Dissociating Arabic Numeral Reading and Basic Calculation: A Case Study

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Abstract

This study is about JS, a patient who suffered from anomia, phonological dyslexia and severe writing problems following a left hemispheric stroke. He showed good arabic numeral comprehension as evidenced in number-comparison tasks, but impairment in transcoding arabic numerals into verbal numbers and verbal numbers into arabic numerals. Although JS had several operand reading errors, the four arithmetic operations were not affected. In calculations with arabic numerals, he produced the correct results both in oral and written responses. For instance, when presented with the multiplication “7 × 3”, JS read the operation as “four times five”, but provided the correct response orally “twenty one” and written “21”. This behavior goes against those hypotheses which posit that multiplication facts are verbally-based, and those which establish the same route for verbal number production in calculation and arabic numeral reading.

Introduction

Patients with impairments in calculation and preservation of transcoding processes (going from verbal to arabic numerals and vice versa) have been well documented (e.g. Sokol et al., 1991; Cohen and Dehaene, 1994); however, there is little evidence of the opposite dissociation. Cipolotti and Butterworth (1995) have provided the case of SAM, who had many difficulties when reading or writing arabic numerals, but was able to understand them and give correct answers to calculations, both in reading and writing (arabic numerals). Recently, Whalen et al. (2002) have reported the case of KSR, a patient who had problems in reading and writing arabic numerals. He also failed to provide correct oral responses to calculations; however, when he had to write down his answers to calculations, he did it correctly. In this article we are going to focus on (a) the difficulties in reading and writing arabic numerals and (b) the relationship between these processes and calculation procedures.

Several theories have tried to explain these points. McCloskey’s (1992) model posits that single abstract representations of numbers are involved in both calculation and transcoding processes. According to the model, when people are presented with an arithmetical problem, they have to translate the input (arabic or verbal) into an abstract code, solve the problem and translate the abstract response into an output code (arabic or verbal). Similarly, when transcoding arabic numerals into verbal numerals, the first representation is transcoded into an abstract semantic representation and, later, into a verbal representation of the number. According to this model, difficulties in reading arabic numerals aloud could be independent from arithmetical calculations: if reading impairments are located at input processes, there will not be access to abstract representations, which prevents correct calculation. It is also possible that arabic reading problems are located at verbal output. In this case the patient, despite his/her reading problems, should make the correct response. That is, when the patient with verbal output problems is presented visually with “7 × 3”, he can read it as “four times five”; however, he would actually activate the correct multiplication and the correct result, “21”. When trying to give the answer, he might produce an erroneous verbal response related to his verbal output problems.

Cipolotti and Butterworth (1995), in the multi-route model, claim that we are equipped with a calculation system that operates with abstract representations; however, processes like reading arabic numerals aloud or writing arabic numerals to dictation can be achieved through the use of asemantic transcoding processes. The main modification of this model, in comparison to McCloskey’s model, consists of adding three asemantic routes. These routes would be involved in number transcoding, but not in the activation of the semantic representation of numbers (in fact the use of a route implies the inhibition of the others). Calculation implies the activation of
abstract (or semantic) representations, but simply transcoding from verbal numerals to arabic numerals (or vice versa) is done without semantic implication. According to the multi-route model, arabic numeral reading problems can be located at one of the asemantic transcoding routes, but as calculation involves semantics, arithmetical operations can be perfectly preserved. That is, when presented visually with “7×3”, although he reads it as “four times five”, the patient calculates the correct response to the problem. Asemantic and semantic transcoding processes share only peripheral systems; consequently, if problems in the asemantic route are not located at these input and output systems, reading errors should not lead to errors in calculation.

In the third model, called the triple-code model, Dehaene and his colleagues (Dehaene, 1992; Dehaene and Cohen, 1995; Cohen and Dehaene, 2000; Cohen et al., 2000) claim that simple arithmetical operations are based on three types of codes: the visual arabic code, the analog magnitude code and the auditory verbal code. Transcoding processes would imply the connection between the arabic code and the verbal code, (although Cohen and Dehaene, 1995, also suggest that, depending on the task, some reading processes can be achieved through the analog magnitude code). The auditory verbal code mediates verbal numeral input and output, some counting processes, and the retrieval process for simple addition (although addition can also be accomplished through other codes) and multiplication facts. From the point of view of this model, multiplication tables are considered to be the best example of the use of a verbal code for calculation. They would be retrieved as automatic verbal associations as a consequence of learning them by rote at school. In one version of the model, called the phonological storage hypothesis, the problem and the answer are stored as phonological representations (/slks tajmz ejt Iz fordi ejt/) (e.g. Cohen and Dehaene, 2000), that is, the phonological representation is used to address the memorised arithmetical facts. In a more elaborated version, Dehaene and Cohen (1995) consider that producing a verbal response like “twenty-one” to “7×3” would depend on transcoding these arabic numerals into a “verbal word frame”, a syntactic plan which includes a lexical stack choice and positions within the stack for the numbers (e.g. Tens: 6, Ones: 4 for “sixty-four”). The verbal word frames would be responsible for (a) automatically retrieving the operation result and (b) activating the phonological (or orthographic) representation of numbers to give an oral (or written) solution (Dehaene and Cohen, 1995). Multiplications, no matter what the presentation format is, have to be coded into verbal representations to get the solution. The solution is activated as a verbal word frame, and depending on task demands, the solution will be translated into an arabic, orthographic or phonological representation later.

Regarding the role of verbal codes in calculation, the prediction of the triple-code model is that difficulties in reading arabic numerals aloud will influence the calculation of basic addition and, mainly, basic multiplication. That is, according to the phonological storage hypothesis, when a patient is presented visually with “7×3” and reads it as “four times five”, he could activate and produce, if multiplication facts and arabic numeral production are preserved, “20” and “twenty” (4×5) as response, and not “21” or “twenty-one”. In its current formulation (Dehaene and Cohen, 1995), where verbal word frames mediate between arabic codes and phonological (or orthographic) representations, the model could explain correct calculation in written output in the presence of reading problems. If reading problems are caused by the impairment of phonological output mechanisms, arabic numeral writing of problem solutions will be spared in the presence of errors in oral responses: he would read “7×3” as “four times five”, and write the correct response “21”, but name it as another number (see Delazer and Girelli, 1997; Whalen et al., 2002).

The relationship between verbal impairments and multiplication difficulties stated in the triple-code model is supported by several findings in the literature. In a group study Delazer et al. (1999) showed that, as linguistic problems of patients increase, their performance in simple multiplication decreases. The authors interpreted these data as proof that the retrieval of multiplication facts is mediated by a verbal code. A similar pattern has been reported in single case studies. Cohen and Dehaene (2000) have recently reported the case of a left hemisphere damaged patient, VOL, who, in spite of her arabic numeral reading problems (90% errors in 2-digit length numbers), was able to decide which of two numbers was the larger. Although she was unable to read the operands of problems presented in arabics correctly, she provided the correct results in addition, subtraction and division problems. For example, when VOL was presented with the problem 7-1, she read it aloud as “four minus three” but provided the correct result verbally: “six”. We have to point out that her performance was not perfect in these arithmetic problems – she failed about 30% of the time – but her performance was considerably better than her operand reading in these tasks. On the contrary, in multiplication problems, she read the operands incorrectly, as before, and she made a high proportion of errors when providing the results (87%). In fact, statistical analysis showed that there was no difference between the error rate in calculation and the rate of reading errors in multiplication. The data suggest that multiplication functions via a different system than those employed in other arithmetical operations. According to the data, the conclusion established in the triple-code model is straightforward: multiplication is verbally-based. And, as suggested by defenders of the model, “Assuming that multiplication facts are retrieved as rote verbal memories, a prerequisite to retrieval is that arabic operands be encoded in a verbal format first” (Cohen and Deahene, 2000, p. 573).

In this article we present the case of JS, a patient with difficulties in reading arabic numerals aloud. When presented with basic operations, including multiplication, he is able not only to name the correct result but to write (in arabic numerals) the correct response, although he fails in reading the operators. We argue that this case cannot be explained by McCloskey’s and the triple-code models.
Case report

JS is a 68-year-old, right-handed man with 8 years of schooling. He mastered reading, writing and arithmetic abilities, and made normal use of them in his job as owner of a building company. In the spring of 2000 he suffered from a left-hemisphere infarct that caused right hemiparesis and a slight anterograde amnesia. According to the adaptation into Spanish of the BDAE by Garcia-Albea and Sanchez-Bernardos (1986), JS showed a pattern of mixed aphasia with alexia and agraphia. A CT scan showed a left cortical lesion located at the surface and anterior sylvian regions that was caused by an obstruction of the medial cerebral artery. Ten months post-onset the amnesia had disappeared, and he showed good obstruction of the medial cerebral artery. The evaluation of JS’s linguistics skills with the adaptation into Spanish of the PALPA (EPLA; Valle and Cuetos, 1995) and other tasks showed phonological dyslexia and severe writing problems.

JS’s reading behaviour showed the pattern associated with phonological dyslexia. His pseudoword reading was severely affected; he only answered 10/24 items correctly, showing difficulties also in letter to sound matching, with 17/24 correct responses. Although he committed some errors in a visual/lexical decision task, 141/160 correct responses, these errors were concentrated in low frequency words. In irregular word reading he answered 19/30 items correctly, making more visual errors than regularisations. Although this might suggest lexical problems, JS’s educational level could possibly account for his performance, as he did not know many of the irregular words presented. No semantic errors were observed in reading, making it unlikely that lexical and sublexical difficulties occur together.

The problems in writing were dramatic. JS had difficulties managing phoneme/grapheme conversion rules (phonological dysgraphia) as observed in pseudoword writing and letter writing by name, 0/24 and 17/28 correct responses respectively. In addition, JS was also practically unable to write high frequency words (4/20); his writing was full of neologisms, and non semantic errors appeared, suggesting a pattern compatible with jargon dysgraphia (see Schonauer and Denes, 1994).

The initial evaluation of numerical skills showed deficits in arabic and verbal numerals reading and writing, but not in calculation tasks. He made errors that can be considered lexical (e.g. to say 43 when reading the number 93) and syntactic (e.g. to say 47 when reading the number 407), according to the terminology established by Deloche and Seron (1982). JS could be classified as suffering from what has been termed alexic/agraphic acalculia (Hecaen et al., 1961, cit. Cipolotti and Van Harskamp, 2001). A deeper evaluation of his numerical skills was carried out and is described below.

First, we explored his abilities to process arabic and verbal numbers. Number repetition, number reading, writing and copying, and number semantic knowledge were assessed. In the second part of the analysis the four basic calculation skills were evaluated.

Numerical processing abilities

Several tasks were presented to assess JS’s numerical processing skills. His digit span was 5 items. Counting orally from 1–20 was carried out with some difficulty but was correct, and oral repetition of 1–4 digit length numerals was almost perfect (39/40). Delayed copying of 2–5 digit length arabic numerals showed slight difficulties (14/16) that can be considered normal. His problems appeared in 5-digit length numerals, where he failed two out of the four items. JS’s behaviour in other numerical processing tasks is described more profoundly below; Table 1 summarises the results JS obtained in these tasks.

Response to quantity questions

The patient had knowledge about numbers, as shown by his accurate response to some questions (e.g. “How many minutes are there in a soccer match?”); JS named 47 out of 50 questions about quantity during different sessions correctly, although twice he overtly relied on a counting strategy. JS was also required to complete this task giving writing answers (in arabics) to these questions and his responses were identical to those provided in the oral version of the task (47/50). These data suggest JS has no problems in oral and arabic number production; however, his use of counting strategies force us to make this statement with some reservation.

Reading arabic numerals aloud

JS had problems in reading arabic numerals aloud; he only read correctly 17/40 arabic numerals. Reading was affected by length, so JS read 10/10 one digit numerals, 6/10 two digit

<table>
<thead>
<tr>
<th>Number processing tasks</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naming 1–4 digit length numerals from questions</td>
<td>47/50</td>
<td>94</td>
</tr>
<tr>
<td>Writing 1–4 digit length numerals from questions</td>
<td>47/50</td>
<td>94</td>
</tr>
<tr>
<td>Reading 1 to 4-digit length arabic numerals</td>
<td>17/40</td>
<td>43</td>
</tr>
<tr>
<td>Reading 1-digit length arabic numerals</td>
<td>70/80</td>
<td>88</td>
</tr>
<tr>
<td>Reading 2-digit length arabic numerals</td>
<td>122/176</td>
<td>69</td>
</tr>
<tr>
<td>Reading 1 to 4-digit length verbal numerals</td>
<td>22/40</td>
<td>55</td>
</tr>
<tr>
<td>Writing 1 to 4-digit length arabic numerals to dictation</td>
<td>23/40</td>
<td>58</td>
</tr>
<tr>
<td>Writing 1 to 4-digit length verbal numerals to dictation</td>
<td>6/40</td>
<td>15</td>
</tr>
<tr>
<td>Magnitude comparison with 1 to 4-digit length arabic numerals</td>
<td>40/40</td>
<td>100</td>
</tr>
<tr>
<td>Computerised magnitude comparison with 1-digit length arabic numerals</td>
<td>40/40</td>
<td>100</td>
</tr>
<tr>
<td>Computerised magnitude comparison with 2-digit length arabic numerals</td>
<td>85/88</td>
<td>97</td>
</tr>
<tr>
<td>Magnitude comparison with 1 to 4-digit length written verbal numerals</td>
<td>40/40</td>
<td>100</td>
</tr>
<tr>
<td>Magnitude comparison with 1 to 4-digit length oral verbal numerals</td>
<td>40/40</td>
<td>100</td>
</tr>
</tbody>
</table>
numerals, only 1/10 three digit numerals and was unable to read any four digit numerals correctly. His errors were mainly lexical (18/23) and mixed (5/23), that is, a combination of lexical and syntactic errors (e.g. JS read 47 as 400). In reading, he sometimes relied on the strategy of counting to get the word for the number he had to name. The use of this strategy has been reported in other patients (Cohen and Dehaene, 2000).

JS was also asked to read aloud a set of 80 single digits (1–9) and a set of 176 2-digit length numerals to compare his reading abilities with his performance in magnitude comparison tasks (see below). One pair of digits was presented at a time, one beside the other (separated by a dash), on a computer screen until the patient read them (erroneously or correctly). JS made 10 errors when reading the set of 1-digit numerals, that is, he correctly read 70/80. Three times he overtly used a counting strategy to name the arabic numerals; for instance, to read 3 he said ‘one, two . . . three, three’. This strategy could be minimising JS’s reading problems.

JS’s performance in 2-digit numerals reading was considerably worse. He only read 122/176 items correctly. His 54 errors were mainly lexical, and in two items he read each of the digits of the number (71 read as ‘seven-and-one’, and 61 as ‘six-and-one’). He overtly relied on counting strategies to name each of the digits of the numeral, before reading it as a whole, many times.

Reading verbal numerals aloud

JS’s reading was clearly deficient; he only read about half of the items presented, 22/40 correctly, which were numbers ranging from one to four digits. He provided 7/10 correct responses in two digit numbers, 1/10 correct responses in three digit numbers, and 4/10 correct responses in four digit numbers. JS’s errors were lexical (12/18) and mixed (6/18). His accuracy in numbers ranging from one to two digits could be attributed to the role of lexical reading in verbal number comprehension, as these have higher frequency.

Writing arabic numerals from dictation

Writing 1–4 digit arabic numerals was clearly impaired, he failed in 17/40 items presented. JS committed 11/17 lexical errors, and 6/17 mixed errors. Length effects were also observed in this case: 3 and 4-digit length numerals were more difficult to write correctly, 3/10 correct responses in both cases, than 1 and 2-digit length numerals, 10/10 and 7/10 correct responses respectively.

Writing verbal numerals from dictation

As in the linguistic evaluation, where JS suffered from severe difficulties in word and pseudoword writing, he had serious problems in writing 6 out of 40 1–4 digit verbal numerals correctly. All his correct responses, 6/10, correspond to numbers from one to ten. He was not able to write any two, three or four digit-length verbal numbers. Some of his errors had some similarities, mainly in the beginning of the word, with the correct response (e.g. writing “mil cuatro” – one-thousand and four – as “miootrei”). Sometimes JS’s responses also represented the digits that composed the number accompanied by lexical errors (e.g. wrote “ochocientos ochenta y ocho” – eight-hundred and eighty-eight – as “ochochoydos” – eight-eight and two). His error pattern in this task was highly coincident with his word (4/20) and pseudoword writing problems (0/24).

Comparison of magnitude on arabic numerals

In this task JS had to compare pairs of numbers of the same lexical class (ones, tens, hundreds, thousands) that were presented on a sheet of paper. The list was comprised of 40 pairs, ten pairs each of 1, 2, 3 and 4-digit length. Independently of the characteristics of the pairs (some of them were syntactically complex and in some of them the last digit of the smaller number was higher than the last digit of the higher number of the pair), JS had no problems in circling the higher numbers of the pair, that is, his performance was flawless, 40/40. This result showed that, although JS had difficulties in reading arabic numerals aloud (see above), he was able to correctly access the quantity representations.

It could be argued that JS’s comprehension system is impaired, but the patient relied on a segmentation strategy to analyse separately each digit in solving this task. To avoid this criticism, JS was evaluated in a new version of the task in which response times were controlled. The same procedure employed in Cohen and Dehaene (2000) was used. In the first task, 40 pairs of 1-digit length arabic numerals were presented (mean absolute difference = 3.1; range 1–6). In the second task, the stimuli were 88 pairs of 2-digit length arabic numerals (mean absolute difference = 8.8; range 2–36). The pairs appeared one at a time on a computer screen for an unlimited amount of time. The patient had to press the key on the side of the larger numeral. Response accuracy and reaction times were collected using ERTS software. In the 1-digit comparison task, the performance of JS was flawless, 40/40, and his response latencies can be considered normal (mean RT = 1651 ms; SD = 467.2).

In the 2-digit comparison task, he answered 85/88 items correctly. In the automatic (non-strategic) realisation of this task it is expected that response time increases as number distance decreases (see Dehaene et al., 1990). The analysis of correct response times (4 times lower than 250 ms and 3 times higher than 3500 ms were excluded from the RT analysis) showed that JS’s performance is quite similar to that found in normal subjects (mean RT = 1889 ms; SD = 515.1; r(78) = .16; p = .08). The short response-time periods and the marginally significant negative correlation between distance and response-time periods suggest that JS was not relying on segmentation strategies to solve this task.

The differences between the proportion of correct responses in the 2-digit comparison task (97%) and in the
reading of these digits (67%) (p < .001) clearly showed that, despite his problems in reading arabic numerals, JS accessed to semantic representation of these stimuli. Similar results derived from the comparison between correct performance in the 1-digit comparison task (100%) and the reading of these digits (88%) (p < .001).

**Comparison of magnitude on verbal numerals**

In this task JS had to compare pairs of verbal numbers of the same lexical class (ones, tens, hundreds). Forty pairs of verbal numbers were presented on a sheet of paper and JS had to circle the highest number of the pair. Although JS failed in reading some of the numbers aloud, he did the task without any problem (40/40). This suggests that JS has no problem in comprehending verbal numbers. According to dual route models, JS should use sublexical procedures to correctly understand non-frequent verbal numbers; however, these procedures seem to be impaired in JS, as shown in non-word reading, letter-to-sound matching and verbal number reading. We argue that frequent numbers can be understood using the lexical route, and that JS understands non-frequent numbers due to the fact that they consist of number words frequently read.

JS’s comparison skills were also evaluated with verbal numbers presented orally (he had to say “the first” or “the second”, as a response). The same number pairs in the preceding comparison task were used and, as before, JS performed the task flawlessly.

**Summary of number processing skills**

The assessment of number processing (see Table 1) showed clear results. JS had problems in reading verbal and arabic numerals aloud and in writing arabic and verbal numerals to dictation. On the contrary, he had no difficulties in counting, in repeating numbers orally or in delayed copying of arabic numerals. He only had slight difficulties in answering questions about quantities. The magnitude comparison tasks with arabic or verbal numbers were also error free. That is, in spite of his difficulties in reading arabic and verbal numerals aloud, JS had access to the quantity representations of the numbers.

In regard to the aim of this research the role of verbal codes in transcoding and calculation abilities, it is clear that JS had problems with encoding arabic numerals in a verbal format, as shown by his accuracy in reading arabic numerals aloud. According to McCloskey’s model, JS’s pattern suggests that his abstract representations are intact, but he has problems with verbal and arabic number output. McCloskey’s model predicts that JS can calculate, but his output problems lead him to provide erroneous responses. Hence, the proportion of his errors in calculation should be equal, or less, to the proportion of his errors in arabic numeral reading and writing.

The multiroute model explains JS’s behaviour as the consequence of impairments in the asemantic routes for transcoding arabic numerals into spoken verbal numbers, and transcoding spoken verbal numbers into arabic numerals. On the contrary, semantic routes are preserved, which explains his accurate performance in comparison tasks. According to the model, calculation problems would be done correctly if there were no specific problems in the (semantic) mechanisms involved in calculation, or in those output systems used in number production from quantity representation.

In this framework, the triple-code model explains JS’s transcoding difficulties as being caused by impairments in the link between the visual arabic and the verbal code. Comparison tasks would be preserved as the analog magnitude code can be accessed from the visual arabic code or from the verbal code, depending on the input modality. Regarding operations, the model claims that simple multiplication (and addition) should be impaired, due to the fact that arabic numbers should be translated into verbal code to activate multiplication (and addition) facts. On the contrary, other arithmetical operations, like subtraction or division should not be affected by the difficulty in converting arabic codes into verbal codes (Dehaene, 1992). Consequently, it is to be expected that JS makes errors in multiplication (and perhaps in addition), but not in division or subtraction.

In the next section we will analyze JS’s calculation skills, and the relationship between his performance in these tasks and the reading of the operands.

**Study of number calculation skills**

**Materials and procedure**

The four basic calculation skills were explored using arabic numerals. To assess simple mental arithmetic, the same material as that of Cohen and Dehaene’s (2000) was employed. This material was comprised of the same pairs of numbers in addition, multiplication and subtraction, each problem operand always being a single-digit arabic numeral between 1 and 9. The position of the operands in subtractions was manipulated in order to always obtain positive results. In multiplication, the first operand was always smaller than the second one. To assess division skills, 28 problems were designed, with the first operand ranging from 3 to 20 and the second one larger than 1 and smaller than the first operand. Results were always entire numbers ranging between 2 and 10 in division, 2 and 72 in multiplication, 3 and 17 in addition, and 1 and 8 in subtraction.

Different arithmetical operations were presented on different days. The patient had to read aloud the operands presented on a sheet of paper and, first, provide an oral response and, second, a written response in arabic numerals to the problems. Problems were not covered after they were read as JS’s responses were too fast to do so. Correct responses to arithmetical problems in both formats were registered for analysis. Operand reading accuracy was also registered. Whenever JS provided different responses in a given trial, only the last response was scored.
Table 2. Summary of correct responses in calculation tasks and reading problems

<table>
<thead>
<tr>
<th>Operation</th>
<th>Calculation written response</th>
<th>Calculation oral response</th>
<th>Problem reading aloud</th>
<th>Operand reading aloud</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Addition</td>
<td>72/72</td>
<td>100</td>
<td>69/72</td>
<td>96</td>
</tr>
<tr>
<td>Subtraction</td>
<td>72/72</td>
<td>100</td>
<td>69/72</td>
<td>96</td>
</tr>
<tr>
<td>Multiplication</td>
<td>70/72</td>
<td>97</td>
<td>64/72</td>
<td>89</td>
</tr>
<tr>
<td>Division</td>
<td>55/56</td>
<td>98</td>
<td>53/56</td>
<td>95</td>
</tr>
<tr>
<td>Total</td>
<td>269/272</td>
<td>99</td>
<td>258/272</td>
<td>95</td>
</tr>
</tbody>
</table>

Table 3. JS’s errors in oral response to calculation

<table>
<thead>
<tr>
<th>Operation</th>
<th>Operands reading</th>
<th>Errors in oral response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addition</td>
<td>6+8 = 4×6 =</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>4+8 = 8×9 =</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>1+7 = 1×6 =</td>
<td>7</td>
</tr>
<tr>
<td>Subtraction</td>
<td>5−1 = 5−1 =</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>3−2 = 3−2 =</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4−1 = 4−3 =</td>
<td>2</td>
</tr>
<tr>
<td>Multiplication</td>
<td>3×7 = 8×7 =</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>4×5 = 6×5 =</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>6×8 = 8×8 =</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>7×9 = 4×9 =</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>3×5 = 6×5 =</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>5×8 = 2×8 =</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>4×7 = 4×7 =</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>2×3 = 2×3 =</td>
<td>8</td>
</tr>
<tr>
<td>Division</td>
<td>15:3 = 15×3 =</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>20:2 = 20×2 =</td>
<td>9</td>
</tr>
</tbody>
</table>

**Results**

First, we have to point out that when JS read the operations aloud, they were full of reading errors related to operational signs, both in division and addition. In addition, he read the “+” sign as the “×” sign in 58/72 problems. That is, he read 2+5 as “two times five”. When reading division problems aloud, the patient had 47/72 errors; JS read the “:” sign as the “×” sign. As these errors were not related to his calculation responses, they were not considered operand reading errors.

Results can be seen in Table 2. As expected in the initial analyses, JS had no difficulties in calculation. The analysis of the written responses showed an almost flawless performance in all the arithmetical problems. Correct rates do not differ across operational types as shown in multiple comparisons ($\chi^2(3) = 3.7, p = .29$); that is, there were no significant differences in JS’s performance in the calculation tasks. The two errors committed in multiplication fell within the correct row of the multiplication table; for instance, JS wrote “42” (6×7) when solving “3×7”. The error in division was probably a lexical error; JS answered “9” when solving “20:2”, a very simple division. Only in the two multiplication errors were the operands erroneously read; however, the response provided by JS was not directly related to these reading errors.

The total number of errors in the oral response to the problems was 14/272 items. Although the data suggest the existence of more errors in multiplication compared to other operations, the statistical analysis showed that the rate of correct responses was uniformly distributed throughout the four basic operations ($\chi^2(3) = 4.03, p = .23$). JS’s errors can be seen in Table 2. None of the errors consisted in responding to the number of operands JS had read erroneously. 6/8 multiplication errors and 2/3 of the division errors fell within the correct row or column in the multiplication table of the problem presented; that is, they are not unrelated lexical errors. In contrast to other cases reported, see VOL (Cohen and Dehaene, 2000), the analysis of JS’s errors shows that he did not rely on erroneous reading of the operands to solve multiplication problems.

When comparing written responses to oral responses, we found significant differences when all the operations are taken together ($Z = −3.742, p < .001$). The analysis that considered operational types separately showed that JS had more errors in oral responses when these were compared to written responses in addition ($Z = −1.7, p < .05$), subtraction ($Z = −1.7, p < .05$) and multiplication ($Z = −2.5, p < .01$). The differences between written and oral responses to division problems were only marginally significant ($Z = −1.4, p = .08$).

In regard to problem reading errors, they affected 24% (66/272) of the problems and 16% (85/544) of the operands, most of them being perseverations and anticipations (around 80% of reading errors). All the operand reading errors JS made were critical, that is, they would lead to erroneous responses if they were used in calculation. The distribution of problem and operand errors differed clearly across arithmetic operations ($\chi^2(3) = 15.91, p < .001$, $\chi^2(3) = 14.59, p < .01$, respectively). For example, JS’s reading errors in subtraction were unexpectedly very low. During practically all the subtraction tasks, and twelve times in the division tasks, JS overtly relied on a counting strategy when reading operands. Cohen and Dehaene (2000) have speculated that subtraction is solved through counting more naturally than in other tasks, favouring the theory that patients rely on this strategy when reading subtraction operands. No evidence of counting was observed in addition and multiplication.

In operand reading, as well as in problem reading, differences between errors in the four operations were similar. Error rates in addition and multiplication differed significantly from errors in subtraction and division (all $ps < .05$). There were no differences in error rates between division and
subtraction and between addition and multiplication (all $p > .2$). The use of the counting strategy in subtraction and division, as pointed out earlier, could be responsible for these differences.

When comparing overall problem reading errors (all were critical) to oral and written responses across the four arithmetical operations, statistical differences arose (respectively, $Z = 7.93, p < .001$; $Z = 7.0, p < .001$); the rate of correctly read problems was considerably lower (76%) than the rate of correct results to operations in written (99%) and oral (95%) modalities. These differences remained when the analyses took into account the different kinds of operations. Written and oral responses to addition and multiplication were clearly more accurate than problem reading (all $p < .001$). In division and subtraction problems, reading errors also differed significantly from written and oral response errors to the problems (all $p < .05$).

The almost error-free accuracy in problem solving, both in written and oral responses, and JS’s problem reading difficulties, can be taken as a proof of the independence between reading problems and solving arithmetical problems. For instance, JS provided the correct response to 22 out of 25 addition problems where at least one operand was read incorrectly, and to 19 out of 24 multiplication problems that were read incorrectly.

However, the analysis described previously does not offer a matched comparison (that is, for numbers in the same range) of JS’s accuracy in response to arithmetical operations and numerical reading. Hence, we contrasted the ability to name calculation answers with the naming of the same numbers in a reading task. This analysis was carried out five months later than the rest of the evaluation included in this research, and comprised the evaluation of JS’s reading of the solutions to the problems in addition and multiplication: JS’s performance was practically perfect (35/36 in both tasks). At the time of this evaluation, JS had already generalised the strategy of counting to name numbers when he had difficulties in producing them (he overtly applied it in 6 of the addition digits and 8 of the multiplication digits). Consequently, it seems that JS’s naming ability cannot be inferred from these data.

To avoid problems generated by the use of the counting strategy, cited above, in reading numbers, we employed reading data from the tasks described in the “reading arabic numerals aloud” section. We collected JS’s reading data of numbers between 3–17, and we compared them to the naming of addition solutions (range of addition solutions: 3–17). Likewise, we collected reading data of numbers between 2–72, and we compared them to the naming of multiplication solutions (range of multiplication solutions: 2–72). The statistical comparison between responses to addition problems (69/72, 96%) and reading of these numbers (63/72, 88%) showed significant differences ($p < .01$). The comparison between oral responses to multiplication problems (64/72, 89%) and reading of numbers in the same range (43/56, 77%) also showed significant differences ($p < .05$). These data show that JS performed better when he had to produce oral response to arithmetical problems than when he had to read those numbers aloud.

We have also compared JS’s accuracy when reading the operands in addition, subtraction and multiplication (range 1–9) to the reading of numbers in a context without calculation (see tasks in “reading arabic numerals section”). Although the analysis showed more accuracy when numbers were read individually (70/80, 88%) than when they were read in the context of calculation (359/432, 83.1%), this difference was not significant.

After adding these analyses to those carried out previously, the dissociation between calculation processes and arabic numeral reading processes is more evident. In summary, JS solved the problems on the basis of the original operands, even when reading them aloud erroneously.

**Discussion**

We have reported the case of JS, a 68-year-old right-handed man who suffered from a left hemispheric lesion affecting the sylvian region that causes phonological dyslexia and severe writing problems.

The analysis of number processing skills showed arabic and verbal numeral reading aloud problems, as well as arabic and verbal numeral writing problems. On the contrary, JS performed flawlessly in magnitude comparison with arabic and verbal numerals, and in naming and writing arabic numerals to quantity questions. The dissociation between arabic numeral reading skills and the capacity to access the semantic representations of these numbers has been previously reported in the literature. Cohen and Dehaene (1995) described two pure alexic patients who, although severely impaired in reading arabic numerals aloud, were still able to decide which of two numbers was the larger. Similar findings have also been reported by Miozzo and Caramazza (1998), and Cohen et al. (2000) in pure alexic patients. Other cases of patients with different linguistic problems have also shown a dissociation between arabic numeral reading and the access to quantity representations from arabic numerals (e.g. McCloskey et al., 1986). The case presented here constitutes new evidence of access to semantics directly from arabic numerals in the absence of verbal mediation.

In regard to number-processing abilities, JS also showed a dissociation between reading verbal numerals aloud and verbal number comparison. As JS suffered from phonological dyslexia, we contend that JS relied on his lexical abilities to directly access the semantic representation of verbal numbers. SAM, the case reported by Cipolotti and Butterworth (1995), showed a pattern similar to JS but, on the contrary, SAM only had slight problems with reading non-familiar words. JS provides clear evidence of access to semantics directly from verbal numerals via a lexical mechanism.

The analysis of calculation operations – addition, subtraction, division and multiplication – showed practically a flawless performance. JS had no problems with writing down the solution in arabic numerals. His performance was slightly
worse, but still better than in his reading skills, when he had to provide an oral answer to multiplication problems (see Table 2).

The main point of the present case is that JS performed all operations correctly, in spite of committing several errors in reading arabic numerals aloud which were presented as part of arithmetical problems (operands) or one by one. He wrote the correct results of simple arithmetic problems that he could not read aloud. That is, although he read “6×7” as “four times six”, he wrote “42”, and almost always gave the correct response orally, “forty-two”. When giving the result of problem calculations, reading and writing errors were significantly lower than errors when reading arabic numbers or writing them from dictation.

The analysis of JS’s errors when giving oral response to the problems also shows a lack of relationship between operand naming errors and calculation errors. JS never provided the results of an arithmetical problem he had incorrectly read as the solution to the problem. This lack of relation between operand reading errors and spoken response errors constitutes additional evidence of the dissociation between arabic digit reading errors and basic arithmetical calculations.

To summarise, JS’s solutions to arithmetic operations were blind to his reading errors, suggesting a lack of relationship between arabic numeral reading and calculation. Our case is strikingly similar to the one described by Cipolotti and Butterworth (1995), although they explored the role of verbal codes in calculation less directly. In the following paragraphs we will try to explain JS’s performance in the light of theoretical models of number processing.

Implications for functional models of numerical processing

In regard to JS’s pattern, numerical processing models have to explain two phenomena that are closely related: (a) the fact that verbal and arabic numbers are responded to better when they are the result of an arithmetical problem (and/or as response to a quantity question) than when they only have to be read; (b) the ability of JS to provide the correct response to the four arithmetical operations despite his difficulties in reading the operands.

In the framework of the triple-code model, Dehaene and Cohen (Dehaene, 1992; Cohen and Dehaene, 1995, 2000; Dehaene and Cohen, 1995) have suggested that transcoding arabic numerals into verbal numbers is carried out through: (1) processing the arabic visual code; (2) activation of the corresponding verbal word frames (in the latest version of the model) or phonological representations (in the phonological storage hypothesis); and (3) execution of verbal output processes (orthographic or phonological). Consequently, difficulties in reading arabic numerals aloud should be located at some of these systems. However, the ability to solve simple basic calculations from arabic numerals, giving the correct response both in naming and in writing a process that uses the same systems involved in transcoding arabic numerals into verbal numerals, plus others, is at odds with the prediction of the model.

As regards the role of verbal codes in calculation, the triple-code model claims that difficulties in transcoding arabic numerals into verbal representations (phonological or word frames) give rise to multiplication (and addition) errors, while other operations are spared. As we indicated in the introduction, several cases support the relationship between verbal and multiplication impairments (e.g. Delazer et al., 1999; Cohen and Dehaene, 2000). However, it should be taken into account that we are dealing with two different phenomena when considering these cases: (a) the relationship between verbal representations and the code implicated in multiplication, and (b) the dissociation between arithmetical operations. While we have nothing to object to in the last point, we have more reservations regarding the first point. The hypothesis that multiplication is based on verbal codes arises from the association between impairments in multiplication and reading numbers aloud. However, associations do not constitute a firm basis for theoretical proposals in Cognitive Neuropsychology (see Shallice, 1988); consequently these data do not warrant that multiplication is verbally based. On the contrary, JS’s pattern contradicts the two versions of the model: the phonological storage hypothesis and the verbal word frames hypothesis (Dehaene, 1992; Dehaene and Cohen, 1995).

In regard to the phonological storage hypothesis, the arithmetical facts for multiplication and addition are stored in a verbal phonological code; the activation of the phonological representation of the problem should activate the phonological representation of the solution. Consequently, operand reading errors should cause errors in reaching the solution to the problems, otherwise, the solution provided would be related to operand reading errors. JS’s pattern contradicts this prediction. Although he reads the problems incorrectly he produces the correct responses both in writing and reading. Another argument against this hypothesis is that JS read 27/36 addition problems as multiplication problems (he read the “+” sign as the “×” sign). In this cases he never provided an error related to erroneous reading, that is, he did the addition not the multiplication (while it is possible that signs are not represented as word frames, it is plausible that they are part of the phonological representation in the framework of the phonological storage hypothesis; see Whalen et al., 2002).

The triple-code model in the revised version suggests that addition and calculation tables are stored as verbal word frames (an abstract verbal representation) that activate phonological, orthographic or arabic representations. JS’s data show that arabic input processes were not impaired as perfect performance in comparison tasks with arabic numerals showed. Verbal word frames cannot be impaired, as JS was able to multiply. The phonological representations of JS were not impaired, as shown in the proportion of his correct responses to quantity questions and in all the calculation operations, even in multiplication operations. If JS has difficulties in reading operands, the model predicts he should also have problems in producing the results to the problems,
because both tasks share output processes. However, the proportion of correct responses in multiplication (naming and writing) is clearly higher than his operand reading difficulties. Consequently, the triple-code model does not offer an explanation of JS’s pattern.

It could be argued that JS is relying on some compensatory strategies to solve multiplication problems. This argument seems unlikely. Although JS’s oral response time to calculation was not measured, the time needed for multiplication and other arithmetical operations was quite similar, once he had read the problem. JS read the problems with some difficulties but, just after the operands had been read, he immediately provided the response. Sometimes he read the problem erroneously, but he immediately provided the correct response and tried to read the problem correctly again. JS had no doubts about calculation solutions.

Whalen et al. (2002) have suggested that the triple-code model is able to explain reading errors and good calculation abilities if reading errors are perseverations and anticipations, as is the case of JS’s errors. Perseverations “might occur after the generation of the (correct) phonological problem presentation” not affecting calculation. According to this explanation, problem responses could also be affected by perseverations, leading to errors in oral responses to the problems. However, JS was better at giving oral responses to the problems than reading the operands. In this case, the triple-code model must explain why operand reading is subject to perseverations but problem responses are not.

A similar account to the triple-code model, although less specific, has been proposed by Campbell (1994). According to this model, number transcoding and calculation are based on a series of modality-specific codes. Campbell’s model adds a direct link between arabic codes and arithmetical facts to the triple-code model (Campbell, 1994); however, this modification is also unable to explain how arabic and verbal responses to calculation are correct yet reading arabic and verbal numerals are impaired. This model finds the same problems the triple-code model in explaining JS’s pattern.

In any case, our data do not contradict all possible verbal-based explanations of multiplication; the defence of different routes (which could be verbally-based) for operand reading and calculation response fit the pattern shown by JS. The triple-code model should analyse whether this variation of the model would fit well with the whole model.

McCloskey’s model (McCloskey, 1992) is not able to explain the dissociation between arabic numeral reading and performance in comparison tasks and calculation tasks. According to the model, all the processes implicated in arabic numeral reading are implicated in calculation from arabic numerals; consequently, if the second process is preserved, the first should be preserved too. JS was able to calculate and give the correct response orally, but had more difficulties when reading arabic numerals aloud. Both tasks imply comprehension of arabic numerals, activation of abstract representations, and activation of the verbal number production system and output phonological representations. The dissociation between both tasks cannot be achieved through alteration of any of these systems because the impairment of one system would imply errors in responding to the problems.

JS showed good comprehension abilities with arabic numerals. He accessed the semantic system without any problem as shown by his behaviour in magnitude comparison. In spite of his difficulties in reading numerals aloud, this task suggests that JS’s arabic numeral comprehension procedures are preserved, and his ability to solve arithmetic operations presented in arabic numerals confirms this statement. These results and the observed difficulties in reading and writing words, pseudowords and numbers, suggest that the problem could be located at the verbal and arabic numerals output systems. However, in this case, the lack of errors in providing the solution to arithmetical problems in written or spoken modalities has to be explained. That is, JS made several errors when reading the operands aloud, however, he did not fail to provide responses to the problem orally. If JS had problems in spoken output when reading the operands, it is expected – at least from the triple-code model and McCloskey’s – that he suffered from the same problems when providing the result for an arithmetical problem. Contrary to these predictions, JS performed better when answering calculation problems than when reading or writing arabic numerals.

The multiroute model (Cipolotti and Butterworth, 1995) provides an explanation to JS’s pattern by appealing to the differential implication of semantics in the tasks. According to the model, producing solutions to arithmetical problems is done by activating quantity representations; on the contrary, transcoding arabic numerals into verbal numerals is performed without semantic activation. In the case of JS, the transcoding task from arabic numbers to verbal numbers as well as the reading-operands-aloud task, are carried out by an impaired semantic route; semantic processes provide correct responses to calculations and to quantity questions. The model posits that the activation of a route, although working inefficiently, inhibits the functioning of the others, making possible the correct naming of numbers when the semantic route is used, and the misnaming of numbers when semantic is not required. That is, the structure and dynamics of the model would account for (a) JS’s difficulties in transcoding numbers in reading, and (b) JS’s ability to provide the correct answers to calculations, magnitude comparison tasks and quantity questions.

Conclusion
The case of JS, a patient who shows clear dissociation between arabic numeral reading and calculation, has been presented. Contrary to the proposal of the triple-code model defended by Dehaene (1992), JS can solve multiplication problems and correctly report the result in writing and naming, in spite of his difficulties to transcode arabic operands of numerical problems into a verbal code. In contrast to McCloskey’s model, JS is not able to transcode arabic numerals into verbal responses, but is perfectly able to comprehend arabic numerals and produce verbal answers from calculation.
It is likely that JS relied on a non-verbal type of representation to solve those arithmetical problems in which he erroneously read the operands. Arabic number reading errors could be explained as a problem in transcoding arabic into verbal numbers. The lack of errors in giving answers to arithmetical problems suggests that, when deeper processing is required for task response, naming difficulties disappear. The multiroute model proposed by Cipolotti and Butterworth (1995) seems to provide the best explanation for JS’s pattern.

Our results clearly show that number processing is task dependent and, also, that calculation, including multiplication, is not dependent on verbal reading. In at least the case of JS, arabic numeral reading and basic calculation are dissociated.

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References


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Dissociating arabic numeral reading and basic calculation: a case study

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Abstract
This study is about JS, a patient who suffered from anomia, phonological dyslexia and severe writing problems following a left hemispheric stroke. He showed good arabic numeral comprehension as evidenced in number-comparison tasks, but impairment in transcoding arabic numerals into verbal numbers and verbal numbers into arabic numerals. Although JS had several operand reading errors, the four arithmetic operations were not affected. In calculations with arabic numerals, he produced the correct results both in oral and written responses. For instance, when presented with the multiplication “7 × 3”, JS read the operation as “four times five”, but provided the correct response orally “twenty one” and written “21”. This behavior goes against those hypotheses which posit that multiplication facts are verbally-based, and those which establish the same route for verbal number production in calculation and arabic numeral reading.

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Primary diagnosis of interest
Alexic/agraphic acalculia with preserved calculation

Author’s designation of case
JS

Key theoretical issue
Dissociation between reading arabic numerals (impaired) and oral responses to basic calculation (preserved)

Key words: arabic numbers; transcoding; magnitude comparison; calculation

Scan, EEG and related measures
CT scan

Standardized assessment
Rey Complex Figure, Trail Making Test, Benton’s Visual Retention Test, Hooper’s Visual Organization Test, Benton’s Visual Form Discrimination Test, Spanish adaptation of BDAE (Garcia-Albea and Sanchez-Bernardos, 1986); Spanish adaptation of PALPA (Valle and Cuetos, 1995).

Other assessment
Reading arabic and verbal numbers, writing from dictation arabic and verbal numbers, magnitude comparison tasks with arabic and verbal numbers, computerised magnitude comparison task with arabic numbers, operands reading, calculation tasks

Lesion location
Left hemisphere: Surface and anterior sylvian regions

Lesion type
Obstruction of medial cerebral artery

Language
Spanish