A common neural substrate for number comparison, hand reaching, and grasping

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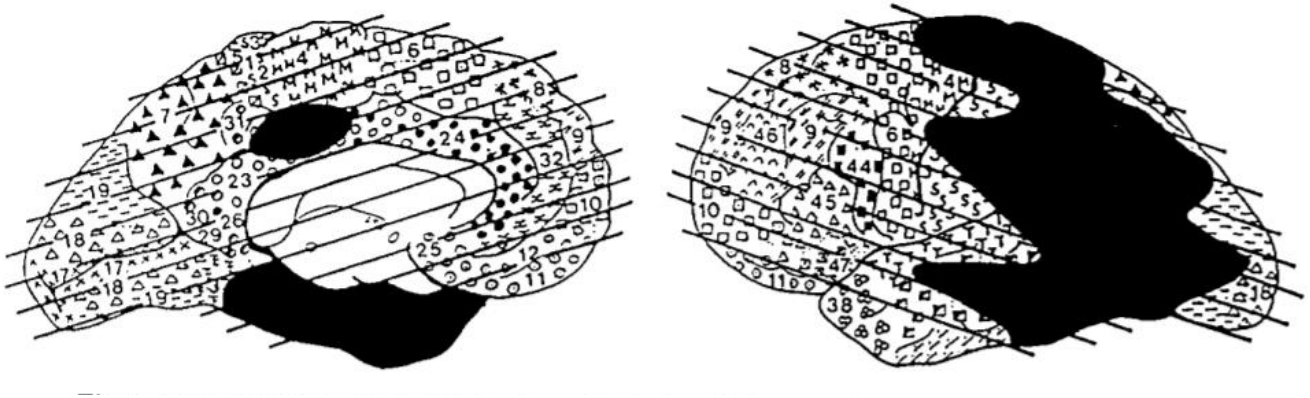
GRINP

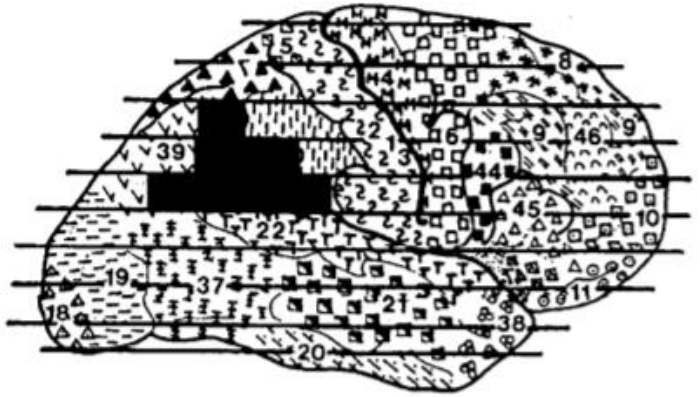
Grasping and Reaching in Number Processing

Background: the number system

Neuropsychological case reports in the last century have revealed the **independence of number processes from language**.

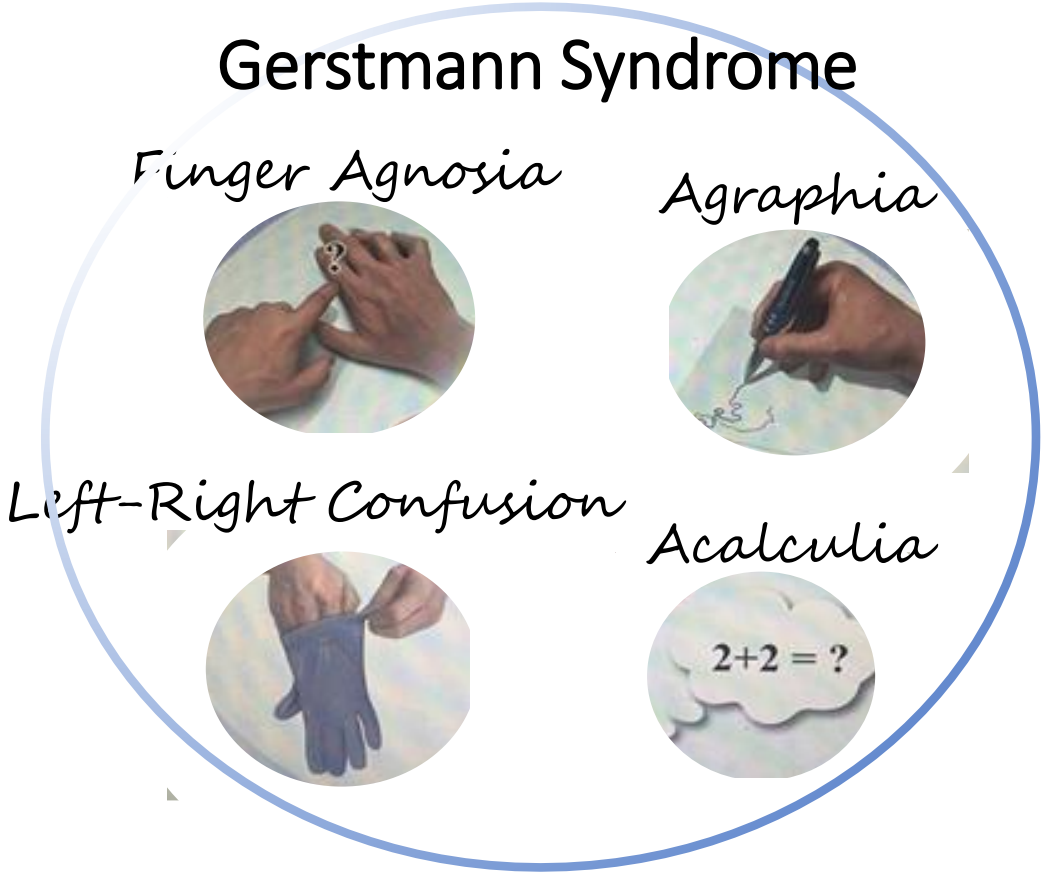


Dehaene & Cohen, 1991



Dehaene & Cohen, 1997

Background: number and hand action

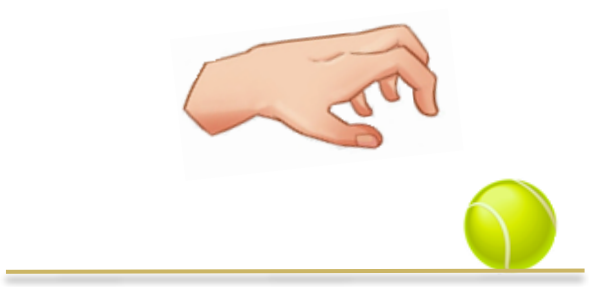


The Gerstmann syndrome highlights the existence of links between number and hand actions.

Background: number and hand action

Reach (arm transport)

Grasp (hand preshaping)

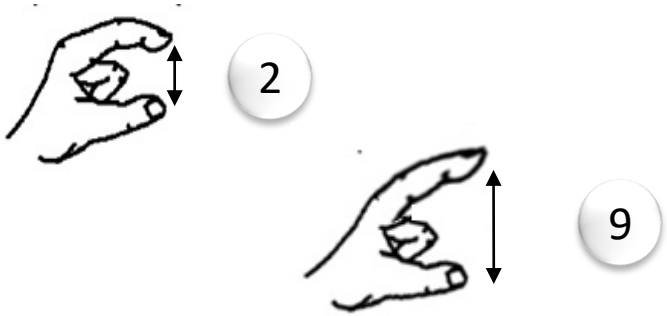


Reach & numbers

Number magnitude influences **trajectory**, **velocity** or **final position** of reaching (e.g. Song, & Nakayama, 2008; Girelli et al. 2016; Gianelli, Ranzini et al. 2012).

Grasp & numbers

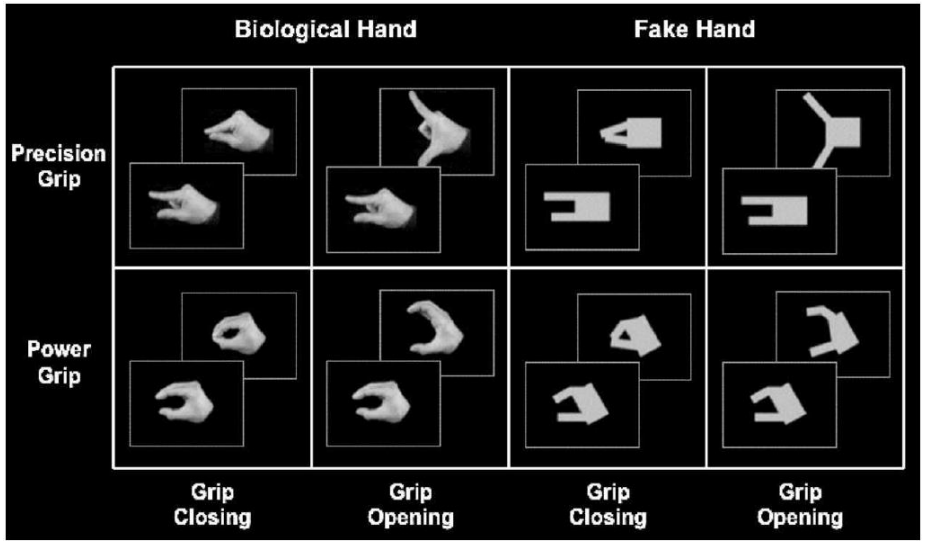
Number magnitude influences response times during **closing or opening grip** movements (e.g. Lindemann et al., 2007), as well as **grip aperture** during grasping (Andres et al., 2008).



Background: number and hand action

Interactions between number and hand actions are **bidirectional**.

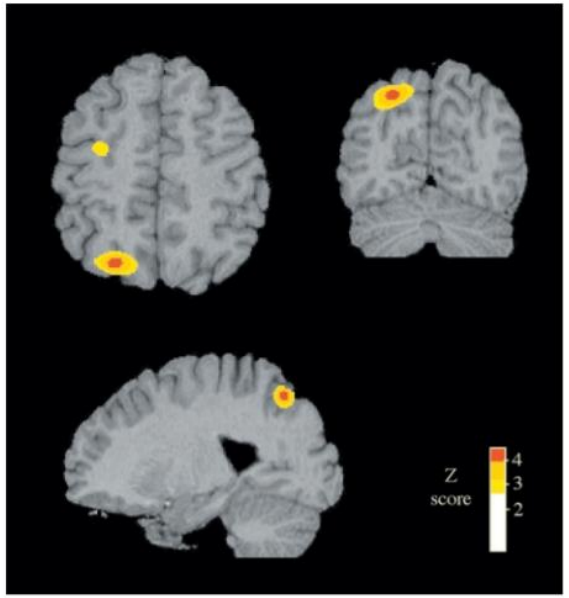
Observing fingers depicting **grip closing** (es. Badets & Pesenti, 2010), as well as observing **graspable objects** (e.g., Ranzini et al. 2011), impacts the processing of number magnitude in numerical tasks, e.g., number comparison or parity judgment.



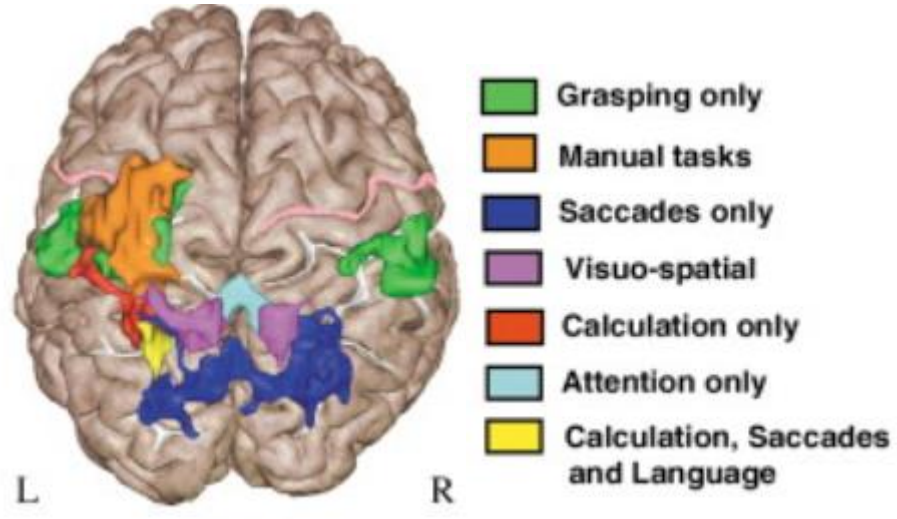
Badets & Pesenti, 2010

Background: number and hand action

Do number processing and hand action involve **common brain areas**?

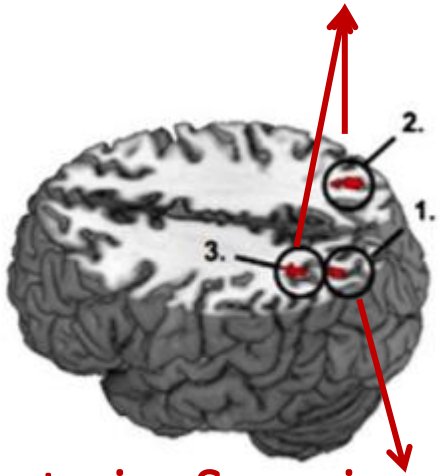


Pesenti et al., 2000



Simon et al., 2002

Intraparietal sulcus (IPS)



Posterior Superior Parietal Lobule (PSPL)

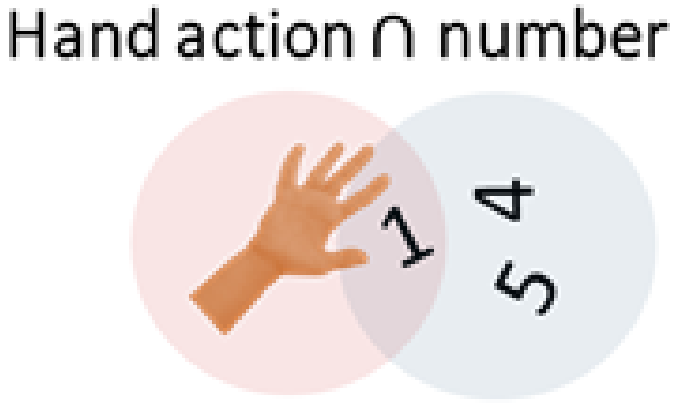
Andres et al., 2012

GRINP
Grasping and Reaching in Number Processing

Aim of the study

To which extent do number, reach and grasp involve common brain areas?

We performed a **meta-analysis of neuroimaging studies** to investigate the degree overlap between brain areas involved in **number, hand reach and grasp**.



Method: metanalytical approach

Meta-analysis of neuroimaging studies (MRI, PET) on number, hand reach and grasp

Literature search: studies on symbolic number comparison, or execution of hand reach and or grasp

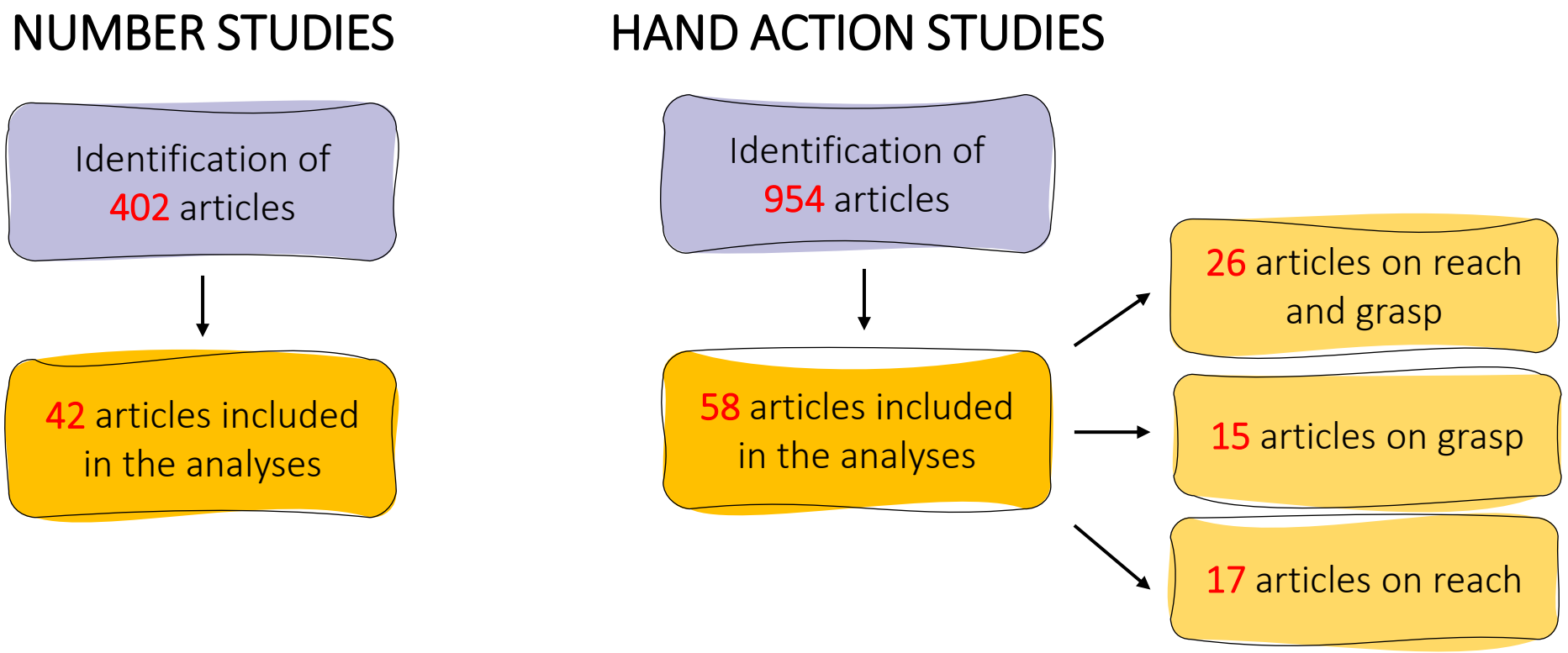
Article selection: whole brain studies reporting results of univariate analyses

Coordinates extraction and conversion into the same reference space

Analyses: seed-based d mapping with permutation of subject images (SDM-PSI method, Albajes-Eizagire et al., 2019)

Moher et al., 2009; Müller et al., 2018

Results: search and article selection



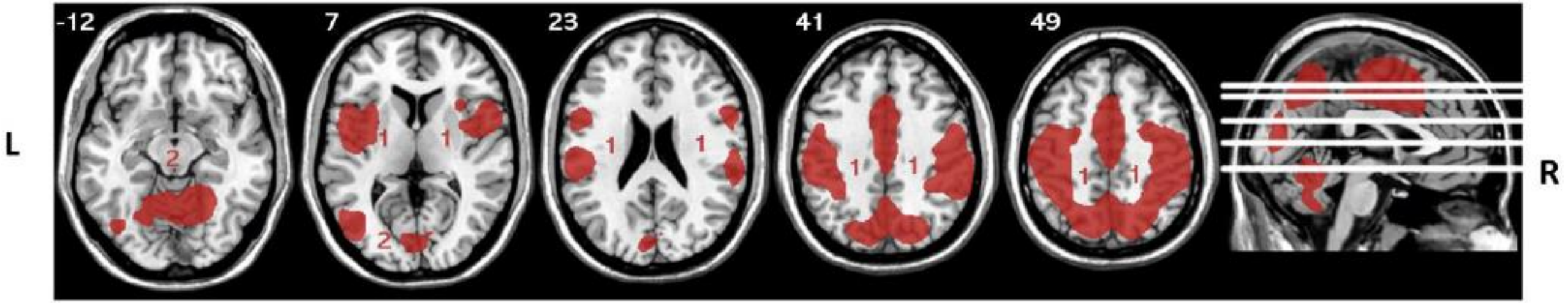
Literature search on **Pubmed**, **PsyArXiv**, **references**, or **related articles** on Pubmed

Results: set of analyses

- Meta-analytical maps of symbolic number comparison, hand reach and grasp, hand grasp only, hand reach only
- Conjunction analyses between number & reach/grasp, number & grasp, number & reach
- Functional characterization (www.neurosynth.org)

Results: meta-analytical map of hand reaching and grasping

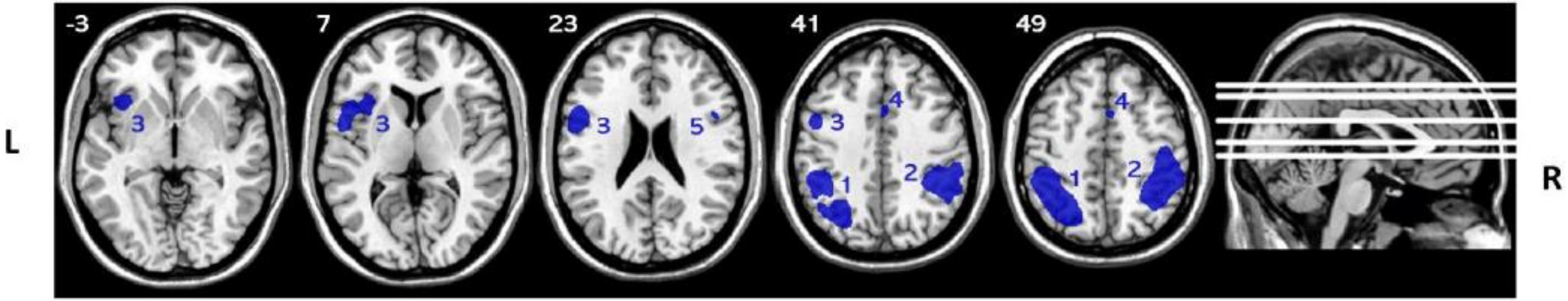
aIPS=anterior intraparietal sulcus PSPL=posterior superior parietal lobule M1=primary motor cortex
S1=primary somatosensory cortex SMA=suppl. motor area



The reach and grasp network is also highly consistent with previous findings (e.g., di Bono et al., 2015): at the cortical level, it involves **aIPS**, **PSPL**, **S1**, **M1**, and **SMA**.

Results: meta-analytical map of symbolic number processing

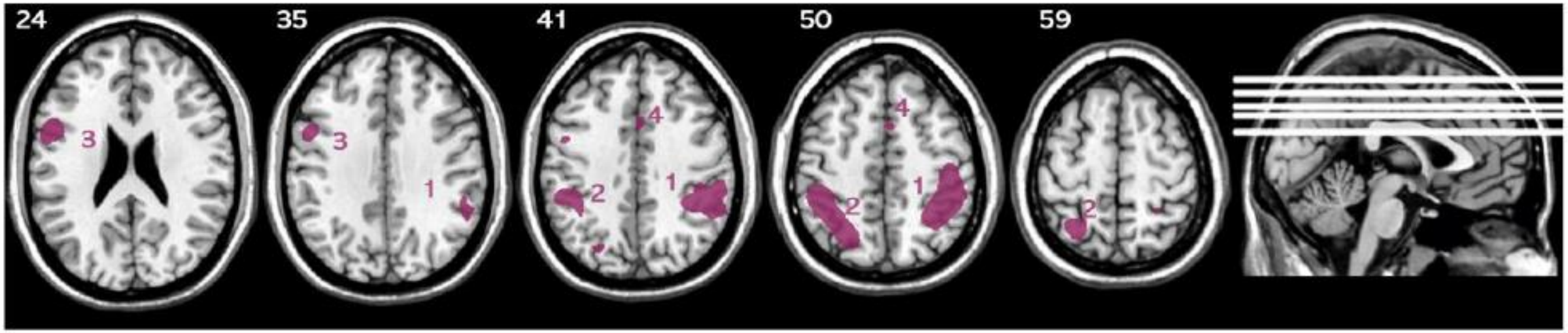
IPS=intraparietal sulcus SMA=suppl. motor area PCG=precentral gyrus IFG=inferior frontal gyrus



The brain areas of the number system is highly consistent with what observed in previous study (e.g., Sokolowsky et al., 2018). They involve areas around the **left and right IPS**, the **left PCG**, and to a lesser extent the **right IFG** and the **SMA**.

Results: conjunction between number, hand reach and grasp

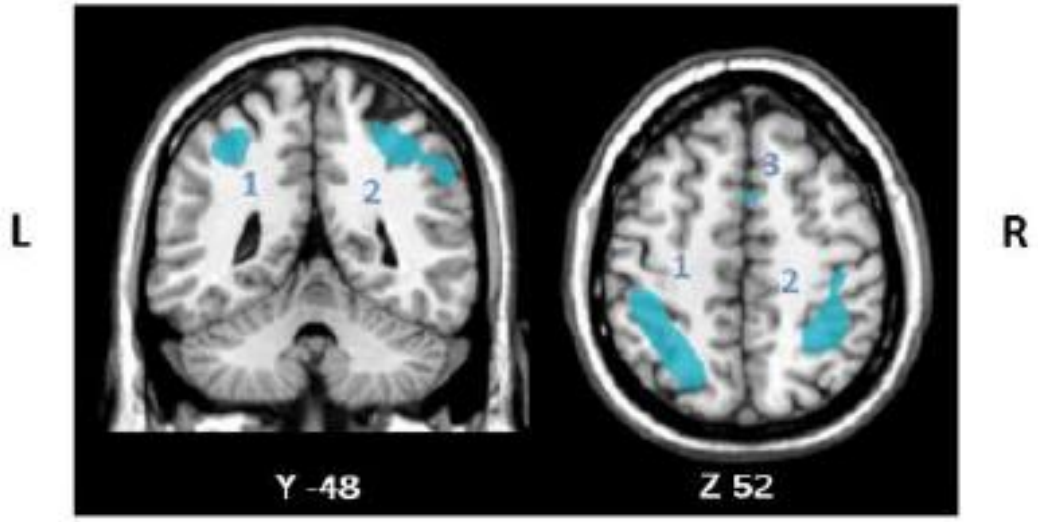
IPS=intraparietal sulcus SMA=suppl. motor area PCG=precentral gyrus



The number network is largely embedded in the motor network involved in reach and grasp actions. Spatial convergence was observed in **left and right IPS**, the **left PCG**, and the **SMA**.

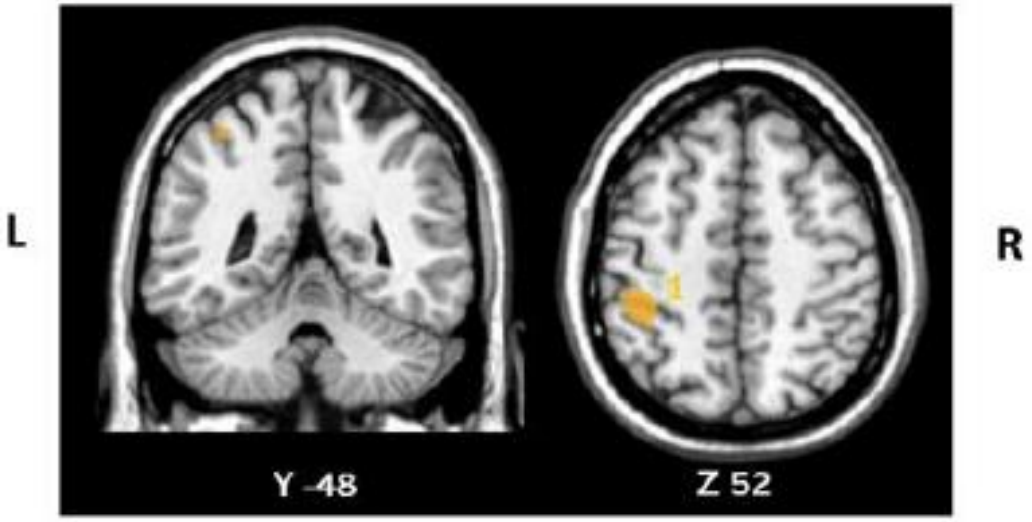
Results: conjunction between number, hand reach and grasp

Number & Hand Reach



Common involvement of
left and right IPS regions

Number & Hand Grasp



Common involvement of
left aIPS

Results: analysis of functional characterisation

Category	Terms	Correlation coefficient (Pearson)
Hand and Action	*action observation, action, actions, finger movements, finger tapping, executed, execution, finger, grasping, hand, hands, imitation, index finger, motor task, motor, movement, movements, reaching, sensorimotor, tapping, tools, visuomotor*	.22 (.10-.39)
Memory and Imagery	*Imagery, memory load, memory wm, motor imagery, rehearsal, working memory*	.22 (.12-.30)
Space, Eye, and Attention	*attention network,attention, attentional, eye field, eye fields, eye movements, eye, frontal eye, orienting, saccade, saccades, spatial attention, spatial, visual, visually, visuospatial*	.20 (.10-.29)
Number	*arithmetic, calculation, subtraction*	.20 (.13-.28)
Language	*language, letter, orthographic, phonological, reading, speech production, verbal, word*	.14 (.12-.20)
Other	*articulatory, conflict, contralateral, coordination, demands, force, gain, handed, interference, load, mainteinance, mirror, monitoring, performance, planning, preparation, preparatory, production, rotation, sensory, sequential, somatorensory, stimulation, symbolic, tactile, target, task difficulty, task, tasks, touch, working*	.17 (.10-.42)

www.neurosynth.org

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www.neurosynth.org

Discussion: Summary of the results

- The sensorimotor brain network of hand reach and grasp **highly contributes** to number processing.

- Spatial convergence has been found in left and right **IPS**, extending to left **PSPL**, left **PCG**, and **SMA**.

- The overlapping network is shared with other cognitive functions, such as **working memory, imagery and visuospatial attention**.

Discussion: limits of the study

- What is the specific function of each brain region?
- Are interactions between number and hand occurring because of highly specialized group of neurons within neighbouring brain regions?
- … or are they the result of common functional nodes located within shared brain regions (as suggested for the Gerstmann syndrome)?

Conclusion

Similarly to language, numbers seem to be **grounded and embodied** into sensorimotor processing.

Nature and nurture probably both contribute to the **grounding and embodiment of numbers** into sensorimotor mechanisms.

Many thanks for your attention

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