, H. B., & Saffran, E. M. (1993). Reading in pure alexia: The effect of strategy. *Brain*, 116, 21–27.
- Crawford, J. R., & Garthwaite, P. H. (2002). Investigation of the single case in neuropsychology: Confidence limits on the abnormality of test scores and test score differences. *Neuropsychologia*, 40, 1196–1208.
- Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: A proposal. *Trends in Cognitive Science*, 9, 335–341.
- Dehaene, S., Jobert, A., Naccache, L., Ciuciu, P., Poline, J. B., Le Bihan, D., et al. (2004). Letter binding and invariant recognition of masked words: Behavioral and neuroimaging evidence. *Psychological Science*, 15, 307–313.
- De Renzi, E., Motti, F., & Nichelli, P. (1980). Imitative gestures: A quantitative approach to ideomotor apraxia. *Archives of Neurology*, 37, 6–10.
- Ellis, A. W. (1993). *Reading, writing and dyslexia: A cognitive analysis*. Hove, UK: Psychology Press.
- Ellis, A. W. (2004). Length, formats, neighbours, hemispheres, and the processing of words presented laterally or at fixation. *Brain and Language*, 88, 355–366.
- Ellis, A. W., Flude, B., & Young, A. W. (1987). Neglect dyslexia and the early visual processing of letters in words and nonwords. *Cognitive Neuropsychology*, 4, 439–464.
- Farah, M. J., & Wallace, M. (1991). Pure alexia as a visual impairment: A reconstruction. *Cognitive Neuropsychology*, 8, 313–334.
- Ferrand, L., & New, B. (2003). Syllabic length effects in visual word recognition and naming. *Acta Psychologica*, 113, 167–183.
- Ferrand, L., Segui, J., & Grainger, J. (1996). Masked priming of words and picture naming: The role of syllabic units. *Journal of Memory and Language*, 35, 708–723.
- Goldenberg, G. (1992). Loss of visual imagery and loss of visual knowledge—a case study. *Neuropsychologia*, 30, 1081–1099.
- Goldenberg, G. (1998). Is there a common substrate for visual recognition and visual imagery? *Neurocase*, 4, 141–147.

- Grainger, J., & Whitney, C. (2004). Does the human mind read words as a whole? *Trends in Cognitive Neuroscience*, 8, 58–59.
- Hanley, J. R., & Kay, J. (1992). Does letter-by-letter reading involve the spelling system? *Neuropsychologia*, 34, 237–256.
- Hanley, J. R., & Kay, J. (1996). Reading speed in pure alexia. *Neuropsychologia*, 34, 1165–1174.
- Istituto di Linguistica Computazionale del CNR di Pisa. (1989). *Corpus di Italiano scritto contemporaneo* [Corpus of contemporary written Italian]. Unpublished manuscript.
- James, M., Plant, G. T., & Warrington, E. K. (2001). *CORVIST—Cortical Vision Screening Test manual & test materials book*. Bury St. Edmunds, UK: Thames Valley Test Company.
- Kinsbourne, M., & Warrington, E. K. (1963). The localizing significance of limited simultaneous visual form perception. *Brain*, 86, 697–701.
- Ladavas, E., Shallice, T., & Zanella, M. T. (1997). Preserved semantic access in neglect dyslexia. *Neuropsychologia*, 35, 257–270.
- Luzzatti, C., Willmes, K., & De Bleser, R. (1996). *Aachener Aphasia Test: Versione Italiana* (Italian version, 2nd ed.). Firenze, Italy: Organizzazioni Speciali.
- McClelland, J. L. (1976). Preliminary letter identification in the perception of words and nonwords. *Journal of Experimental Psychology: Human Perception and Performance*, 2, 80–91.
- McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, 88, 375–407.
- Miozzo, M., & Caramazza, A. (1998). Varieties of pure alexia. The case of failure to access graphemic representations. *Cognitive Neuropsychology*, 15, 203–238.
- Mozer, M. C., & Behrmann, M. (1990). On the interaction of selective attention and lexical knowledge: A connectionist account of neglect dyslexia. *Journal of Cognitive Neuroscience*, 2, 96–123.
- Osswald, K., Humphreys, G. W., & Olson, A. (2002). Words are more than the sum of their parts: Evidence from detrimental effects of word-level information in alexia. *Cognitive Neuropsychology*, 19, 675–695.
- Patterson, K., & Kay, J. (1982). Letter-by-letter reading: Psychological descriptions of a neurological syndrome. *Quarterly Journal of Experimental Psychology*, 34A, 411–441.
- Perri, R., Bartolomeo, P., & Silveri, M. C. (1996). Letter dyslexia in a letter-by-letter reader. *Brain and Language*, 53, 390–407.
- Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review*, 103, 56–115.
- Price, C. J., & Devlin, J. T. (2004). The pro and the cons of labelling a left occipitotemporal region: “The visual word form area”. *Neuroimage*, 22, 477–479.
- Price, C. J., & Humphreys, G. W. (1992). Letter-by-letter reading? Functional deficits and compensatory strategies. *Cognitive Neuropsychology*, 9, 427–457.
- Prinzmetal, W., Hoffman, H., & Vest, K. (1991). Automatic processes in word perception: An analysis from illusory conjunctions. *Journal of Experimental Psychology: Human Perception and Performance*, 17, 902–923.
- Prinzmetal, W., Treiman, R., & Rho, S. H. (1986). How to see a reading unit. *Journal of Memory and Language*, 25, 461–475.
- Rapp, B. C. (1992). The nature of sublexical orthographic organization: The bigram through hypothesis examined. *Journal of Memory and Language*, 31, 33–53.
- Raven, J. C. (1962). *Coloured progressive matrices: Sets A, AB, B*. London: H.K. Lewis.
- Reuter-Lorenz, P. A., & Brunn, J. L. (1990). A prelexical basis for letter-by-letter reading. *Cognitive Neuropsychology*, 7, 1–20.
- Riddoch, M. J., & Humphreys, G. W. (1993). *BORB: Birmingham Object Recognition Battery*. London: Psychology Press.
- Rouibah, A., & Taft, M. (2001). The role of syllabic structure in French visual word recognition. *Memory and Cognition*, 29, 373–381.
- Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: Part 2. The contextual enhancement effect and some tests and extensions of the model. *Psychological Review*, 89, 60–94.
- Saffran, E. M., & Coslett, H. B. (1998). Implicit vs. letter-by-letter reading in pure alexia: A tale of two systems. *Cognitive Neuropsychology*, 15, 141–165.
- Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's Guide*. Pittsburgh: Psychology Software Tools Inc.
- Shallice, T. (1979). Case study approach in neuropsychological research. *Journal of Clinical Neuropsychology*, 1, 13–211.

- Shallice, T. (1981). Neurological impairments of cognitive processes. *British Medical Bulletin*, *37*, 187–192.
- Shallice, T. (1988). *From neuropsychology to mental structure*. Cambridge, UK: Cambridge University Press.
- Shallice, T., & McCarthy, R. (1985). Phonological reading: From patterns of impairment to possible procedures. In K. E. Patterson, M. Coltheart, & J. C. Marshall (Eds.), *Surface dyslexia*. Hove, UK: Lawrence Erlbaum Associates Ltd.
- Shallice, T., & Warrington, E. K. (1977). The possible role in acquired dyslexia. *Neuropsychologia*, *15*, 31–41.
- Spinnler, H., & Tognoni, G. (1987). Standardizzazione e taratura italiana di test neuropsicologici [Italian standardization of neuropsychological tests]. *The Italian Journal of Neurological Sciences*, *8*, 1–120.
- Stella, V., & Job, R. (2001). Le sillabe PD/DPSS. Una base di dati sulla frequenza sillabica dell'Italiano scritto [Set of data on the syllabic frequency of written Italian]. *Giornale Italiano di Psicologia*, *28*, 633–639.
- Taft, M. (1979). Lexical access via an orthographic code: The BOSS. *Journal of Verbal Learning and Verbal Behaviour*, *18*, 21–39.
- Warrington, E. K., & James, M. (1991). *The Visual Object and Space Perception Battery*. Bury St Edmunds, UK: Thames Valley Test Company.
- Warrington, E. K., & Langdon, D. W. (2002). Does the spelling dyslexic read by recognizing orally spelled words? An investigation of a letter-by-letter reader. *Neurocase*, *8*, 210–218.
- Warrington, E. K., & Shallice, T. (1980). Word form dyslexia. *Brain*, *103*, 99–112.
- Wechsler, D. (1986). *Scala d'intelligenza Wechsler per adulti (WAIS)* [Wechsler Adult Intelligence Scale for Adults]. Firenze, Italy: Organizzazioni Speciali.
- Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin Review*, *8*, 221–243.