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*Brief communication*

# Functional mapping of left parietal areas involved in simple addition and multiplication. A single-case study of qualitative analysis of errors

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All electrostimulation studies on arithmetic have so far solely reported general errors. Nonetheless, a classification of the errors during stimulation can inform us about underlying arithmetic processes. The present electrostimulation study was performed in a case of left parietal glioma. The patient's erroneous responses suggested that calculation was mainly applied for addition and a combination of retrieval and calculation was mainly applied for multiplication. The findings of the present single-case study encourage follow up with further data collection with the same paradigm.

One set of cognitive functions that has received some attention in the context of intraoperative mapping in recent years concerns mathematical skills (Duffau *et al.*, 2002; Pu *et al.*, 2011; Roux, Boukhatem, Draper, Sacko, & Démonet, 2009; Whalen, McCloskey, Lesser, & Gordon, 1997; Yu *et al.*, 2011). The left parietal areas have been singled out as critical for number and calculation skills since the first clinical studies on acquired calculation disorders as well as by means of modern techniques like neuroimaging (Dehaene, Piazza, Pinel, & Cohen, 2003), or TMS (Della Puppa *et al.*, 2013; Salillas, Semenza, Basso, Vecchi, & Siegal, 2012). The present study, in a case of left parietal glioma, used both one-digit addition and multiplication. Differences between these two operations, classically considered as based on retrieval, were suggested by recent detailed neuroimaging studies (Dehaene *et al.*, 2003; Rosenberg-Lee, Chang, Young, Wu, & Menon, 2011). All electrostimulation studies on arithmetic have so far solely reported general errors (such as omissions and commissions). Nonetheless, a classification of the errors during stimulation can inform us about underlying arithmetic processes (McCloskey, Harley, & Sokol, 1991).

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## Case presentation

The patient was a 44-year-old, right-handed man who came to our consultation for headache. A pre-operative anatomical MRI showed a low-grade glioma at the left parietal lobe white matter (Figure 1a). Because of the location of the tumour in the dominant hemisphere, it was decided to perform awake, intraoperative functional mapping, before and during surgical resection, to reduce the risk of neurological sequelae. The patient gave his written informed consent. Neither language deficits nor emotional problems were detected before the operation. A full assessment of calculation skills showed a normal use of numbers and calculation.

### *Intraoperative mapping*

Cortical and sub-cortical mapping was performed by means of a bipolar stimulator. The functional cortical map was obtained using the method described by other authors

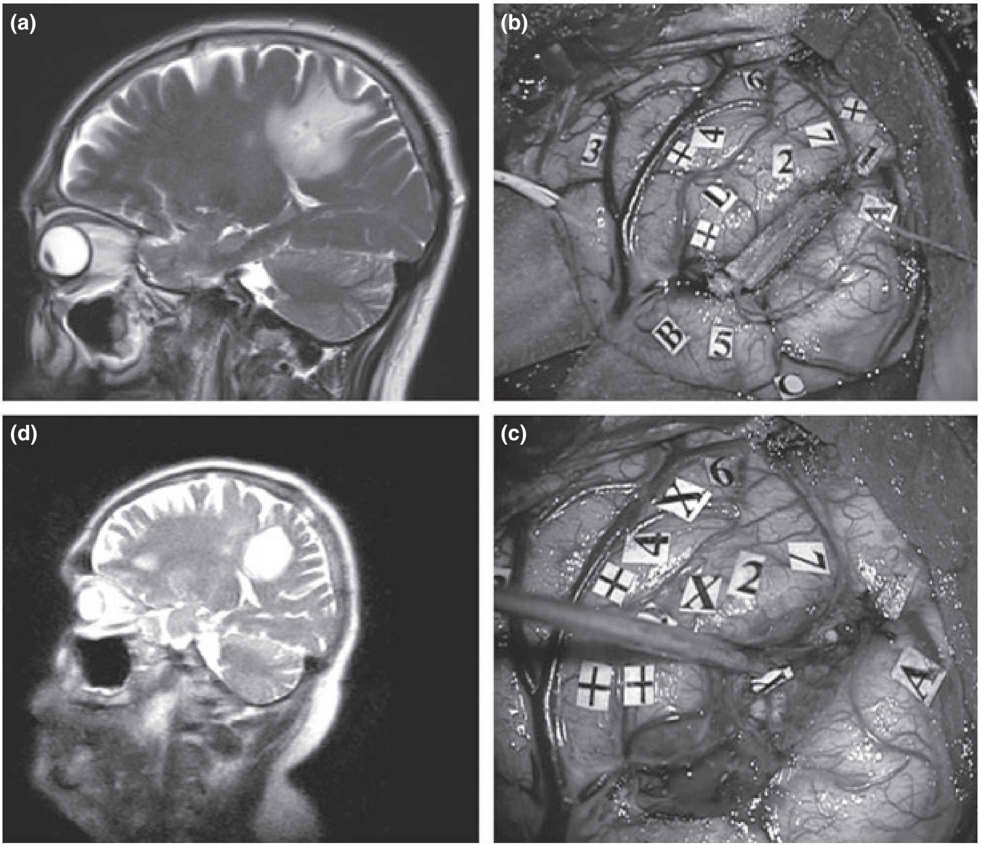


**Figure 1.** Pre-operative images showed a left parietal tumour in sagittal flair-weighted MRI sequences (a). Intraoperative view (b and c): the tumour is delineated by the letter tags. A cottonoid was placed in the portion of the Intra-Parietal Sulcus that resulted functional for calculation and consequently spared. Tags were placed corresponding to somato-sensory area (tag 1), speech arrest site (tag 2), naming interfering sites (tags 3–7), addition interfering sites (tags +), multiplication interfering sites (tags x; b). Tag x in the bottom of the Intra-Parietal Sulcus corresponding to the site which was functional for multiplication. Post-operative images (d) showed the surgical cave boundaries in sagittal flair-weighted MRI sequences.

(Duffau *et al.*, 2002). The patient was asked to perform counting and picture naming. Finally, calculation tasks were administered. Each cortical site (5 × 5 mm) of the entire cortex exposed by the bone flap was tested three times. The IntraParietal Sulcus (IPS) was then stimulated. Functional sites were marked with tags when an error was detected at three repeated stimulations.

### *Calculation tasks*

All the numerical stimuli were presented visually on a PC screen, using Arabic digits. Only addition and multiplication were studied, due to time constraints. Two different types of calculation were administered to the patient:

- one-digit addition with one operand (e.g., 4 + 7; 8 + 6; 5 + 7. . ..).
- one-digit multiplication with one operand (e.g., 8 × 4; 5 × 6; 9 × 7. . ..).

Each operation had to be solved within the time of stimulation (i.e., 4 s) and was presented at the centre of the screen without the sign '='; the patient was asked to give a vocal response. The patient did not know when the electrical stimulation was performed. The administration procedure was as follows: A block of 14 additions was presented to the patient, in random order, alternating the use of electrostimulation and repeated three times. On each stimulation site, the patient performed three additions, for a total of 21 trials with and 21 trials without. A block of 15 multiplications was then administered (and repeated three times) with the same procedure, for a total of 22 tests with and 23 without stimulation. A speech therapist monitored the type of errors.

### *Intraoperative data*

The functional stimulation mapping resulted in the identification of the following cortical sites (Figure 1b).

- The primary somato-sensory areas of the face (tag 1);
- The speech arrest site in the anterior part of the Inferior Parietal Lobule (IPL; tag 2);
- Five sites where stimulation interfered with naming (tag 3–7);
- Three sites were involved in addition, all located within the posterior part of the IPL (tags +);
- Two sites were involved in multiplication, all located within the anterior part of the IPL (tags x);
- A site located in the horizontal segment of the IPS where stimulation interfered with multiplication (Figure 1c)

No site was positive for both addition and multiplication. No site was positive for both calculation and language. A qualitative analysis of errors was then performed (Table 1). In the presented case, errors inducted by stimulation differed qualitatively between addition and multiplication. Note that errors cannot be explained by semantic paraphasias, since even when the error started by the same sound of the correct response, the verbal response was complete, or ended following the described patterns.

A post-operative MRI showed the complete removal of tumour (Figure 1d).

**Table 1.** In *operand errors* (evidenced as black in the table): the erroneous answer is correct for a problem that shares an operand with the presented problem (i.e., 8 × 6 = 40, where the shared operand is 8, as 8 × 5). In *table errors* (dark grey), the erroneous response does not share an operand with the stimulation problem, but is an answer to any single-digit problem (e.g., 6 × 9 = 56). In *operation errors*, the erroneous response is correct for a problem involving the same operands, but in a different arithmetic operation (e.g., 9 × 8 = 17). McCloskey *et al.* (1991) explain these errors (on the whole called *retrieval errors*, black or dark grey) as due to interference during the retrieval of verbally learned, by rote, arithmetic operations, stored in memory as an associative network. The authors further classify all other errors as *non-table/non-retrieval errors* (light grey). In the following classification, *approximation* (underlined) occurs for operand errors when the erroneous solution is the solution for the following or for the preceding problem in the table; approximation occurred for table and non-table errors, when the erroneous solution is close to the correct solution. For the present analysis, a maximum deviation up to 9 was considered as an approximation in multiplication, where the maximum solution was 81 (9 × 9). For addition, the proportional maximum deviation of 2, according to the maximum addition equal to 18 (9 + 9) was taken as maximum. Approximation occurred in 100% of the commission errors for addition, but only on the 55% of the commission errors for multiplication. For multiplication, 55% of commission errors were retrieval errors. Of these, 80% were operand errors and 10% were table errors not implying approximation. Importantly, all except one of the operand errors were close in the table to the correct solution. Since every number can be a solution for addition and solutions related to operands are less well defined for addition, all errors were classified as table-related errors. No operation error appeared in both multiplication and addition

| Operation | Correct solution | Test 1 | Test 2 | Test 3 | Operation | Correct solution | Test 1 | Test 2 | Test 3 |
|---|---|---|---|---|---|---|---|---|---|
| 4 × 6 | 24 | ✓ | ✓ | ✓ | 4 + 7 | 11 | ✓ | ✓ | Anomia |
| 4 × 7 | 28 | *55* | 56 | *58* | 8 + 3 | 11 | ✓ | 13 | ✓ |
| 5 × 6 | 30 | ✓ | ✓ | Anomia | 4 + 8 | 12 | 11 | ✓ | ✓ |
| 8 × 4 | 32 | ✓ | ✓ | ✓ | 3 + 9 | 12 | ✓ | ✓ | ✓ |
| 7 × 5 | 35 | ✓ | ✓ | ✓ | 5 + 7 | 12 | Anomia | ✓ | ✓ |
| 9 × 4 | 36 | ✓ | ✓ | ✓ | 8 + 5 | 13 | ✓ | ✓ | ✓ |
| 8 × 5 | 40 | ✓ | ✓ | ✓ | 9 + 4 | 13 | 15 | 11 | 15 |
| 7 × 6 | 42 | 45 | *55* | *52* | 7 + 6 | 13 | ✓ | ✓ | ✓ |
| 9 × 5 | 45 | ✓ | ✓ | ✓ | 8 + 6 | 14 | ✓ | ✓ | ✓ |
| 8 × 6 | 48 | 40 | 46 | 40 | 9 + 5 | 14 | ✓ | ✓ | ✓ |
| 9 × 6 | 54 | 45 | 52 | 56 | 7 + 8 | 15 | ✓ | ✓ | ✓ |
| 8 × 7 | 56 | 48 | 58 | 48 | 9 + 6 | 15 | ✓ | ✓ | ✓ |
| 7 × 9 | 63 | 54 | | *53* | 9 + 7 | 16 | ✓ | ✓ | ✓ |
| 8 × 8 | 64 | ✓ | ✓ | ✓ | 9 + 8 | 17 | ✓ | Anomia | ✓ |
| 9 × 8 | 72 | Anomia | Anomia | ✓ | | | | | |
| | Total errors | 7 | 7 | 7 | | Total errors | 3 | 3 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| Operand | Operand approximation | Table related | Table approximation | Non-table approximation | Non-table |
| Retrieval errors | | | | Non-retrieval errors | |

## Discussion

Simple, one-digit, addition and multiplication are at the basis of more complex operations and they are daily performed by most numerate people. These facts make them an ideal stimulus material for intraoperative mapping of the lower left parietal lobe. Distinct locations in the anterior and the posterior portions of the Inferior Parietal Lobe were found. While simple addition seems to be processed in the posterior portion, simple multiplication is processed in a more anterior portion. One-digit multiplication and one-digit addition have often been considered as alike processes since they both share the property of being retrieved automatically by rote (Dehaene *et al.*, 2003); Rosenberg-Lee *et al.*, 2011). There must be instead a level where the two operations are distinctly treated (Rosenberg-Lee *et al.*, 2011). This is suggested by the type of errors that may be different for the two operations. In fact, the patient's mistakes may suggest that calculation was mainly applied for addition since every error entailed an approximation to the correct sum. In other words, here we hypothesize that exact calculation fails and is replaced by approximation when sites in the posterior left IPS are transitorily disrupted during addition. When stimulating the anterior IPS during multiplication, approximation errors were usually close in the table to the correct solution, suggesting that a correct retrieval of the exact solution failed, with higher interference from operand-related solutions. Almost every time, these operand-related errors were close to the correct solution. Approximation was thus combined with retrieval for multiplication. The majority of addition errors, in fact, seemed to unveil an underlying arithmetic procedure of approximation while multiplication clearly relied on a sort of approximate retrieval. That is, when stimulation was applied on anterior portions of the Inferior Parietal Lobe, a sub-serving process of retrieval appeared to be altered for multiplication, giving rise to frequent retrieval-related errors. When the posterior portions of the parietal gyrus are stimulated while performing addition, errors characterized by approximation procedures (100% of the times) arise instead. Therefore, the patterns of errors suggest the interplay of different essential arithmetic functional components that distinguish between operations. Neurosurgery thus proves to be a useful tool to explore arithmetic processing components. The findings of the present single-case study encourage follow up with further data collection with the same paradigm.

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