Calculation processing in right parietal cortex. Possible implications for neurosurgery.

Alessandro Della Puppa[1] MD, Serena De Pellegrin[2] ST, Elena Salillas[3] PhD, Carlo Semenza[2] MD

[1] Department of Neurosurgery, University Hospital of Padova, Italy

[2] Department of Neuroscience, University Hospital of Padova, Italy

[3] Basque Center on Cognition Brain and Language, Donostia, Spain

Corresponding Author Information:

Alessandro Della Puppa, M.D.
Department of Neurosurgery
University Hospital of Padova
Via Giustiniani 2, Azienda Ospedaliera di Padova, 35128, Padova, ITALY
Tel: +39.049.8213641 Fax. +39.0498213672

e.mail: alessandro.dellapuppa@sanita.padova.it

The authors report **no conflict of interests** concerning the materials or methods used in this study or the findings specified in this paper

No **funding was** received for this study

We certify that the contents are **original work** and are not under review at any other publication.

Text

Dr.Sagher's thoughtful comments regarding our manuscript "Right parietal cortex and calculation processing…" provide us with the opportunity to clarify the implications of our findings for neurosurgery by further discussing the localization of simple calculation in the brain. As Dr. Sagher points out, conventional wisdom holds indeed that computational processing, including simple calculation, is housed in the left hemisphere. But even the "triple code model" theory [3], that summarized the state of knowledge in the mid-90s, suggested that only verbally mediated simple calculation is performed exclusively in the left hemisphere. More precisely, according with this view, rote learned addition and multiplication are a function of the left angular gyrus (lANG) while even simple subtraction requires also the right hemisphere. In a later work, Dehaene et al.[4] further suggestedthat the lANG mainly concerns linguistic processing and that in calculation such structure depends on the left horizontal intraparietal sulcus. These views have evolved upon further evidence in recent years, however.

A meta-analysis conducted on fMRI-based studies [2] found that activity is dominant in the left hemisphere for addition, either bilateral or right hemisphere for subtraction, and primarily right-dominant for multiplication. Consistently with this finding, Rosemberg-Lee et al.[8] found that multiplication evokes significantly greater activation in the right posterior intraparietal sulcus. More recently, Price et al.[7] also evidenced the role of the right hemisphere in math learning, insofar a greater activation in the right intraparietal sulcus during calculation was related to lower Preliminary Scholastic Aptitude Test (PSAT) math scores.

The importance of the right intraparietal sulcus has been further shown by Transcranial Magnetic Stimulation (TMS). Using TMS, Andres et al.[1] found that disruption to both left and right horizontal intraparietal sulcus lead to impaired multiplication. Interestingly, frequent errors of the retrieval type (i.e. table results other than the target, e.g., 7x3=14) suggested that bilateral disruption of the horizontal intraparietal sulcus impaired retrieval processes. Salillas et al.[9] further showed that efficiency in simple multiplication is dependent on the ventral region of the intraparietal sulcus in the right hemisphere, considered to be critical for motion representation and automatization.

It was data like the above that encouraged us to use simple calculation coupled with DCES during operations in the right parietal areas. The result is that eloquent areas for simple calculation were indeed found in the right parietal cortex. This may not be surprising if one considers traditional neuropsychological literature on right hemisphere acalculia (RHA). Indeed these data

provide new insights on the still understudied nature of RHA. Understandably, the main focus of studies on RHA was on its spatial origin, whether determined by neglector not [5]. No specific data for such condition on the amount of errors in simple calculation are reported by group studies. But surely non-spatial errors significantly contribute to the impairment [6]

There is a long way to go in order to demonstrate that, as it happens with linguistic functions, damaging a positive site for calculation would provoke irreparable post-operative acalculia. In our preliminary investigation we found, however, a considerable amount of errors by inactivating distinct portions of the right parietal cortex, in particular in the intraparietal sulcus, a privileged way for the surgical approach of deeply seated lesions. In a case we operated on the left hemisphere, that will be independently reported, a decision had to be taken about whether to go through a language-positive or through a calculation-positive site. The decision to go through the calculation site lead to post-operative calculation deficits. We keep investigating.

References

1. Andres M, Pelgrims B, Michaux N, Olivier E, Pesenti, M : Role of distinct parietal areas in arithmetic: an fMRI-guided TMS study. **Neuroimage 54**: 3048-3056, 2011

2. Arsalidou M., Taylor MJ : Is 2+2=4? Meta-analyses of brain areas needed for numbers andcalculations. **Neuroimage 54**:2382-2393, 2011

3. Dehaene S, Cohen L: Towards and anatomical and functional model of number processing. **Mathematical Cognition 1**:83–120, 1995

4. Dehaene S, Molko N, Cohen L, Wilson A J: Arithmetic and the brain. **Current Opinion Neurobiology 14**:218–224, 2004

5. Granà A, Hofer R, Semenza C : Acalculia from a right hemisphere lesion dealing with "where" in multiplication procedures. **Neuropsychologia 44**:2972-2986, 2006

6. Miceli, G, Capasso R : Calculation and number processing, in Denes G, Pizzamiglio L (ed.): **Handbook of clinical and experimental neuropsychology**. Hove, England: Psychology Press/Erlbaum (UK) Taylor and Francis,1999, pp. 583–612

7. Price GR, Mazzocco MM, Ansari D: Why mental arithmetic counts: brain activation during single digitarithmetic predicts high school math scores. **J Neurosci 2**:156-163, 2013

8. Rosenberg-Lee M, Chang TT, Young CB, Wu S, Menon V: Functional dissociations between four basic arithmetic operations in the human posterior parietal cortex: a cytoarchitectonic mapping study. **Neuropsychologia. 49**:2592-2608, 2011

9. Salillas E, Semenza C, Basso D, Vecchi T, Siegal M : Single pulse TMS induced disruption to right and left parietal cortex on addition and multiplication. **Neuroimage 59**: 3159-3165, 2012