SELECTIVE IMPAIRMENT IN MANIPULATING ARABIC NUMERALS*

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Abstract

This paper describes an acalculic patient (B.A.L.) with an unusual selective deficit in manipulating arabic numerals. The patient was unimpaired in reading aloud letters, words and written number names but unable to read aloud single arabic numerals. Furthermore, his ability to produce the next number in the sequence and his ability to produce answers to simple addition and subtraction was relatively spared when the stimuli were presented as number names but impaired when the stimuli were presented as arabic numerals. Using magnitude comparison tasks it was demonstrated that his knowledge of cardinal values of arabic numerals was preserved. His impairment in manipulating arabic numerals was interpreted in terms of a deficit in the connection between format specific number codes and the verbal numeral production system.

Introduction

The question of whether the linguistic distinction between arabic numerals and alphabetic written elements is complemented by the involvement of two different, script dependent, reading mechanisms has been addressed by a number of studies (for a review see Deloche and Seron, 1987, and Cipolotti, 1993). Of particular interest are the studies which have reported differences in the performances of alexic patients when confronted with arabic numerals and alphabetic material. A number of studies have demonstrated that patients who cannot read aloud letters and/or words can often read aloud arabic numerals (e.g. Déjérine, 1892; Hinshelwood, 1899; Henschen, 1919, 1920; Bonhoffer, 1923; Hécaen, Angelergues and Houillier, 1961; Hécaen, 1967; Albert, Yamadori, Gardner et al., 1973; Hécaen and Kremin, 1976; Anderson, Damasio and Damasio, 1990; Cipolotti, Butterworth and Denes, 1991). The evidence for the existence of a reverse pattern, that is a selective impairment in reading arabic numerals without alexia for written number names, letters and words, has also been observed in an attenuated form. This patient (S.F.) was only impaired in reading aloud multidigit arabic numerals (Cipolotti, 1993, 1995).

An influential information processing model developed by McCloskey and co-workers has been utilized for presenting and discussing data generated by patients with difficulties in number reading and writing and in calculation (see

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McCloskey, 1992, for a review). One of the model's fundamental assumptions is that an abstract code is assumed to underlie all numerical operations including arithmetic and the transcoding among the numerical surface codes. It then follows that functional damage to the abstract code would result in an impaired performance on all numerical operations.

The evidence supporting the notion of the abstract code is based mainly on two patients (P.S. and R.H.). One patient (P.S.) presented a similar overall error rate for multiplication problems whatever the modality of input or output (e.g. arabic numerals, written number names and dots). His performance showed a striking consistency for individual problems across stimuli format. His error pattern in each of the conditions tested was also very similar (Sokol, McCloskey, Cohen et al., 1991). The second patient (R.H.) presented the same pattern of errors across 12 number transcoding tasks in which the stimuli were presented and responses were given in the form of arabic numerals, written and spoken number names and dots (Macaruso, McCloskey and Aliminosa, 1993).

However, the assumption that the form of internal representations of numbers is abstract has being challenged. It has been argued that the internal representations of numbers are not abstract but format specific (e.g. Gonzalez and Kolers, 1982, 1987; Campbell and Clark, 1988; Clark and Campbell, 1991; Vaid and Frenk-Mestre, 1991; Dehaene, 1992; McNeil and Warrington, 1994).

We describe a patient, B.A.L., who provides an example, not previously reported, of a selective impairment in reading aloud single digit arabic numerals whilst being able to read aloud written number names, letters and words. Furthermore, the patient presented difficulties in a range of number manipulation tasks that require spoken number name retrieval when the stimuli were presented as arabic numerals but not as number names. The implications of his deficit for the notion that there are abstract internal representations will be discussed.

Case Report

B.A.L. a 63 year old retired printer was admitted to Maida Vale hospital on 18.8.92. In 1944, at the age of 14, he developed intractable epilepsy. Angiography demonstrated an arterio-venous malformation in the left parietal region. Since then the arterio-venous malformation bled three times leaving him aphasic, hemiplegic and hemianopic. He was readmitted in August 1992 for investigation of his worsening aphasia and hemiplegia. There, his global aphasic difficulties improved rapidly. A MRI angiogram demonstrated a large left parietal AVM fed by hypertrophied anterior arteries. The present experimental investigation lasted for only one week during which time his condition was stable. He then suffered a further vascular event after which no further testing was attempted.

Neuropsychological Assessment

B.A.L. was assessed on a shortened form of the verbal scale of the WAIS-R and he obtained a Verbal IQ of 63. His scaled score on the digit span and arithmetic subtests was 1 and 3 respectively. On a simple 3-choice recognition memory test he scored 24/30 correct which, although below the 5% cut-off score for his age, is by no means disastrous. On two tests of space perception — Dot position and Dot counting — his performance was error-free (Warrington and James, 1991).

His spontaneous speech was sparse and he rarely initiated conversation. When he spoke his speech production was slow and effortful. However, his performance on 1, 2 and 3 syllable single word repetition was relatively well preserved (18/20; 19/20 and 24/25 respectively). His naming ability was only mildly impaired. He scored 9/30 on the Graded Naming test, a stringent object naming test, which is at the lower limits of the normal range (McKenna and Warrington, 1980). His verbal comprehension was impaired: he was only able to point to 34/48 pictures (arrays of 6) taken from the Snodgrass and Vanderwart.

His literacy skills were compromised. B.A.L. was dysgraphic and dyslexic. His oral spelling was extremely impaired: he was unable to spell even 3-letter high frequency words. In a previous paper we described his dyslexia. He was able to read single letters and words presented in isolation without any difficulty. However, his reading of prose was very disrupted and his ability to read rows of letters and words was significantly impaired. Thus, his performance presented with the cardinal feature of an attentional dyslexic syndrome (Warrington, Cipolotti and McNeil, 1993).

In addition to his literacy impairment the patient was severely dyscalculic. On an initial numeracy screening test, severe difficulties were present in number processing and calculation skills. In particular, B.A.L. appeared to be impaired in reading aloud arabic numerals and in calculation tasks: he was unable to score on a graded difficulty arithmetic test (Jackson and Warrington, 1986).

Experimental Investigation

The difficulties shown by B.A.L. in number reading and calculation tasks are the subject of the following experimental investigation. The first series of tasks sought to establish the limits of the patient's ability to read aloud arabic numerals and written number names.

Reading Aloud Arabic Numerals

The stimuli were written in the centre of individual cards in large type and were presented in a pseudo random order to the patient for reading aloud. B.A.L. was under no pressure to respond quickly. The patient was asked to read the first 9 arabic numerals and 11 two digit arabic numerals which included 5 "teens" (e.g. 14). He was asked to read the arabic numerals from 1 to 10 on 5 further occasions on 5 different days. Table I presents B.A.L.'s error rate in reading aloud arabic numerals on the 6 different days.

He read the stimuli promptly but frequently inaccurately and only once he omitted to give an answer. He very rarely gave self corrected responses. When the attempted correction was still wrong, the final error was recorded.

Error Analysis. B.A.L.'s reading errors were analyzed in terms of the distinction between *lexical* and *syntactic* errors introduced by Deloche and Seron

TABLE I

Number of Correct Responses in Reading Aloud Arabic Numerals and Written Number Names

	1st day	2nd day	3rd day	4th day	5th day	6th day
Arabic numerals (1-10)	6/10	4/10	6/10	5/10	6/10	4/10
Arabic numerals (two digit)	1/10					
Written number names	10/10	10/10				

(1982). His errors were classed according to the following criteria:

Lexical if it involved the replacement of one or more of the correct spoken number names with an incorrect spoken number name of the same range (e.g. 2 — "eight").

Syntactic if it involved the replacement of one or more of the correct spoken number names with an incorrect number name of a different range but in the same position as the target arabic numeral (e.g. 4 — "fourteen").

Lexical and Syntactic if it involved the replacement of one or more of the correct spoken number names with an incorrect number name occupying a different position in a different range (e.g. 7 — "eleven").

The majority of B.A.L.'s errors in reading aloud arabic numerals were lexical errors (73%). Table II shows the error distribution (the corpus of errors is reported in the Appendix).

TABLE II

Reading Aloud Arabic Numerals; the Lexical (L−S+), Syntactic (L+S−) and Lexical and Syntactic Errors

	L−S+	L+S−	L−S−
Arabic numeral form 1-10	20	3	6
%	68.9	10.3	20.6
Two digit arabic numerals	7	1	
%	77.7	11.1	

There was no suggestion of a specific deficit for any individual number, as was observed in the patient described by Weddell and Davidoff (1991), nor was a systematic relationship between target and response noted [R (adjusted) = 5.6%, F = 2.65, p < 0.12].

Comment. It has been demonstrated that B.A.L. had a significant impairment in reading aloud arabic numerals which was characterized mainly by lexical errors.

Reading Aloud Written Number Names

By comparing B.A.L.'s reading performance on the same number written as an arabic numeral or a written number name it is possible to determine whether he is employing different mechanisms for reading the two types of script.

The patient was asked to read aloud 10 written number names corresponding to the numbers from 1 to 10. Two sets of written number names were presented on two different days. His performance was flawless (see Table I).

Comment. B.A.L.' ability to read aloud single written number names was essentially normal.

Tests of Number Processing

In order to assess whether B.A.L.'s reading impairment reflected impaired recognition and/or comprehension and/or production of numbers a series of number recognition, comprehension and production tasks were presented to him.

Number Recognition

The stimuli consisted of the numbers from 1 to 10 and 10 two digit numbers. The patient was tested using two conditions:

1. *Matching Arabic Numerals to Spoken Number Names.* B.A.L. was asked to match 20 spoken number names to the corrisponding arabic numerals presented together with nine alternatives. B.A.L. scored 19 out of 20 correct.

2. *Matching Written Number Names to Spoken Number Names.* He was asked to match 20 spoken number names with the corresponding written number names. His performance was flawless (20/20 correct).

Comment. The results of these two tasks suggest that B.A.L.'s ability to encode numbers is largely preserved and therefore his deficit in reading aloud arabic numerals cannot be due to a misrecognition of the number stimuli.

Number Comprehension

Visual Magnitude Comparison. 30 pairs of arabic numerals from 1 to 10 were presented to B.A.L. He was asked to circle the larger of two arabic numerals. He gave 29 out of 30 correct responses.

Auditory Magnitude Comparison. The number pairs employed were those used in the above task. The patient was asked to repeat the larger of the two numbers spoken by the examiner. He responded flawlessly to all items.

Selection of Chips. The stimuli consisted of the first 10 arabic numerals and 10 multidigit arabic numerals (e.g. 451; 180; 236; 2500). The arabic numerals were presented written in the centre of individual cards. The patient was asked to select the chips (poker chips ranging from 1 to 500) to the value of arabic numerals. His performance was flawless.

Seriation Task. Three single digit arabic numerals in large type in the centre of three card were presented to the patient. B.A.L. was asked to reorder the stimuli cards according to their cardinal value. His performance was flawless.

Reading. After having ordered the three arabic numerals he was asked to read them aloud. His reading performance was still significantly impaired (17/30 correct).

Comment. These results indicated that B.A.L.'s ability to comprehend arabic and verbal numerals is largely intact and therefore his difficulty in reading arabic numerals aloud cannot be attributed to an impaired comprehension of the number stimuli.

Tests of Verbal Numeral Production

Number Repetition Tasks. The same set of numbers used for the reading aloud task (the arabic numerals from 1 to 10 and 10 two digit arabic numerals) was administered as a number repetition task. The examiner read each number once, and the patient was asked to repeat the stimulus immediately after the examiner had finished. B.A.L.'s performance was flawless.

Reciting Number Names. B.A.L. was asked to count forward from 1 to 10 and backward from 10 to 1. The patient's performance was flawless in both conditions and he did not use finger counting.

Counting Blocks. The stimuli consisted of sets of blocks ranging from 1 to 10. He was required to count each set of blocks. His performance was perfect (15/15 correct).

Non Personal Number Facts. The patient was asked 41 questions concerning numerical information generally known by subjects of his educational background (e.g. year of America's discovery). Again his performance was satisfactory (37 out of 41 correct answers).

Personal Number Facts. The patient was asked 9 questions concerning personal numerical information (e.g. year of birth). He responded correctly to 7 out of 9 questions.

Comment. The results obtained in all the above tasks show clear evidence of a well preserved ability to produce the appropriate spoken number names in tasks that did not require the reading of arabic numerals.

"What Comes Next?" Task

Procedure. Presented with one number B.A.L. was asked to produce the next one. The 10 numbers ranging from 1 to 9 and were presented in a pseudo random order in each condition. There were 6 conditions, in three of which his responses were tested using a multiple choice format:

(1) arabic numeral-spoken number name (e.g. 4-"five")
(2) arabic numeral-arabic numeral (e.g. 4-5; multiple choice)
(3) arabic numeral-written number name (e.g. 4-five; multiple choice)

TABLE III
Number of Correct Responses in "What Comes Next?" Task

Type of input	Type of answers: Spoken	Pointing arabic	Pointing number names
Arabic numerals			
trial 1	4/10		
trial 2	5/10		
trial 3	5/10	10/10	8/10
Written number names			
trial 1	10/10		
trial 2	10/10		
trial 3	10/10	8/10	
Spoken number names			
trial 1	8/10		
trial 2	8/10		

(4) written number name-spoken number name (e.g. four-"five")
(5) written number name-arabic numeral (e.g. four-5; multiple choice)
(6) spoken number name-spoken number name (e.g. "four"-"five").

Conditions 1 and 4 were replicated three times and condition 6 was replicated twice.

Table III presents B.A.L.'s error rate in "what comes next?" tasks.

Results. The patient was severely impaired in saying the next number in the sequence when the stimuli were presented as arabic numerals. The majority of his errors (12/16; 75%) were + or −2 distant from the correct answer (see Appendix). However, if instead of saying the next number in the sequence in response to an arabic numeral he was asked to point to the next number presented in an array, his performance clearly improved. In fact he was flawless in pointing to an array of arabic numerals and nearly flawless in pointing to an array of written number names. Remarkably, he could say the next number of the sequence when the stimuli where presented as written number names without error. Indeed, when the numbers were given as written number names he could also point to the next number in an array of arabic numerals. Furthermore, when the stimuli were presented as spoken number names his performance was also relatively unimpaired.

Comment. The results obtained in this tasks clearly demonstrated that the patient had difficulty in producing verbal numerals *only* when the input was an arabic numeral. In addition, his answers in this condition were very distant from the correct target.

Tests of Arithmetic

The patient was able to read aloud, point and correctly define the four arithmetical symbols.

Addition and Subtraction Problems. The stimuli consisted of 15 single digit

TABLE IV
Addition and Subtraction Problems: Percentage of Correct Answers and Average Response Latencies

	Answers			
	Spoken		Pointing arabic	
Questions	+	−	+	−
Written number names	93.3	80		
Mean response latency	2.7	10		
S.D.	1.1	11.3		
Arabic numerals	66.6	46.6	100	86.6
Mean response latency	6.9	10	7.3	24.8
S.D.	9.6	14.5	5.9	16.5

+ = addition problems.
− = subtraction problems.

addition and 15 single digit subtraction problems. The arithmetical problems involved the combinations of numbers from 1 to 9 requiring, as solutions, numbers below 10 (e.g. $5+4=9$ or $9-3=6$). The same addition and subtraction problems were tested varying the modality of input (arabic numerals or written number names) or output (spoken number names or arabic numerals). There were 3 conditions:

(1) written number names-spoken number names (e.g. three plus two = "five")

(2) arabic numerals-spoken numerals names (e.g. $3+2=$ "five")

(3) arabic numerals-arabic numerals (e.g. $3+2=5$; multiple choice).

In the arabic numerals-arabic numerals condition the patient was not asked to produce the answer but to point the correct answer in an array of 10 arabic numerals. The patient's speed of response was timed to the nearest second by stop watch. His latency of response (in seconds) was recorded from the time he initiated the first response. The percentage correct for each three operation for each condition and his average response latencies for the three conditions are given in Table IV.

Results. B.A.L. was almost completely unimpaired with the written number names-spoken number names condition. However, with the arabic numeral-spoken number name condition he was significantly impaired (McNemar's test d.f. $1=5.1$; $p<0.05$). Remarkably, with the arabic numerals-arabic numerals condition he performed quite well. It is clear that his response latency for the arabic numerals-spoken number names condition was very much slower than that for the written number names-spoken number names and arabic numeral-arabic numeral condition.

Error Analysis. Given the small error sample only a qualitive description of the errors is appropriate. The patient's few incorrect responses in the written number names-spoken number names and in the arabic numerals-arabic numerals conditions were all within + or −2 of the correct target. In contrast only 6/13 of his incorrect spoken answers to addition and subtraction problems presented as arabic numerals were within + −2 of the correct target.

Comment. At this simple level of addition and subtraction the same dissociation as we observed with "what comes next?" tasks emerged. His performance was more impaired when he had to produce spoken answers to problems presented as arabic numerals.

Discussion

In this study we have described an investigation of the residual numerical skills of a severely dyscalculic patient. His numerical abilities were found to be dependent on the form of input. Verbal numeral processing was relatively spared across a series of tasks: reading them aloud, when producing the next number in the sequence and when producing answers to simple addition and subtraction tasks. In contrast, arabic numeral processing was compromised in all of the above tasks. It appears that the patient's numerical skills were determined by the surface features of the number representations. B.A.L.'s reading performance suggested two functionally distinct reading routines one specialized for processing alphabetical materials and the other for arabic numerals (for similar conclusions see Besner and Coltheart, 1979; Anderson et al., 1991; Cipolotti, 1993, 1995). It has been proposed that these two functionally distinct reading routines are subserve by different anatomical loci (e.g. Anderson et al., 1990). Indeed in a recent paper Cohen, Dehaene and Verstichel (1994) suggested that while alphabetical script is process by left hemisphere structures, the right hemisphere has the capacity to read single digits. In our patient the structural damage was apparently restricted to the left hemisphere yet he had virtually no residual capacity to read single digits. We would therefore suggest that although the anatomical correlates of the two reading routines are as yet unspecified it seems unlikely, at least at the level of single digits, that the right hemisphere is implicated.

Our discussion will focus on the significance of B.A.L.'s selective impairment in manipulating arabic numerals. First, it will be argued that this impairment cannot be accounted for by the model for number processing and calculation proposed by McCloskey (1992). Secondly, we will consider how McCloskey's framework can be modified so that the observed dissociation in manipulating numbers according to their surface representations can be accounted for.

In McCloskey's model, number processing and calculation should initially involve the generation of an abstract internal number representation. These representations are obtained through the comprehension mechanisms. These mechanisms translate the surface forms of numbers into abstract internal number representations. These abstract internal number representations are then translated by the production mechanisms into a specific code for the appropriate type of output. The model therefore predicts that code specific number processing and calculation deficits might arise from a deficit in the number comprehension mechanisms and/or a deficit in the number production mechanisms. From this perspective, an impairment in processing arabic numerals could have arisen from a deficit in the arabic numeral comprehension mechanisms or a deficit in the verbal numeral production mechanisms. However, there is no suggestion that our patient had poor arabic numerical comprehension, at least in so far as is necessary for the experimental tasks. His performance was, in fact, good on a series of arabic numeral comprehension tasks requiring him to judge which of two numerals was larger, to seriate arabic numerals according to their cardinal value and to select the appropriate number of chips corresponding to an arabic numeral. Nor is there any suggestion that B.A.L.'s production of verbal numerals is impaired. His production of spoken number names is well preserved when the input is not an arabic numeral. The patient had a normal or nearly normal ability to retrieve spoken number names in personal and non personal number fact tasks. He was also unimpaired in tasks requiring him to recite and to repeat number names. Moreover, with verbal input he was mostly unimpaired in producing spoken answers in a "what comes next?" task.

It is the case that some of these verbal numeral production tests could possibly be subject to alternative interpretations. Let us consider three examples. Cohen et al. (1994) have argued that some very familiar numbers, such as for example famous dates or brands of cars, may be 'lexicalized'. Their spoken production would not involve retrieving and assembling phonological representations of the individual words, but rather retrieval of the entire word string as a unit from a phonological output lexicon. Therefore a preserved performance in these tasks could be attributed to a preserved access to the 'lexicalized' number word sequence rather than to intact verbal numeral production processes. B.A.L.'s preserved ability to recite number names should perhaps not be adduced in evidence for the preservation of his verbal numeral production processes. Reciting number names could merely require access to stored phonological counting strings, that can be retrived in sequences and are separately represented from the phonological output lexicon (McCloskey, personal communication). Such an hypothesis might gain partial support from the common observations that some aphasic patients can nevertheless recite "automatic sequences". It is also certainly plausible that the repetition of number names can be assisted by auditory to phoneme conversion rules rather than requiring verbal numeral production processes. However, these alternative interpretations are post-hoc and it is not altogether clear how they would fit into the McCloskey model, where the only communication between input and output modules passes through abstract internal representations of numbers. Moreover, we would argue that the activation of the verbal numeral production processes would be an essential component in at least two tasks in which our patient's performance was relatively well preserved. First, consider the "what comes next?" task, in order to reply "seven" when presented with *six*, it is necessary to map an internal number representation into a phonological number name. Secondly, our patient was largely unimpaired in giving spoken answers to addition and subtraction problems when the input was a verbal numeral. This latter finding, not only excludes the possibility of an impairment in the calculation system, at least for these simple sums[2], but also indicates that our patient was not impaired in mapping from semantic representations to verbal numerals. So, taking into account all these findings, we would argue that our patient's verbal numerals production processes are unimpaired, to the extent they are needed for the experimental tasks.

The core *difficulty* in explaining B.A.L.'s arabic numeral processing difficulties within the McCloskey model is that he had no obvious difficulties in comprehending arabic numerals while, at the same time, he was only impaired in retrieving verbal numerals when they were responses to arabic numerals. According to his account, once an abstract number semantic representation is formed, the surface features of the number representation (i.e. whether the stimulus is an arabic numeral or a verbal numeral) should have no effect on the production processes. Yet in our patient they do. Indeed, the result obtained provides evidence that the type of input (i.e. arabic numeral) can determine the ability of the subject to produce the corresponding verbal numerals. This suggests that the verbal numeral production processes can be activated by internal representations whose structure and derivation are format specific (e.g. he can say "six" in response to *four + two* but not in response to $4+2$).

Several models have rejected McCloskey's hypothesis that the abstract internal representations are an obligatory bottle-neck in number processing (e.g. Deloche and Seron, 1982; Cohen and Dehaene, 1991; Dehaene, 1992; Cohen et al., 1994; and Cipolotti, 1993, 1995). These models have proposed the existance of asemantic transcoding algorithms in which there is direct translation of arabic numerals to verbal numerals which bypass the intermediate semantic representations. For example, a patient (S.A.M.) has been reported who, while being severely impaired in reading and writing numbers, was still able to solve complex calculations (Cipolotti, 1993, and Cipolotti and Butterworth, 1995). This type of dissociation provides strong evidence for the necessity of additional asemantic transcoding algorithms. Thus, we would accept that transcoding numbers from one surface form to another does not necessarily require semantic processing and that for B.A.L.'s this "asemantic route" is inoperative. But even so, this does not account for why his impairment is present in tasks such as "what comes next?" and calculation when the stimuli are arabic numerals. It seems plausibile that these operations requiring the manipulation of numbers according to their ordinal or their cardinal values, would necessitate the generation of some form of semantic representation. So, even if B.A.L.'s impairment in reading aloud arabic numerals can be interpreted as due to a deficit in the 'asemantic route', this does not account for his poor performance on the arabic numeral "what comes next?" and arithmetical tasks.

Following Campbell and Clark (1988), Clark and Campbell (1991) and Dehaene (1992), we would propose that B.A.L.'s pattern of impairment on tasks requiring semantic mediation challenges the abstract internal representations hypothesis and supports the view that numerical processing can be effected by

[2] This finding would also exclude the possibility that a calculation impairment could be the explanation of B.A.L.'s inability to produce spoken answers to arabic numerals arithmetical problems, especially, when it is considered that he could answer such problems correctly if he had to respond by pointing to the correct answer.

format specific number codes. In order to account for the present observations we suggest that arabic and verbal numerals may have access to partially separable internal representations. These would in turn activate, through separable channels, the verbal numeral production system. B.A.L.'s deficit when having to provide spoken answers to arithmetical problems and "what comes next?" tasks when the stimuli were arabic numerals would be a failure in the connection between the internal arabic representations and the verbal numeral production system. This failure would result in B.A.L.'s inability to map internal arabic representations onto output verbal numeral representations.

In conclusion, we would argue that B.A.L.'s pattern of impairments reflects a double deficit in both an 'asemantic route' in which there is direct translation of arabic numerals to verbal numerals (e.g. Cipolotti, 1993, 1995) and in the 'semantic route' to verbal numeral production. The deficit in the 'asemantic route' would result in our patient's inability to read aloud arabic numerals. It is hypothesized that the deficit in the 'semantic route' is format specific; only the connection between internal arabic representations and the verbal numeral production system is impaired. This deficit in the 'semantic route' would result in our patient's inability to retrieve spoken number names in arabic numeral "what comes next?" and calculation tasks. Finally, we would note that our interpretative framework for number processing has some similarities with dual route models of word reading (e.g. Morton and Patterson, 1980; Shallice and Warrington, 1980; Ellis and Young, 1988) and speech production (e.g. McCarthy and Warrington, 1984). The principal difference between these frameworks of language and number processing is that in the framework for number processing the semantic representations appear to be format specific.

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APPENDIX

Errors in Reading Aloud Arabic Numerals

1 – 11; 7
2 – 8; 17; 1
3 – 7; 9
4 – 10; 14; 3
5 – 9; 7; 3; 3; 9
6 – 9; 4; 9; 8; 9
7 – 11; 19
8 – 9
9 – 14; 11; 6
10 – 11; 20; 9

18 – 10
39 – 14
20 – 17
45 – ?
14 – 19
25 – 21
12 – 2
61 – 71
34 – 23

Errors in "What Come Next?" Task

arabic numeral-spoken response

1 – 10; 0
2 – 9; 11
3 – 8
4 – 7; 9; 9
5 – 9; 3
6 – 8
7 – 9
9 – 20; 17
10 – 9; 5

pointing written number name

7 – 6
9 – 1

Errors in Addition and Subtraction Problems

Written numbers name–spoken response

5 – 3 = 3
6 – 2 = 2

4 + 2 = 8

Arabic numeral–spoken response

9 – 4 = 1
9 – 3 = 7
7 – 2 = 2
8 – 4 = 3
10 – 5 = 10
9 – 2 = 3
9 – 5 = 9
8 – 1 = 9

9 + 1 = 9
4 + 2 = 10
7 + 3 = 9
4 + 3 = 10
8 + 2 = 8

Arabic numeral–pointing response

5 – 3 = 3
9 – 4 = 6
7 – 3 = 3