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WHY SEMANTIC DEMENTIA DRIVES YOU TO THE DOGS (BUT NOT TO THE HORSES): A THEORETICAL ACCOUNT

Marinella Cappelletti
King's College London at St Thomas's Hospital, and University College London, UK

Michael Kopelman
King's College London at St Thomas's Hospital, UK

Brian Butterworth
University College London, UK

This paper describes a patient (IH) with semantic dementia and severe impairment in all semantic categories except for numerical knowledge, which was preserved. IH showed a severe deficit in reading and writing non-number words (e.g., *candle*, *juice*) and nonwords, and preservation of reading and writing number words (e.g., *one*, *forty*) and numerals (e.g., *1*, *40*). IH's pattern of performance can be explained by the combination of a selective sparing of one semantic category—i.e., numbers—with a total deficit of nonsemantic processes for mapping letters and sounds. As number was the only spared semantic category in the presence of these other nonsemantic deficits, it follows that the semantic route is *sufficient* for accurate reading and spelling. Our data clarify the nature of reading and writing processes and support the functional and neuroanatomical independence of the number domain.

INTRODUCTION

We will describe a patient with a progressive disorder of semantic memory who can understand, read, and write *three* but not *tree*, *ten* but not *then,* and *second* but not *station*. In this paper, we consider how this striking observation can be explained in terms of theories of reading, spelling, and semantic memory.

Following Marshall and Newcombe (1973), most current models of reading assume two processes for mapping from orthography (O) to phonology (P). The first process maps via semantics (S), O → S → P, whereas the second does not, O → P. Models differ mainly in how the O → P and P → O processes operate. According to Coltheart, Curtis, Atkins, and Haller (1993), and Zorzi, Houghton, and Butterworth (1998), there are separate lexical and nonlexical subsystems for nonsemantic mapping. Other models suppose that all orthographic sequences are mapped onto phonology without regard to their lexicality, which is a function of the semantic process (Plaut, McClelland, Seidenberg, & Patterson, 1996). The "summation model" of Hillis and Caramazza

Requests for reprints should be addressed to M. Cappelletti, Institute of Cognitive Neuroscience, University College London, 17 Queen Square, London, WC1N 3AR, UK (Tel.: +44 20 7679 1151; Fax: +44 20 7813 2835; Email: m.cappelletti@ucl.ac.uk).

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(1991, 1995) proposes that the O → P process operates solely at the sublexical level.

Although the involvement of semantics has been postulated in all these models, its role has been interpreted differently. For instance, some models assume that the semantic route contributes relatively little to word naming in skilled readers since, being indirect, it is slow in delivering a word pronunciation (Paap & Noel, 1991). Van Orden (1987) has argued that semantic access strictly follows phonological access—that is the only route is O → P → S.

A similar, though inverse, process is used for retrieving orthographical representations (O) from phonology (P) via a semantic (S) pathway, P → S → O, as well as via a sound-spelling mapping process, P → O (Ellis & Young, 1988; Miceli, Benvegnù, Capasso, & Caramazza, 1997). There are comparable debates as to whether the P → O pathway includes both lexical and sublexical mappings (see Tanturier & Rapp, 2001, for a review) and also whether access to orthography is always mediated by phonology (Van Orden, Jansen op de Haar, & Bosman, 1997). However, the balance of evidence from both normal spellers and patients is that orthography can be accessed from both semantics and phonology.

The critical role of semantics in reading has been supported by evidence from semantic dementia. The association between semantic dementia—where semantics are impaired—and surface dyslexia has been described in a number of cases, supporting the hypothesis that correct irregular word[1] reading is dependent upon semantic representations (Patterson & Hodges, 1992). This association has been explained by proposing that semantics provide the "glue" that holds the elements of a word together, both the letters and the phonemes (Patterson & Hodges, 1992). This position implies that the orthographic and the phonological representations of words will disintegrate in the absence of semantics, and it predicts, for instance, that auditory or visual lexical decision should fail for words that are not understood. However, other models of reading imply that semantics contribute mainly to the reading of irregular words, rather than to words in general.

In the model proposed by Plaut et al. (1996, Simulation 4), the connection between semantics and phonology is particularly important for low-frequency and irregularly spelled words. The semantic route contributes more to the pronunciation of these words, which are thus more vulnerable to impairments of the semantic system such as semantic dementia (Patterson et al., 1996). When the O → P route is lesioned, correct reading can be achieved by the O → S → P route. Note that lexical decision is modelled by interactions in the O → S → P route. The authors suggested that category effects will be revealed in irregularly spelled words which require semantic mediation for correct pronunciation (Patterson et al., 1996; Plaut et al., 1996).

In the "summation hypothesis" (Hillis & Caramazza, 1991, 1995), the authors state that "the combination of the two types of information (semantic and sublexical mapping) activates the lexico-phonological output when neither type of information *alone* is sufficient" (Hillis & Caramazza, 1995, p. 189, note 1). This implies that the combination of the two types of information is redundant when one or the other alone is *sufficient* to access the phonological representation. Destruction of O → P would still allow correct reading by O → S → P. Correct lexical decision would be independent of semantics in this model, since orthographical and phonological lexical representations are separate processes.

The summation hypothesis allows three specific predictions about reading in patients with impaired comprehension and an intact O → P mechanism: (1) they should read words correctly (including irregular and exception ones) that activate at least partial semantic information; (2) they should assign regular pronunciation to words for which no semantic information is available; and (3) their

[1] Irregular words are those with the less frequent pronunciation of an inconsistent pattern, e.g., "*pint*," "*flower*". Exception words are those with a unique spelling pattern and pronunciation, e.g., "*yacht*" or "*two*" (Zorzi et al., 1998). In this paper, the expression "irregular" words will be used to include "exception" ones.

reading skills should decline as a function of comprehension. The findings in several patients have supported these predictions (Hillis & Caramazza, 1991, 1995; Patterson & Hodges, 1992). Nevertheless, some patients are able to read *some* irregularly spelled words despite impaired comprehension (Bub, Cancelliere, & Kertesz, 1985; Cipolotti & Warrington, 1995; Funnell, 1983, 1996; McCarthy & Warrington, 1986; Schwartz, Saffran, & Marin, 1980; Shallice, Warrington, & McCarthy, 1983). A detailed analysis of the patients' performance showed that their residual semantic information was sufficient for correct reading (Hillis & Caramazza, 1991, 1995). Correct reading resulted from the interaction of this residual information with information from the O → P mechanism.

Similar accounts have been invoked specifically in the case of numbers. McCloskey and colleagues (McCloskey, 1992; McCloskey, Caramazza, & Basili, 1985) have proposed a model designed to accommodate both reading and writing number words and also numerals. In this model, semantic mediation is *sufficient* for both reading and writing number words. Sublexical processes such as letter-sound mappings are invoked as a backup when semantic mediation fails.

Category-specificity in reading and writing

There is extensive evidence that the semantic system is at least roughly segregated into categories or domains (Borgo & Shallice, 2001; Shelton & Caramazza, 2000; Warrington, 1975; Warrington & McCarthy, 1987), and category-specific deficits and sparing have been observed in a variety tasks but not, to date, in reading or writing.

Four main reasons are suggested to explain this. First, those studies that investigated the relation between word comprehension and reading did not explore category specificity. For example, some authors measured the patients' comprehension disorder only on the basis of "general" semantic tests (Funnell, 1996; Graham, Patterson, & Hodges, 2000; Patterson, Graham, & Hodges, 1994a; Patterson & Hodges, 1992). In addition, different items were used in comprehension and reading tests, ruling out the possibility of a direct comparison between performance in those tests: We do not know whether the patients' incorrect reading of an irregularly spelled word corresponded to impaired understanding of that word. However, even when the same items have been used, the patients' performance could not be always directly compared, as the irregular words used for the reading task were sometimes inappropriate for the naming one; therefore item-specific consistency could not be demonstrated (Graham, Hodges, & Patterson, 1994).

Second, in other studies that demonstrated preservation of a selective semantic category in patients, the authors did not investigate the patients' reading and writing performance as they had different aims in mind (Diesfeldt, 1993; Rossor, Warrington, & Cipolotti, 1995).

Third, in some studies, one semantic category was better preserved than others, but no reading and writing disorders were detected. For instance, although the patients' numerical abilities were better preserved, their residual understanding (which emerged in some semantic tasks), combined with information from the O → mechanism, was sufficient for correct reading (see the cases reported by Remond-Besuchet et al., 1999; Thioux et al., 1998).

Fourth, category-specificity in reading and writing will be revealed only when selective preservation of a semantic category occurs in combination with complete impairment of the O → P and P → O mechanisms (provided that the lexical components of the reading and writing processes are preserved). Though none of the published case studies showed this pattern of performance, some authors suggested this possibility (Hillis & Caramazza, 1995; Plaut et al., 1996). Impairment to the O → P and P → O mechanisms means that the phonological and orthographical word representations are necessarily accessed via semantics. Assuming that this information is preserved only for a specific category of knowledge, corresponding category-specificity is to be expected in reading and writing. This explanation can account for the previously published cases. All the reported patients with semantic impairment and reading disorders correctly read both regularly spelled words and nonwords, and made mistakes with the irregular ones. Moreover, as the patients' comprehension degenerated, only the accuracy in reading irregular words declined, whereas that for regularly spelled words and nonwords was relatively preserved (Patterson & Hodges, 1992). This clearly shows that the patients' O → P mechanism was still preserved and was used to access the phonological and orthographical representations.

The present report describes a patient (IH) with semantic dementia and selectively preserved number comprehension. IH showed intact reading and writing of number words and impaired reading and writing of non-number words. The patient's reading and writing impairment extended to all non-number words, whether regular or not, and to nonwords, consistent with impaired O → P and P → O mechanisms. We will show that category-specificity in reading and writing arises from the co-occurrence of (1) a selectively preserved semantic category and (2) impaired O → P and P → O mechanisms. We have described in detail elsewhere the patient's excellent calculation skills in the context of severely defective general knowledge and language abilities (Cappelletti, Butterworth, & Kopelman, 2001). The patient's reading and writing abilities, which are the focus of this paper, have been described briefly in a short report (Butterworth, Cappelletti, & Kopelman, 2001) and in a conference abstract (Cappelletti, Kopelman, & Butterworth, 2000).

CASE REPORT

At the time of the present investigation (1999), IH was a 65-year-old, right-handed, former banker, with 12 years of formal education. He was first seen at St Thomas's Hospital's Neuropsychiatry and Memory Disorders Clinic (Kopelman & Crawford, 1996) in December 1995. IH complained of difficulties in word-finding and naming, especially for objects and places. His comprehension was impaired, although memory for day-to-day events was quite well preserved (Moss, Cappelletti, De Mornay Davies, Jaldow, & Kopelman, 2000). The patient had also been fond of gambling, and despite his difficulties he continued to bet on dog-racing even in the later stages of the illness. A clinical diagnosis of semantic dementia was made (Hodges, Patterson, Oxbury, & Funnell, 1992; Snowden, Goulding, & Nearly, 1989).

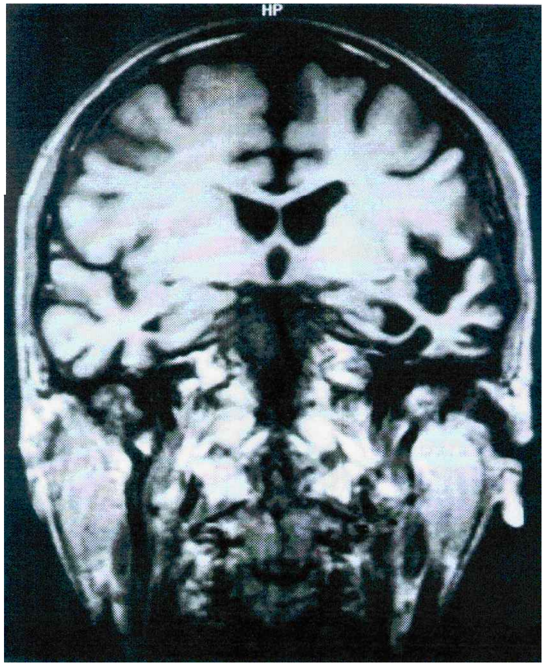

Figure 1. *MRI scan of IH in 1998.*

An MRI brain scan with coronal slices showed severe and disproportionate left temporal lobe atrophy (see Figure 1). There was relative sparing of the left hippocampus, but it did show some atrophy, and there also appeared to be some widening of the subarachnoid space surrounding the right temporal lobe, implying a much lesser degree of atrophy. There was also some evidence of mild-to-moderate general cortical atrophy.

Summary of neuropsychological investigation

Details of the background neuropsychological investigations are reported in a previous paper (Cappelletti et al., 2001). Overall, IH showed preserved general intelligence when tasks not requiring verbal production were performed. The patient's language was severely affected by his comprehension disorder and, although fluent and syntactically correct, it was empty and repetitive. A preliminary examination showed that reading abilities were impaired.

Summary of investigation on semantic and numerical knowledge

A wide range of tests based on matched living and man-made items was used to assess IH's semantic memory. The tests investigated verbal and pictorial non-numerical knowledge. IH was severely impaired on verbal semantic tasks and moderately impaired on the pictorial ones (see Table 1).

Conversely, IH's numerical knowledge was almost completely preserved. The patient performed well on a series of numerical and calculation tasks, the only exception being some multi-digit arithmetical problems. However, it should be noted that the majority of the errors consisted of the use of long and inefficient algorithms, which led to an increase of errors (see Table 2). Therefore, results of semantic and numerical tasks clearly indicated that these types of knowledge dissociated in IH.

EXPERIMENTAL INVESTIGATION

The experimental study was aimed at examining in detail (1) whether IH's semantic memory impairment extended to the reading and writing of words, and (2) whether the integrity of his numerical skills also applied to the reading and writing of numbers. The investigation is reported in seven parts. Part 1 examines IH's oral reading of regular and irregular words and nonwords. Part 2 examines the patient's

Table 1. *Verbal and pictorial semantic memory tests*[a]

	IH	*Controls (% except for fluency tests)*
Verbal tasks		
Phonological fluency (FAS)	0	<1st percentile[b]
Semantic fluency (total 8 categories)	0	117[e]
Graded Naming Test (N = 30)	0	75.1 (4.3)[d]
Category naming (N = 40)	4	99
Naming real objects (N = 15)	0	100
Word classification (N = 50)	0	100
Name-to-picture matching (N = 40)	22	97
Pyramid and Palm Tree Task: verbal version (N = 52)	0	99[c,d]
Verbal definition (N = 73)	0	99.5
Pictorial tasks		
Picture classification (N = 40)	80	99
Subcategory picture classification (N = 9)	66	100
Size judgement task (N = 20)	65	99
Object decision task (N = 20)	70	88[d]
Pyramid and Palm Tree Task: pictorial version (N = 52)	52	99[d]

[a]Modified from: Cappelletti, M., Butterworth, B., & Kopelman, M. (2001). Spared numerical abilities in a case of semantic dementia. *Neuropsychologia*, *39*, 1224–1239.

[b]From Lezak, M.D. (1995). *Neuropsychological assessment* (3rd ed.). Oxford: Oxford University Press.

[c]From Howard, D., & Patterson, K. (1992). *The Pyramids and Palm Trees Test. A test of semantic access from words and pictures*. Bury St Edmunds, UK: Thames Valley Test Company.

[d]Norms instead of controls.

[e]Mean items produced.

Table 2. *Numerical tests (percent correct)*

	IH	*Controls*
Number tests		
Counting (*N* = 80)	100	100
Magnitude comparison (*N* = 20)	100	100
Selection of chips (*N* = 48)	100	100
Transcoding (up to 4-digit numbers)		
Reading Arabic numerals (*N* = 100)	97	100
Reading number words (*N* = 100)	100	100
Writing Arabic numerals (*N* = 100)	97	100
Written Arabic numbers to written number words (*N* = 20)	100	100
Written number words to Arabic numbers (*N* = 20)	100	100
Transcoding arithmetical signs (*N* = 8)	0	100
Calculation		
Single-digit operations (*N* = 254)	89	98
Oral multidigit operations (untimed Jackson & Warrington test) (*N* = 28)	96	
Written multidigit operations (*N* = 96)	80	96
Approximation to the correct result (*N* = 100)	0	100
Approximation of numbers on a line (*N* = 100)	100	100
Other tests		
Personal and non-personal numerical questions (*N* = 20)	5	100
Definition of arithmetical operations (*N* = 4)	0	100

From Cappelletti, M., Butterworth, B., & Kopelman, M. (2001). Spared numerical abilities in a case of semantic dementia. *Neuropsychologia*, *39*, 1224–1239.

ability to read numbers and number words. Parts 3 and 4 analyse the possible effects of word frequency on the patient's reading and writing performance respectively. Part 5 examines the possibility that IH's performance in reading numerals is affected by their closeness in the list of items, or by the selective activation of the domain of numbers. Part 6 investigates IH's ability to read known and unknown words. Finally, Part 7 examines whether IH's reading and writing impairments could result from other deficits in accessing the orthographic and phonological input and output forms of words. Although the present study concerns the patient's performance in 1999, results of previous investigations are reported when a comparison with them is relevant.

Control subjects

The control subjects for numerical and semantic memory tasks were seven people matched as closely as possible to IH for age and education. Mean age for the seven control subjects was 70.7 years (*SD* = 5.1) and mean education was 9.9 years (*SD* = 1.78). Control subjects for reading and writing tasks were nine people matched for age and education. Their mean age was 63.8 years (*SD* = 3.1) and mean education was 10.5 years (*SD* = 1.69). The controls were given all the semantic memory and numerical tasks with the exception of those that already have norms (e.g., Graded Naming Test, McKenna & Warrington, 1983; Object Recognition Task, Warrington, 1984).

Part 1: Tests of reading non-number words

Test 1: Reading regular and irregular words

Methods. Regular and irregular words assembled by Coltheart, Davelaar, Jonasson, and Besner (1977) were presented to IH for oral reading. Words were printed in font 24 in lower case on separate cards and presented one at a time in a random order for reading aloud. The same words, together with other regular and irregular words from the PALPA test (Kay, Lesser, & Coltheart, 1992) had been presented in two previous testing sessions (1996 and 1998).

Table 3. *Tests of reading aloud (percentage correct)*

Tasks performed	*IH Time 1 (1996)*	*IH Time 2 (1998)*	*IH Time 3 (1999)*	*Controls* *Mean*	*SD*
Coltheart set:					
Regular (N = 39)	92		20		
Irregular (N = 39)	74		7		
Palpa set:					
Regular (N = 30)		77		99.6	0.6
Irregular (N = 30)		40		99.3	1.2
Nonwords (N = 60)	98	57	12		

Results. Overall, results show the progressive degradation of IH's reading skills. Table 3 shows the percentages of regular and irregular words read correctly in the tests. Two aspects of IH's performance emerged: (1) on tests done in 1999, reading irregular words was more impaired than reading regular words, Wilcoxon Test, $Z = -2.0226, p < .05$; (2) reading regular and irregular words had significantly deteriorated over time, McNemar Test, $\chi^2(1) = 26.03, p < .001$; $\chi^2(1) = 24.03, p < .001$ respectively.

Analysis of errors in reading non-number words. The majority of the errors made on Coltheart et al.'s test in 1996 consisted of regularisation of the irregular words (70%): that is, words were misread in line with a pronunciation based upon common mappings between letters and sounds. For example, IH read *pint* to rhyme with *mint*, and he sounded the silent letter *b* in the word *subtle*. The remaining errors (30%) were visually related errors, e.g., *sew* → /su/. In 1999 only 1.5% of the errors consisted of regularisation, whereas the rest were mainly fragments (57%), visual (19%), phonological (12%), and other types (e.g., nonwords) of errors (10.5%), in almost the same proportion for regular as for irregular words (see Table 4).

Test 2: Reading nonwords

Methods. A set of 60 simple nonwords was presented to the patient for reading aloud in three different testing sessions (1996, 1998, and 1999). Words were printed in font 24 in lower case on separate cards and presented one at a time in a random order for reading aloud. The list included 20 three-letter CVC words, and 40 four-letter strings consisting of 13 CVVC, 13 CVC, and 14 CCVC/CVCC words (such as "neg", "loat", "glem"). If the sublexical procedure for O → P mapping were still intact, IH should have been able to give acceptable pronunciations for nonwords.

Results. Table 1 shows that the patient's performance deteriorated significantly over time, Cochrane Test, $Q(2) = 72.77, p < .001$. At Time 1 (1996) the patient was able to read nonwords, with only 1 mistake out of 60 items (98% correct answers). At Time 2 (1998) his performance (57%) had deteriorated significantly from Time 1, McNemar Test, $\chi^2(1) = 23.04, p < .001$. Finally, at the time of the present investigation (1999) IH had dropped dramatically from the previous testing session, to only 7 regular nonwords out of 60 (12% correct), McNemar Test, $\chi^2(1) = 25.03, p < .001$. This suggests that, at the last date, the sub-lexical route for mapping letters to sounds was very severely impaired.

Table 4. *Reading errors (Coltheart test at Time 3, 1999)*

Type of errors	*Regular words (n = 31)*	*Irregular words (n = 36)*	*Total %*
Regularisation (N = 1)	0	1	1.5
Visual (N = 13)	12	7	19
Phonological (N = 8)	5	7	12
Fragments (N = 38)	23	34	57
Semantic (N = 0)	0	0	0
Omissions (N = 0)	0	0	0
Other (N = 7)	6	5	10.5
Total (N = 67)	46	54	100

Summary of Part 1. IH's performance clearly showed severe impairment at reading regular and irregular non-number words, and nonwords.

Part 2: Test of reading numbers and number words

Test 1: Reading aloud Arabic numerals

Methods. A set of 100 Arabic numbers was used. The stimuli were divided into different subgroups according to the scheme that has been used in analysing other patients with specific number reading disorders (Cipolotti & Butterworth, 1995). The stimuli consisted of 10 single-digit numbers, 10 numbers between 10 and 19, 20 two-digit numbers between 20 and 99 (8 ending in 0, 12 not ending in 0), 30 three-digit numbers between 100 and 999 (15 ending in 0 or with internal 0, and 15 without 0), and 30 four-digit numbers between 1000 and 9999 (15 ending in 0 or with internal 0, 15 without 0). Each number was printed in font 24 in lower case on separate cards and presented to the patient in random order for reading aloud. There was no time limit to the presentation.

Results. Table 5 shows the results in the number reading test. IH read the numbers accurately but slowly. The only three mistakes made consisted of selecting the wrong word for a power of ten. For instance, in reading "3582," IH said "million" instead of "thousand" for the digit 3. It seems, therefore, that the patient still retained the ability to read numerals, and the few mistakes were due to his linguistic difficulties. Control subjects produced 99% correct answers.

Test 2: Reading aloud number names

Methods. A series of written number words was randomly presented to the patient for reading aloud. The experimental set (*N* = 50) included 10 single-digit numbers (0 to 9), 10 two-digit numbers between 10 and 19, 10 two-digit numbers between 20 and 99, and 10 three-digit numbers between 100 and 999, 10 four-digit numbers between 1000 and 9999. Number words were printed in font 24 in lower case on separate cards and presented to the subjects one at a time in a random order for reading aloud.

Table 5. *Reading Arabic numerals and number words (percentage correct)*

Stimuli	*IH*	*Controls*
Arabic numbers (*N* = 100)	97	99
Number words (*N* = 50)	100	100

Results. IH's performance on this task was flawless (see Table 5). Control subjects produced 100% correct answers.

Summary of Part 2. IH's performance clearly showed preserved ability to read numerals and number words.

Part 3: Do frequency effects explain the patient's reading performance?

In the previous tests, number and non-number words were not strictly matched. To exclude the possibility that a factor covarying with category was responsible for the effects, we constructed new sets of words matched with the number words on frequency, length, and regularity of spelling.

Test 1: Reading cardinal number words

Methods. A set of number words was constructed that included all the numbers from *one* to *twenty*, each tenth word from *twenty* up to *one hundred*, plus *thousand* and *million* (*N* = 30). A set of 60 non-number words was constructed, matched for regularity of spelling (regular, irregular, and exception), frequency, length in letters, and number of syllables (see Table 6). (For a complete list of the words and number words used see Appendix A)[2]. The words

[2] Frequencies represent the frequency of the written form and also offer an estimate of the use of the word in the language as a whole. Of course we know that written frequencies may be misleading as to spoken frequencies and it may be that they are more misleading for number words than some other classes of words; however, there is no evidence available to quantify this. Here, the tasks focus on the written form.

Table 6. *Matching criteria for number and non-number words*

	Number words (N = 30)	*Non-number words (N = 30)*
Frequency per million*	255.6	254.6
Number of syllables	1.8	1.6
Number of letters	5.8	5.3
Spelling		
Regular	19	19
Irregular	8	8
Exception	3	3

*Kucera and Francis, 1967.

were printed in font 24 in lower case on separate cards and presented to the patient in random order for reading aloud. There was no time limit to the presentation of the stimuli. The task was presented over two testing sessions (May and July 1999).

Results. Table 7 shows the percentages of words read correctly. IH's performance revealed: (1) that number words were read more accurately than the matched set, Wilcoxon Test, $Z = -6.1540, p < .001$; (2) that his performance was consistent on two occasions (May and July 1999).

Test 2: Reading ordinal number words and other number words

Although cardinal number meanings may be first-learned and privileged (Butterworth, 1999), further tests explored the reading of other types of number word.

Methods. A set of 80 number words was constructed with 22 ordinal ("unambiguous") number words,

Table 7. *Reading cardinal number words and non-number words (percentage correct)*

Stimuli	*IH Time 1 (12.5.99)*	*IH Time 2 (8.7.99)*	*Controls*
Cardinal number words			
Regular (*N* = 19)	100	100	100
Irregular (*N* = 8)	100	100	100
Exception (*N* = 3)	100	100	100
Non-number words			
Regular (*N* = 19)	26	15	100
Irregular (*N* = 8)	12	12	100
Exception (*N* = 3)	0	0	100

e.g., "*first, second, third,*" and other 18 "ambiguous" number words that have both numerical and non-numerical meanings (e.g., *division, fraction, share*) (for a complete list of the words and number words used see Appendix B). The items were printed in font 24 in lower case on separate cards and presented to the patient in random order for reading aloud. There was no time limit to the presentation of the stimuli.

Results. Table 8 shows the percentages of words read correctly. IH's performance indicates: (1) a marked dissociation between reading non-number words and number words, Wilcoxon Test, $Z = -4.6226, p < .001$, consistent with the results found in the previous test; (2) a significant increase of the number of errors in reading number words compared with Test 1, McNemar Test, $\chi^2(1) = 8.1, p < .01$.

A posthoc qualitative analysis showed that IH made only 1 mistake out of 22 relatively unambiguous ordinal terms (of course, "second" has a non-ordinal meaning), whereas on the ambiguous terms he made 9 errors out of 18 items.

Analysis of errors in reading non-number words and number words (cardinal and ordinal). In reading non-number words, 116 mistakes were made out of the 130 items presented (89%) (see Table 9). Of the total errors 58% consisted of fragments (e.g., "a..a..r-r..a..arr" for *array*), whereas 20% and 6% of errors were words visually and phonologically similar to the target (e.g., "branch" for *brand*, and "south" for *sound* respectively). Semantic errors were only 1% of the total (only one mistake in reading "explorer" that was read as "es..e..boot"). Omissions were 2%, and other errors (e.g., nonwords) were 13%. No regularisation was produced in reading irregular words.

Table 8. *Reading other number words and non-number words (percentage correct)*

Stimuli	*IH*	*Controls*
Ordinal number words (*N* = 22)	95	100
Ambiguous number words (*N* = 18)	50	100
Matched non-number words (*N* = 40)	5	100

Table 9. *Reading errors*

	Number words[a]		*Total*		*Non-number words*		*Total*	
Type of errors	*Regular*	*Irregular*	*No.*	*%*	*Regular*	*Irregular*	*No*	*%*
Regularisations (N = 0)	0	0	0	0	0	0	0	0
Visual (N = 23)	0	1[b]	1	9	17	6	23	20
Phonological (N = 7)	0	0	0	0	5	2	7	6
Semantic (N = 3)	0	2	2	18	1	0	1	1
Fragments (N = 70)	8[b]	0	8	73	44	23	67	58
Omission (N = 9)	0	0	0	0	1	2	3	2
Other (N = 15)	0	0	0	0	7	8	15	13
Total (N = 127)	8	3	11	100	75	41	116	100

[a]Both cardinal and ordinal number words.
[b]All errors made in reading "ambiguous" number words.

Conversely, out of the 130 number words presented there were only 2 errors on cardinal and ordinal words ("forty" for "four"), and "se…on" for "second"), and 9 on the "ambiguous" number words.

Out of the 9 mistakes made at reading "ambiguous" number words, 8 consisted of fragments, and 1 of a word visually related to the target ("shot" for "share"). The frequency of the misread "ambiguous" number words significantly differed from that of "ambiguous" number words read correctly, 36.77 and 132.55 respectively; $t(8) = 1.99, p < .05$.

Summary of Part 3. These results indicate that IH's preserved ability to read number words was not the result of the effects of frequency, length, or spelling (although there was a frequency effect within the "ambiguous" number words taken in isolation).

Part 4: Test of writing number words

Patients with semantic disorders have been reported to show regularity effects in writing (Graham et al., 2000). However, no category-specificity in writing has been reported. In the following section, IH's writing performance is investigated.

Test 1: Writing cardinal number words to dictation

Methods. A writing task was administered, based on the same sets of cardinal number and non-number words used in the first reading task. The experimenter dictated one stimulus at a time and the subjects were asked to write the word on paper. Once written, each item was covered to avoid interference with the others. The task was administered to IH in two different testing sessions (June and July 1999).

Results. Table 10 shows the percentages of words written correctly. Control subjects performed at ceiling on this task. IH's performance reveals: (1) that number words were written more accurately than non-number words, Wilcoxon Test, $Z = -6.4515$, $p < .001$; (2) a better performance for number words at Time 2 compared to Time 1. (Given that the patient performed at ceiling at Time 2 and made only 4 errors out of 30 items at Time 1, the difference between Time 1 and 2 is not significant, Wilcoxon Test, $Z = -1.8257, p = .0679$.

Two of the mistakes that IH made were one letter from the target ("tirty" for "thirty" and "ninteen" for "nineteen"), one error almost corresponded to a different number ("tweenty" for "thirteen"), the last one was close to the target ("mileen" for "million").

Table 10. *Writing cardinal number words and non-number words (percentage correct)*

Stimuli	*IH Time 1 (16.6.99)*	*IH Time 2 (8.7.99)*	*Controls*
Number words (cardinal)			
Regular (N = 19)	89	100	100
Irregular (N = 8)	75	100	100
Exception (N = 3)	100	100	100
Non-number words			
Regular (N = 19)	0	0	100
Irregular (N = 8)	12	0	100
Exception (N = 3)	0	0	100

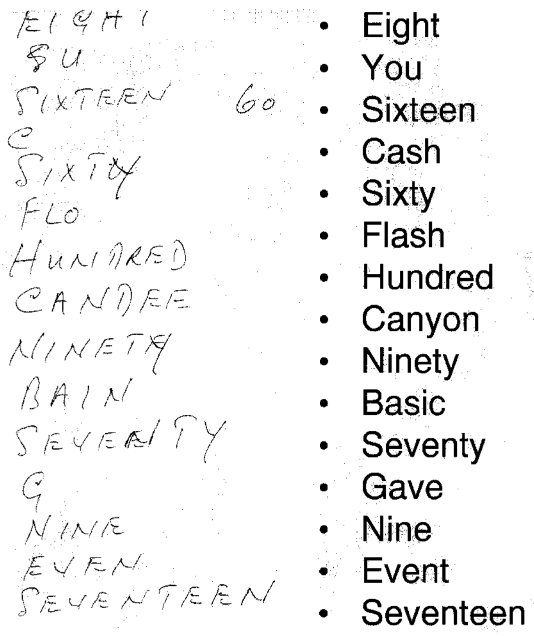

Figure 2. *Example of IH's writing number words and non-number words.*

Test 2: Writing ordinal number words to dictation

Methods. In order to corroborate the results obtained in Test 1, we administered to the patient a second writing task, based on the same sets of ordinal number and non-number words used in the previous reading task (Part 3, Test 2). Again the experimenter dictated one stimulus at a time and the subjects were asked to write a response on paper. Once written, each item was covered to avoid interference with the others.

Results. Table 11 shows the percentages of words spelled correctly. IH' s performance indicates: (1) vastly better writing of number words than non-number words (at floor), Wilcoxon Test, $Z = -4.0145$, $p < .0001$; (2) a strong consistency in the errors in reading and writing number words; the patient read and wrote incorrectly exactly the same 10 number words. Control subjects performed at ceiling on this task.

Summary of Part 4. Results of these tests indicate that the patient was better at writing number words, both cardinal and ordinal, than non-number words.

Table 11. *Writing other number words and non-number words (percentage correct)*

Stimuli	*IH*	*Controls*
Ordinal number words ($N = 22$)	95	100
Ambiguous number words ($N = 18$)	50	100
Matched non-number words ($N = 40$)	0	100

Part 5: Investigating the existence of facilitatory effects on reading number words

We wanted to rule out the possibility that the patient's ability at reading number words was the result of the closeness of number words in the list. That is, the fact that every two-to-three items was a number word might have facilitated the reading of the subsequent number word throughout the trial. Second, we needed to exclude the possibility that highlighting number as a category had not led to its selective preservation: IH may have read number words correctly because the category of numbers was repeatedly activated, and failed at reading non-number words correctly because other semantic domains were not specifically and repeatedly activated.

Test 1: Reading few number words matched with non-number words

Methods. In order to avoid facilitation effects, we constructed a list of items with only a few number words ($N = 5$) which were matched in mean frequency to a longer list of non-number words ($N = 20$). Number words were randomly presented every three-to-six non-number words throughout the list. The items were printed in font 24 in lower case on separate cards and presented to the patient in random order for reading aloud. There was no time limit to the presentation of the stimuli.

Results. IH's performance showed a dramatic superiority for reading number words (5 out of 5 correct answers) compared to non-number words (1 out of 20 correct answers). Therefore the patient was able to read number words no matter what their position in the list.

Test 2: Potential category facilitation effects

Methods. The previous tests had compared a single category of words (numbers) with words from assorted categories. It could have been that simply repeating words from a single category might have facilitated reading. To evaluate this, 12 number words were selected and matched in mean frequency to 12 non-number words belonging to a category with which IH was very familiar, namely sport. The items were printed in font 24 in lower case on separate cards and presented to the patient in random order for reading aloud. There was no time limit to the presentation of the stimuli.

Results. Despite the fact that sport words consisted of items very familiar to the patient, IH was almost at floor at reading non-number words (2 out of 12 correct answers), whereas he performed almost at ceiling at reading number words (11 out of 12 correct answers), Wilcoxon Test, $Z = -2.6656$, $p < .0077$. The only mistake in reading number words consisted of another number word ("thirty" instead of "thirteen"). Therefore, IH was impaired at reading non-number words no matter whether they belonged to a familiar or unfamiliar semantic category.

Summary of Part 5. The results showed that IH's preserved ability to read number words was not a consequence of their position or the proportion of the numerical items in the list.

Part 6: Reading meaningful words

Number words were meaningful to IH, since he was able to produce them accurately in answer to arithmetical questions. In the following test, the general advantage of more meaningful non-number words was explored.

Methods. Thirty-eight words were selected, 23 had been produced correctly in naming or classification tests, and 15 were selected from the patient's spontaneous speech. Following Patterson and colleagues (Patterson, Graham, & Hodges, 1994b), we assumed that words spontaneously produced in the correct context (and to the correct referents) were meaningful for the patient. The set of known words, including also days of the week and months of the year, was matched for frequency and length to 38 unknown or nonmeaningful words, i.e., not used in spontaneous speech (see Appendix C). Words were printed in font 24 in lower case on separate cards and presented to IH one at a time in random order for reading aloud.

Table 12. *Reading known and unknown words (percentage correct)*

Stimuli	*IH*
Known words (N = 38)	68
Unknown words (N = 38)	3

Results. Table 12 indicates the percentages of words read correctly. IH performed much better at reading known words, Wilcoxon Test, $Z = -4.3724$, $p < .0001$. He read correctly almost all the words that he frequently produced in conversation (11 out of 15 correct answers, 73%), and those produced in naming and classification tasks (15 out of 23 correct answers, 65%). The majority of IH's mistakes were at reading the months of the year (7 errors out of 8 items, 88%). However, although IH was only able to read 5 out of 12 (41%) names of months, for many of them (8 out of 12, 67%) he spontaneously gave indications showing that he retained some residual knowledge. For example, when asked to read the word "December," he said "It's the 12th month, the final month" without, however, being able to read the name.

Summary of Part 6. These results showed that IH read "known" words (i.e., meaningful to him) much better than "unknown" words (i.e., not meaningful to him).

Part 7: The intactness of lexical representations

The loci of the patient's impairments in reading and writing non-numerical words seemed to be in both semantics and in O → P and P → O mechanisms. However, it is also be possible that the patient's reading and writing disorders resulted from additional impairments to other components of the reading and writing processes. Although this possibility would not be consistent with the patient's ability to read and write number words, we wanted to exclude any further disorder. We first examined the integrity of access to the orthographic and phonological input forms of words, and second the access to the phonological output form. As the patient performed well with number words, they were included in these tests as control items.

Test 1: Visual lexical decision task

Methods. In order to explore the orthographic input form of words, the patient was administered a visual lexical decision task (PALPA, Kay et al., 1992). IH was asked to decide whether 60 strings of letters corresponded to words or nonwords. Items consisted of 15 words with irregular spelling sound correspondence (e.g., "bind"), and 15 regular words (e.g., "clip"). The 30 nonwords consisted of letter-pairings that do not occur in written English and were almost impossible to pronounce. A decision about whether a string of letters corresponded to a word or not was therefore based only on its orthographic characteristics. In addition, we presented the number and non-number words used in one of the reading and writing tasks, and a set of nonwords (see Part 1, Test 2, p. 489). The use of the same set of items in both reading and lexical decision tasks allowed direct comparison between them. In order to make the instructions clear to the patient, and taking account of his general comprehension difficulties, a different set of words and nonwords was used for practice. These nonwords were clearly implausible items consisting of strings of consonants, such as 'wxxoy', which the patient was expected to distinguish from other simple words, such as "pen". The strings of letters were printed in font 24 in lower case on separate cards and presented to the patient in random order. IH was asked to say whether a word "existed" or not.

Results

The patient performed at ceiling on the items used on the reading and writing tasks and on those from the PALPA test (120 out of 120 and 60 out of 60 correct answers respectively. Control subjects in the PALPA test performed as follows: irregular words, mean = 14.81, SD = 0.56; regular words, mean = 14.96, SD = 0.19; nonwords, mean = 30). Therefore, we can exclude the possibility that IH's reading disorders were due to difficulties in accessing the orthographic form of words.

Test 2: Auditory lexical decision task

Methods. The test aimed at clarifying whether the patient's writing impairment was attributable to a difficulty in accessing the phonological form of words. The same items used in the reading tasks were presented orally to IH, together with a set of similar but pronounceable nonwords. A different set of words and nonwords was used for practice. The experimenter pronounced one word at a time and asked the patient to say whether each word "existed" or not.

Results. The patient performed at ceiling on this task (120 out of 120 correct answers). Therefore, IH's writing disorder could not be attributed to difficulties in accessing the phonological input form of the words.

Test 3: Repetition task

Methods. The test explored whether the patient's impairment at reading non-number words might have originated from disorders in accessing their phonological output form. IH was administered a repetition task, consisting of simply asking him to repeat aloud the same non-number words and number words previously used in the reading and writing tasks. Given that input phonological representation was spared, any problem in repetition could be attributed to output problems. The experimenter pronounced a word at a time and asked the patient to repeat it back.

Results. The patient performed almost at ceiling on the words used in the first reading task (29 out of 30 non-number words and 30 out of 30 number words pronounced correctly). His performance was slightly worse with the second set of words used in the second reading task, where he correctly repeated 32 out of 40 non-number words and 38 out of 40 number words. Out of the nine errors, three were in repeating long words (e.g., "luggage"), four were phonologically similar words, one was a phonologically dissimilar word, and one was an omission. The two mistakes in repeating number words consisted of an omission (the number word "zero"), and of fragments in repeating a long and abstract word ("arithmetic"). Given the small number of errors, we rejected the possibility that IH's reading disorders were the result of difficulties in accessing the phonological output form of the words.

Summary of Part 7. These tests showed that IH had no additional impairments to other components of the reading and writing processes.

GENERAL DISCUSSION

On the basis of existing theories of reading and spelling, we inferred that category-specificity in reading and writing will emerge when (1) selective preservation of a semantic category combines with (2) specific impairment to the O → P and P → O conversion mechanisms. The present findings have confirmed this prediction. IH showed selectively spared knowledge of numbers, together with preserved reading and writing of number words, typically at ceiling. The O → P and P → O mechanisms were completely unavailable: not only was the patient unable to read nonwords, but he showed no advantage for regularly spelled words. However, orthographic and phonological representations of both number and non-number words appeared to be intact, since he performed at ceiling on visual and auditory lexical decision tasks and also on word repetition.

In this discussion, we will first examine the patient's semantic memory impairment and spared numerical knowledge. Second, we will consider IH's reading and writing performance. Third, we will discuss the theoretical implications of the data for general models of reading and writing and for those concerning numbers in particular.

IH showed relatively preserved ability on measures of visual intelligence, recent and autobiographical memory, and executive function (when verbal production was not required). This pattern of performance indicates that the patient's semantic disorder was not a consequence of a more general cognitive impairment. IH's impairment of knowledge was characterised by a severe and specific disruption of the cognitive system subserving conceptual knowledge. This was reflected in his poor performance on a variety of pictorial and verbal semantic tests, with a slightly better performance on closed sets (days of the week and months of the year) consistent with other reported patients (Cipolotti, Butterworth, & Denes, 1991; Dehaene & Cohen, 1997, patient BOO; Thioux et al., 1998).

In the context of severe semantic disorder, IH's numerical understanding was exceptionally well preserved. IH was flawless in counting, transcoding from Arabic to verbal format and vice-versa (e.g., "1 → one," and "one → 1"), reading, writing, and comparing numbers, as well as in solving simple and multi-digit arithmetical operations, which were performed with few mistakes. By contrast, he was impaired when linguistic input and output were required (e.g., in defining arithmetical operations).

The patient's impairment in semantic memory amounted to a severe inability to read and write words. IH performed badly on several reading and writing tests involving regular, irregular, and exception words, and nonwords. Conversely, he showed an exceptionally preserved capacity to read and write number words as compared to non-number words matched by frequency, length, and spelling. For instance, he could read *four* but not *face*. Hence, IH's inability to read and write words cannot be explained in terms of general reading and writing disorders. Consistent with other patients (Graham et al., 1994), IH also showed a better performance at reading known compared to unknown words.

Implications for the processes of reading and writing

Our findings show that the semantic O → S → P and P → S → O pathways are *sufficient* for the accurate reading and writing of all types of words, regular, irregular, and exception. In this particular case, the O → P and P → O pathways were severely impaired and numbers constituted the only semantic category available.

This pattern of results raises questions for models of reading and writing. The Plaut et al. (1996) model allows the semantic route to contribute more to irregularly spelled words. IH, however, was able to read number words whether they had irregular spellings (TWO, ONE) or entirely regular and consistent spellings (TEN, NINE).

Second, the idea that word parts (letters or phonemes) are held together by semantic glue (Patterson & Hodges, 1992) predicted that the only words IH would be able to understand would be represented in phonological or orthographic forms. This implies that in lexical decision tasks, only understood words should be identifiable as words, because only they would have properly glued-together representations. In this account, stimuli that were not understood should be judged as nonwords. However, IH performed at ceiling in both auditory and visual lexical decision tasks for non-number words that he was unable to understand. Moreover, he was able to repeat heard non-number words almost flawlessly, suggesting that the output representations for words were also intact.

IH's performance appeared consistent with informal models in which semantic and nonsemantic routes interact (e.g., Hillis & Caramazza, 1991; Marshall & Newcombe, 1973; Shallice & Warrington, 1980). In these models, semantic representations are used to implement lexical access rather than provide the glue that maintains the integrity of lexical representations. Although these models allow that semantic mediation is sufficient for accurate performance (Hillis & Caramazza, 1991, p. 4, note 1), IH provides the first clear evidence supporting this prediction.

It is tempting to think of two anatomically distinct semantic systems. The first, *parietal semantics* (PS), includes number semantics that are known to have a left parietal locus (Cipolotti & Van Harskamp, 2001), but this system may turn out to include other types of semantics, such as spatial cognition, which is known to have a parietal localisation. The second, *temporal semantics* (TS), is the traditional semantic system located in the temporal lobes which includes knowledge of living and nonliving things (Patterson & Hodges, 1992; Shallice, 1988; Warrington, 1975).

Figure 3 shows how preserved O → Parietal S → P and P → Parietal S → O routes account for IH's preserved reading and writing number words, respectively. In addition, three distinct types of deficits explain the patient's performance in reading and writing non-number words. Since IH was unable to read words he could not understand, models with lexical and sublexical O → P processes (Coltheart et al., 1993; Zorzi et al., 1998) require both of these be defective to require reading via the semantic route, O → S → P. On the other hand, the summation model (Hillis & Caramazza, 1991, 1995) has only a sublexical type of process in O → P or P → O, so a single impairment is sufficient to make reading and writing via semantics obligatory for IH.

A parallel argument can be made for writing. Only words in the preserved semantic domain could be spelled accurately. Nonwords could not be written at all, there were no regularisation errors in writing words—for example, "one" was never written as WUN, nor "two" as TOO or TU. Both were always spelled correctly. This suggest both that the P → O route was not functioning, and that all spelling was mediated by the P → S → O pathway in just the preserved number domain in the parietal lobe. This supports the general theoretical claim that there are separate and independent semantic and nonsemantic routes to spelling (Ellis & Young, 1988; Miceli et al., 1997).

This pattern of errors differed from some of the reported cases of semantic dementia, as even patients with profound loss of comprehension (e.g., KT and PP, Patterson & Hodges, 1992; PB and FM in a follow up investigation, Patterson et al., 1996) showed a significant advantage for regular over irregular words, although regular words

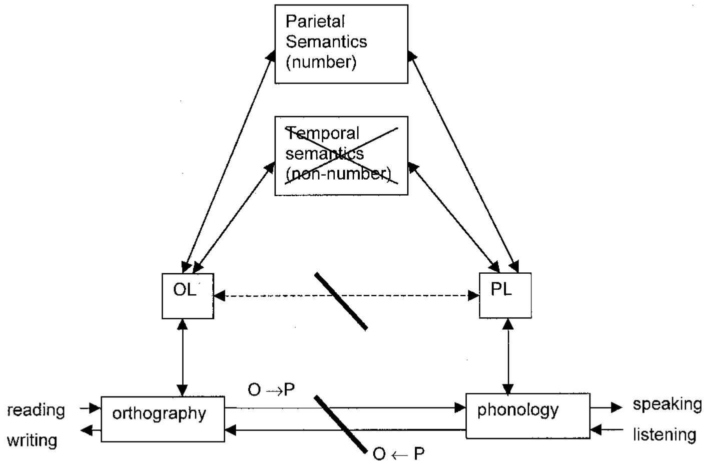

Figure 3. *Model of reading and writing number words and non-number words. OL and PL are orthographic input lexicon and phonological lexicon respectively. Semantic system includes a number and a non-number subsystem. O → P and P → O are orthography-to-phonology and phonology-to-orthography conversion mechanisms respectively. An orthographical (or phonological) input is processed in the semantic system via the orthographical (or phonological) input lexicon and a phonological (or orthographical) output produced. Alternatively, an orthographical (or phonological) input is converted into a phonological (or orthographical) output via O → P (or P → O). The existence of a third route (dotted in the figure) directly connecting orthographical and phonological lexicons is still disputed and our data do not speak to this issue.*

yielded errors and showed frequency sensitivity as the semantic disorder progressed. Although I.H. was consistent with this pattern of performance at earlier stages of the illness, his later performance deteriorated such that there was no advantage for regular words.

Figure 4 shows an alternative account that routes phonological and orthographic processing via abstract lexical representation, sometimes called the "lemma" (Butterworth, 1989; Butterworth, Howard, & McLoughlin, 1984; Levelt, 1989). This account has the advantage of two deficits only, to temporal semantics and non-numerical lemmas

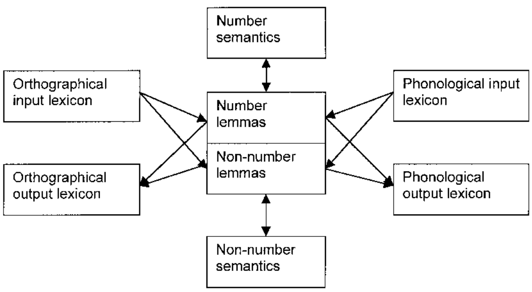

Figure 4. *Model of reading and writing number words and non-number words according to "lemma" theory.*

respectively. However, the evidence presented here does not enable us to decide between the lemma and the nonlemma accounts.

To have clear category-specificity in reading and writing, the preserved semantic category should be sharply distinct from the others. Such a clear-cut dissociation has rarely been reported, as patients showing a better performance on one semantic category usually retained partial understanding of other categories (e.g., Caramazza & Shelton, 1998, for impaired living things; Gonnerman, Andersen, Devlin, Kemler, & Seidenberg, 1997, for impaired man-made objects). This may be because some semantic features (e.g., sensory and/or functional properties) are common to a number of semantic categories in the system of knowledge (Gonnerman et al., 1997; Warrington & Shallice, 1984). This makes it difficult to obtain a clear dissociation between these categories, so that specificity in reading and writing becomes unlikely. In contrast, IH provided a sharp dissociation between numbers and other semantic concepts.

A possible reason of this sharp dissociation may be ascribed to the type of semantic category involved—namely numbers. Numerical concepts cannot be defined in terms of sensory and functional semantic features in the way that living and nonliving, artefact or food categories can be. Rather, cardinal number is defined as a property of a set (Giaquinto, 2001), and therefore has neither sensory nor functional properties. There is, thus, almost no overlap in the kinds of features appropriate for defining numbers and those for defining the various categories of temporal semantics. As we have noted, the neuroanatomical locus of numbers is in the parietal lobes, in particular in the left parietal lobe (Butterworth, 1999; Cipolotti & Van Harskamp, 2001; Dehaene, Dehaene-Lambertz, & Cohen, 1998), whereas the locus of the non-number semantic categories is in the left temporal lobe and may involve some overlap between particular categories (Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Martin, Wiggs, Ungerleider, & Haxby, 1996).

IH was also very accurate in reading and writing Arabic numerals. In McCloskey's model (1992), semantic mediation is necessary for reading and writing numerals. On the other hand, it has been proposed that there is a fully fledged nonsemantic route for reading and writing numbers (Cipolotti & Butterworth, 1995; Cohen, Dehaene, & Verstichel, 1994; Deloche & Seron, 1982; see Seron & Noel, 1995, for a review). Evidence from IH demonstrates the sufficiency of the semantic route, but not its necessity.

Conclusions

IH's selective ability to read and write numerals demonstrates category-specificity in reading and writing. The patient's severe impairment in understanding non-number words extended to reading and writing, consistent with other semantic dementia patients previously described (Funnell, 1996; Graham et al., 1994, 2000; Patterson et al., 1994a; Patterson & Hodges, 1992). In addition, the complete impairment of the sublexical routes in IH is suggested by: (1) the absence of regularisation errors in reading and writing irregular words, and (2) the inability to read both regular words and nonwords. It was the combination of impairment to these mechanisms and the selective preservation of numbers that revealed category-specificity in reading and writing. The selective integrity of numerical knowledge in IH has strengthened the evidence supporting the isolation of the category of numbers at a semantic level. This is consistent with other patients reported (Rossor et al., 1995; Thioux et al., 1998), although IH is the first semantic dementia patient reported with specific preservation of the number domain.

Finally, why does semantic dementia drive you to the dogs (but not to the horses)? According to his ex-wife, IH used to bet on both dogs and horses. At about the time of the present investigation, she noticed that he stopped betting on horses but was still betting on greyhounds. In British betting shops, horses are indicated by their names, and dogs by numbers. Hence, he was driven to (bet on) the dogs, but not to the horses.

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APPENDIX A

Items used in test of reading cardinal number words and non-number words

Cardinal number words (N = 30)			*Non-number words (N = 30)*		
One	Six	Seventeen	River	Array	Gave
Nineteen	Eleven	Thousand	Barrel	Tossed	Event
Ten	Eight	Eighty	Explorer	Take	Brand
Fifteen	Sixteen	Thirty	Afford	Negro	Juice
Forty	Sixty	Three	Decent	You	Status
Seven	Hundred	Million	Candle	Cash	Flat
Four	Ninety	Fifty	Include	Flash	Offer
Twelve	Seventy	Eighteen	Need	Canyon	Exist
Thirteen	Nine	Two	Then	Basic	Sound
Fourteen		Five	Formal		Clear
		Twenty			Agency

APPENDIX B

Items used in test of reading ordinal number words, ambiguous number words and non-number words

Ordinal (unambiguous) number words (N = 22)		*Ambiguous number words (N = 18)*		*Non-number words (N = 40)*		
First	Ninth	Divide	Share	Cream	Frame	Cotton
Sixth	Fifteenth	Zero	Sum	Months	Cheaper	Entry
Tenth	Seventh	Fraction	Digit	Bang	Skinny	Winning
Fourth	Fourteenth	Add	Division	Cereals	Gender	Synthetic
Sixteenth	Second	Plus	Table	Printer	Boat	Super
Nineteenth	Twelfth	Times	Arithmetic	Autumn	Human	Course
Fifth	Thirteenth	Subtract	Number	Comment	Luggage	Disease
Eighth	Seventeenth	Multiply	Percent	Rather	Imply	Drug
Hundredth	Thousandth	Minus	Equals	Distract	Loss	Target
Eleventh	Eighteenth			Sublime	Expose	Peace
Third	Twentieth			Farmer	Upset	Expire
				Such	Diamond	Popular
				Cinder	Cabin	
				Patio	Station	

APPENDIX C

Items used in test of reading known and unknown words

Known words (N = 38)		*Unknown words (N = 38)*	
Words correctly produced in naming/classification tasks		Energy	Yard
Bed	Eyes	Trees	Ignorant
Train	Dog	Next	Future
Words correctly and repeatedly produced in conversation		Teaching	Cherry
Flat	Voice	Nice	Fresh
Glasses	Face	Then	Circle
Dentist	Coffee	Above	Warm
Lottery	Car	Job	Arms
Name	Son	Project	Pounds
Individual	London	False	Bathroom
Garden	Doctor	Shown	Smile
Marvellous			
Days of the week		Jacket	Sad
Monday	Friday	Fast	Birth
Tuesday	Saturday	Creams	Candle
Wednesday	Sunday	Snow	Spider
Thursday		Lot	Carrot
Months of the year		Moon	Frame
January	July	Among	Clock
February	August	Sometime	Clouds
March	September		
April	October		
May	November		
June	December		