Tactile Enumeration and Brain Plasticity in Acquired Acalculia

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Introduction

- A close **relationship**, an embodiment, between **abstract numbers** and **fingers**:
  - **Right hand** muscles (left hemisphere) and **small numerals** (1-4) [1]
  - **Anatomical** closeness between cortical areas for **finger use** and **number magnitude** mediation [2]
- The intraparietal sulcus (**IPS**) - representing the **meaning of number** [3]
- **Acquired (Primary) Acalculia** [4]
  - **Left IPS** damage
  - Deficits in **numerical** abilities
  - Similarities with **developmental dyscalculia** [5]

Current Study

- **NO**, 22, female with **acalculia**, following stroke to the **left IPS** [6]
  - Average intellectual abilities, Intact visuo-spatial, language, memory and attention abilities
  - Difficulties in an arithmetic battery, specifically in procedural knowledge
  - Mental clock and numerical Stroop tasks - Larger distance effect, lack of facilitation and increased interference
- **Task: tactile enumeration (TE) using one hand – How many fingers are stimulated?**
- **Voxel-based morphometry (VBM)** - gray matter (GM) changes over time
- Time**: Acute phase - 1st month (1st),** 1 month later (1ML), **Chronic phases** - **6 months later** (6ML), and 1½ years later (18ML)

Method

- **Tactile Enumeration Task:**

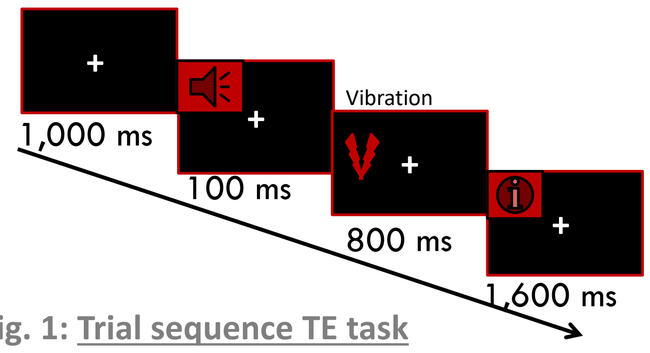

Fig. 1: Trial sequence TE task

Fig. 2: Apparatus

- **Voxel-Based Morphometry:**
- High resolution T1 - weighted images

  TR = 2.2, TE = 3.03 ms, FOV 256 mm, 176 sagittal slices of 1 mm thickness, flip angle = 90°, voxel size 1 x 1 x 1
- Analysis used optimized method of VBM for SPM 12. Spatial normalization to a stereotactic space, segmentation of normalized images (GM, WM, CSF), smoothing the images (8 mm)
- Independent sample *t*-test (covariate, Global Brain Volume)
- **ROI Analysis:**
  Number areas: *Neurosynth* imaging meta-analytic tool (http://www.neurosynth.org/). A meta-analytic activation map based on 99 studies was generated. Each ROI consisted of a 6 mm sphere, which was used on a small volume correction approach

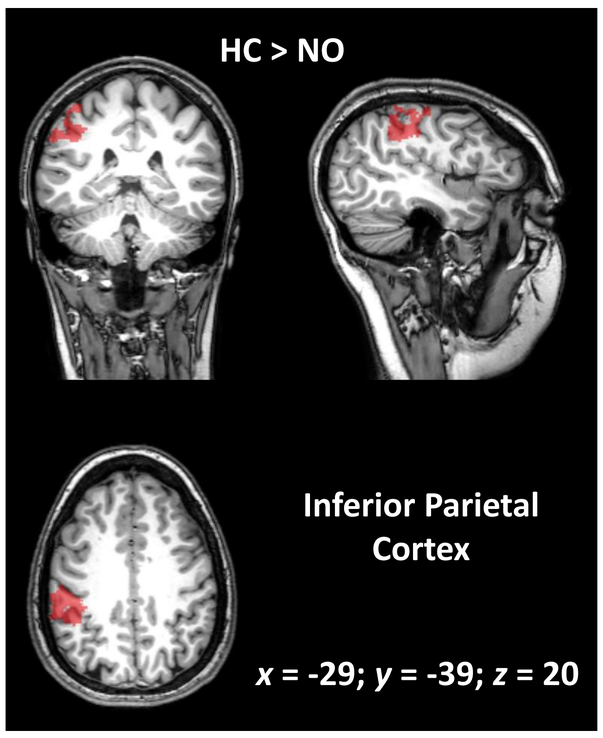

Fig. 3: VBM results showing HC > NO

VBM results showing HC > NO
The activation blob is warped back to NO's native space. Note the correspondence between the blob and NO's lesion boundary

Results

TE task:

- The procedure of Crawford and colleagues [7,8] for comparing an individual's test score against norms derived from small samples:
- Controls (N=44):
  - **Moderate RT slope** for1-4 stimuli and a decrease in RT for 5
  - ACC – reverse pattern, mean accuracy 0.8
- NO:
  - **Steep RT slope** for 1-4 ($p < .0001$) in acute phase, and 1ML ($p < .05$)
  - ACC – Marginally significant difference in acute phase ($p < .08$)

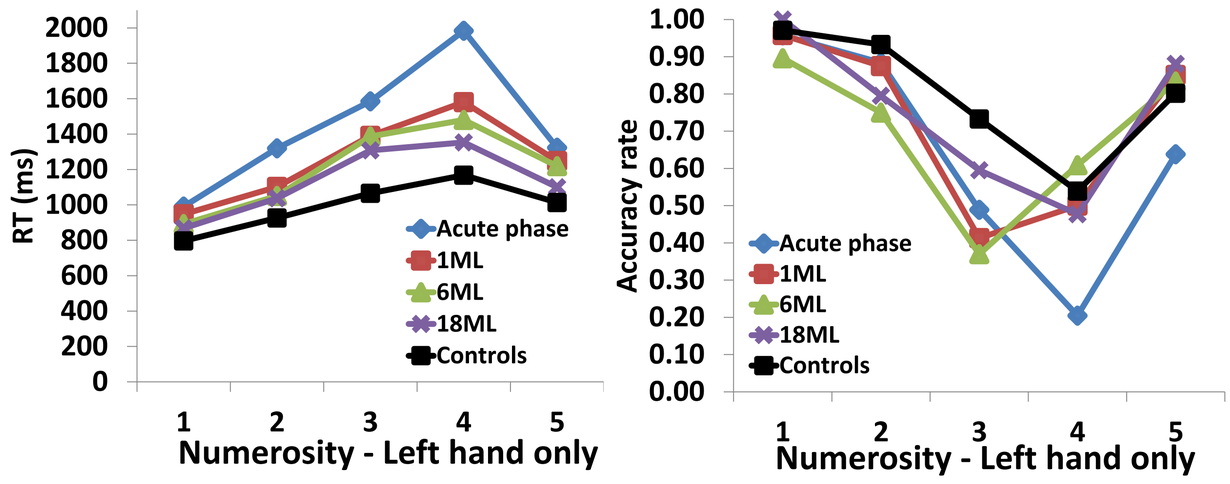

Fig. 4: RT and ACC of stimulating 1-5 fingers of the left hand, NO vs. Controls

Voxel-Based Morphometry:

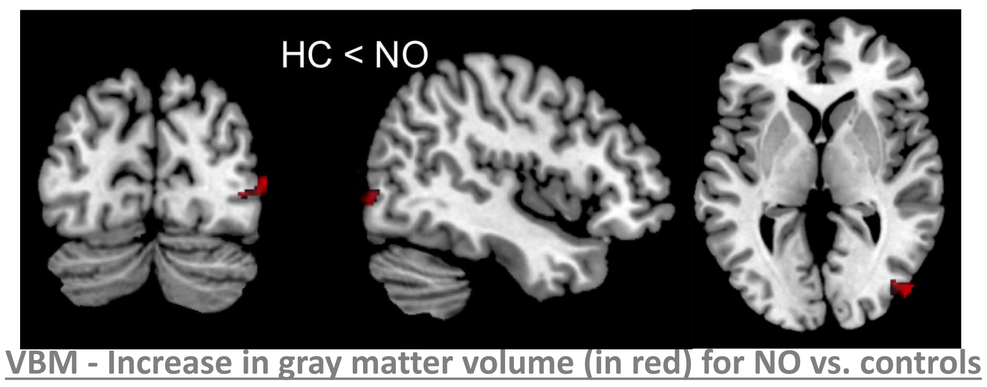

Fig. 5: VBM - Increase in gray matter volume (in red) for NO vs. controls

Region Label	Cluster Size	t-value	X	Y	Z	HC<NO – 1m FEW (.05)	HC<NO-6m FEW (.05)
R SupraMarginal Gyrus	639	7.44	50	-36	50		
L Superior Parietal Lobule	550	7.24	-24	-62	54		
L Inferior Parietal Lobule	550	6.60	-38	-48	46		
R Inferior Occipital Gyrus	31	6.09	42	-86	-4	$p = .035$ (vxl = 53, T = 3.25	$p = .01$ (vxl = 92, T = 3.71
R Middle Frontal Gyrus BA6	46	5.93	30	0	52		
R Middle Frontal Gyrus	38	5.82	50	38	22		
R Middle Temporal Gyrus	20	5.78	58	-52	-2		
L Middle Frontal Gyrus	33	5.13	-46	30	34		

Discussion

- **Slower counting** in the acute phase - Larger RT slope for 1-4 stimuli
- **Embodiment** - traces in long-term memory for numerosity 5
- Rehabilitation effect - change in the RT slope in time
- An increase in GM for NO in the **right inferior occipital cortex** during the acute and the chronic phases
  - May be associated to the **use of visual imagery** and **multisensory object representation** following the loss of numerical and haptic abilities [9]
- **Left IPS** – essential for enumerating small quantities using fingers

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