

3rd Expert Meeting
Mathematics Researchers of the Benelux
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When numbers act as attentional cues: Behavioral and neuroimaging investigations

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Human ideas are, to a large extent,
grounded in sensory-motor experience

(Lakoff and Nunez, 2000)

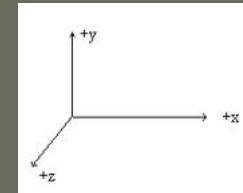
Context of our research

- What is the relation between

Numerical cognition



Spatial cognition



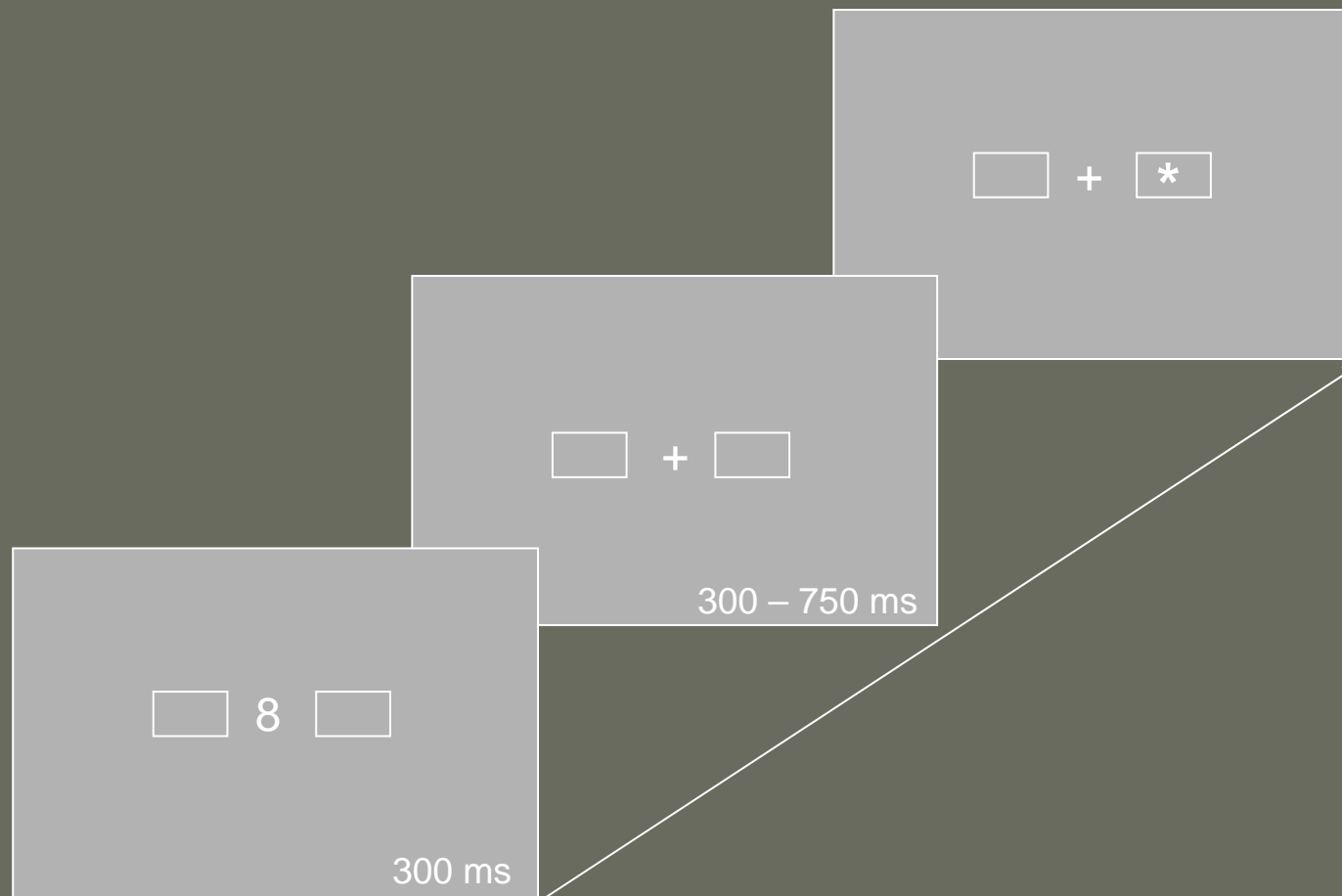
- Visuo-spatial attention shifts induced by numbers:
 - Exact behavioral characteristics?
 - Neuronal correlates ?



The « Fischer paradigm »

Small numbers (e.g. 1 or 2) → left hemispace

Large numbers (e.g. 8 or 9) → right hemispace

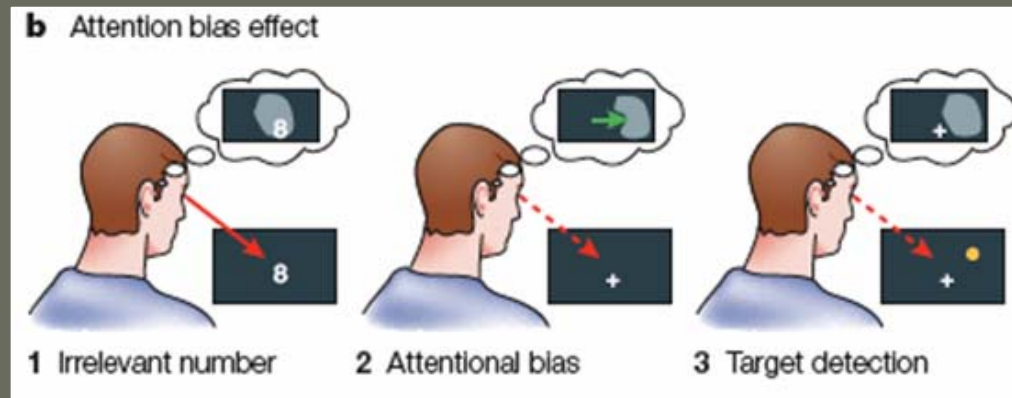


Symbolic spatial attention cueing

(Fischer et al., 2003)

Evidence for a close connection between numbers and space

Number magnitude causes covert shifts of visuospatial attention



(Hubbard et al., 2005)

Spatial attention shifts have been replicated but they are:

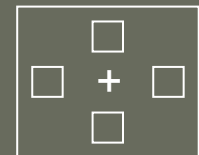
- small
- sensitive to context and task

- Replications -

- Galfano, Rusconi & Umiltà, 2006
- Ristic, Wright, & Kingstone, 2006
- Dodd et al., 2008

- Qualifications -

- Galfano, Rusconi & Umiltà, 2006
- Ristic, Wright, & Kingstone, 2006
- Casarotti et al., 2007
- Stoianov et al., 2008



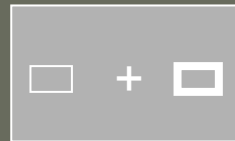
Behavioral evidence for a close connection between numbers and space

If numbers induce **automatic** attention shifts then:

Facilitation followed by **Inhibition of Return**

Inhibition of return in :

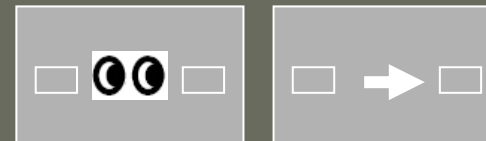
- Exogenous attention shifts



E.g.

- Posner and Cohen, 1984
- Klein, 2000
- etc. ...

- Endogenous attention shifts



E.g.

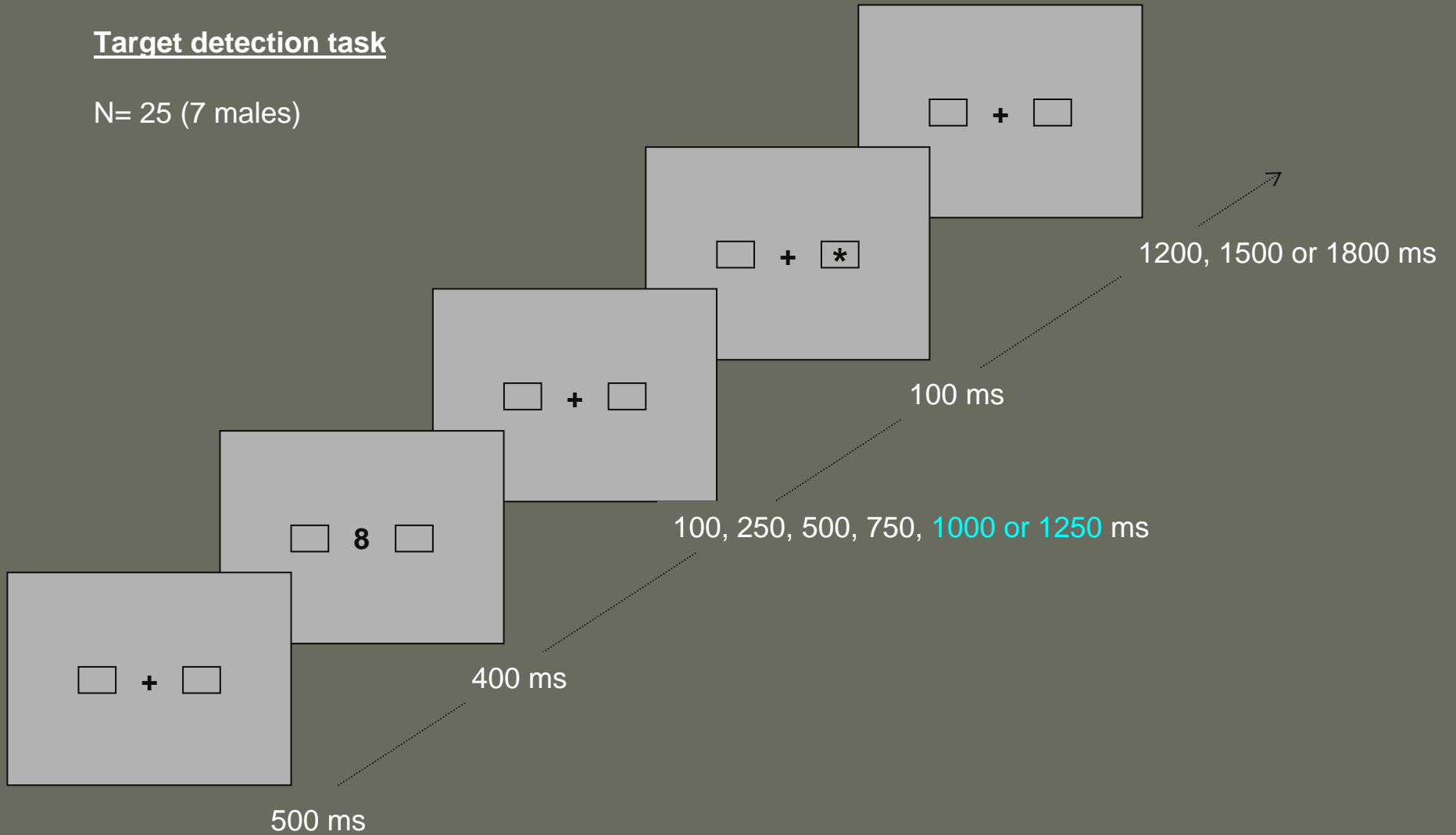
- Frischen and Tipper, 2004
- Okamoto-Barth & Kawai, 2006
- Rafal et al., 1989

Behavioral evidence for a close connection between numbers and space

METHODS

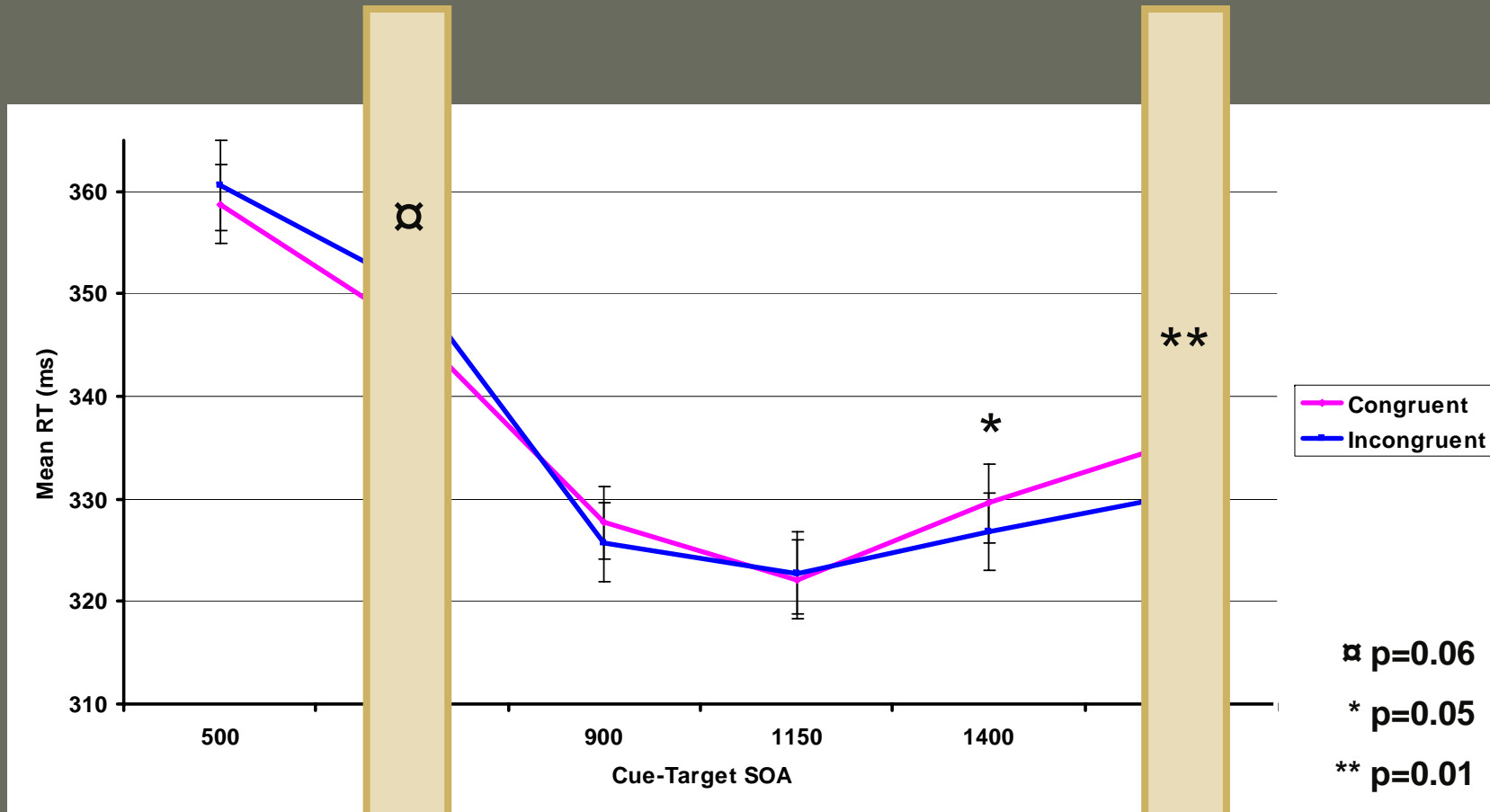
Target detection task

N= 25 (7 males)



Behavioral evidence for a close connection between numbers and space

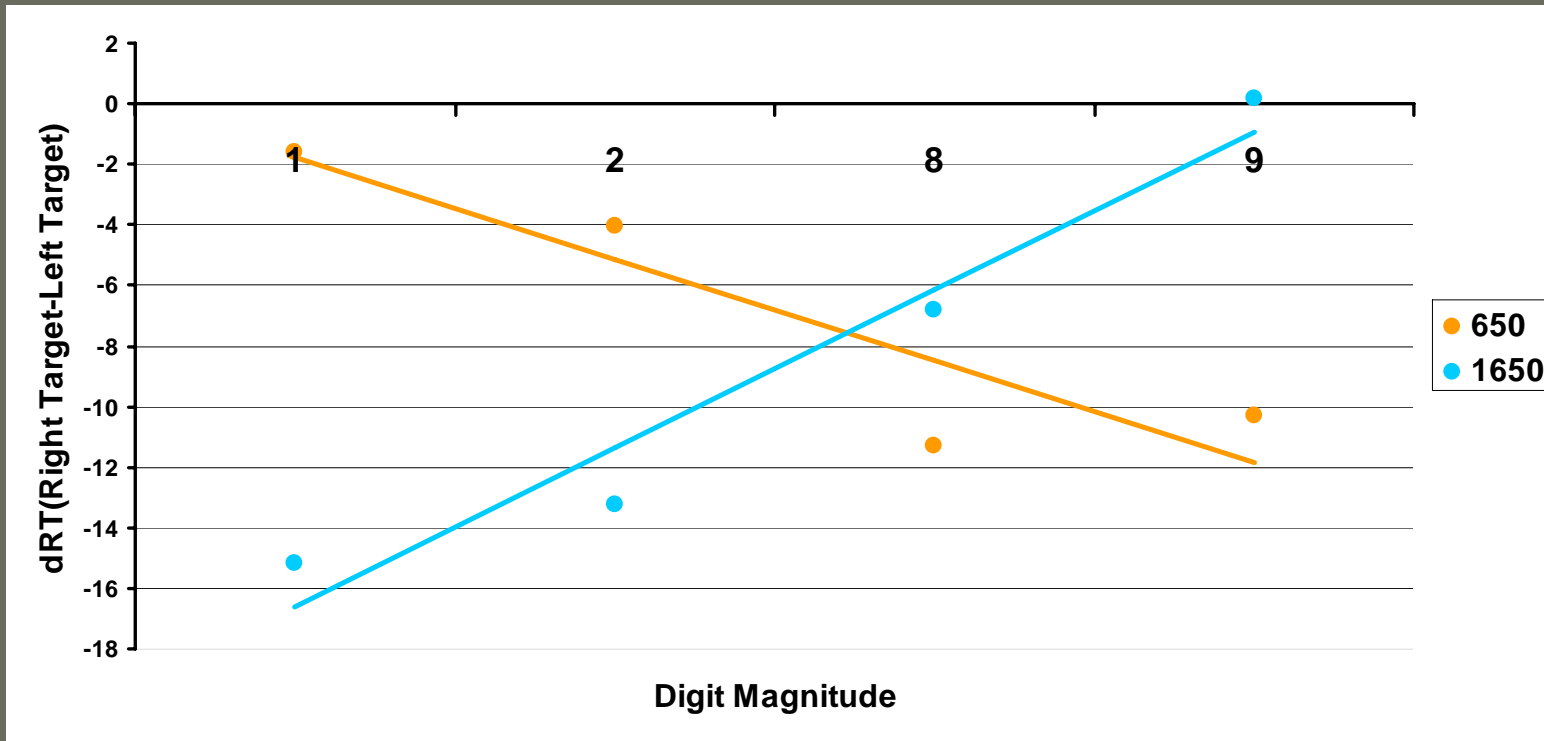
RESULTS



SOA x Congruency (F(5,24)=2.3, p<.05)

Behavioral evidence for a close connection between numbers and space

RESULTS



Positive Slope: 1.7; $t(24) = 2.68, p < .01$

Negative Slope: -1.5; $t(24) = 1.7, p < .05$

Behavioral evidence for a close connection between numbers and space

Facilitation is followed by IOR



Behavioral evidence for a close connection between numbers and space

Facilitation is followed by IOR



- Criteria for **automaticity** are still **not all fulfilled** -

Visuo-spatial attention shifts following numbers:

- are relatively **slow** to emerge
→ facilitation around 650 msec (present study)
- are **greatly influenced** by task instructions and context (task set)
→ e.g. Galfano et al., 2006; Ristic et al., 2006; Bächtold et al., 1998

Numbers induce **unintentional** visuo-spatial attention shifts
(see also Pratt and Hommel, 2003)

Neuro-functional evidence for a close connection between numbers and space

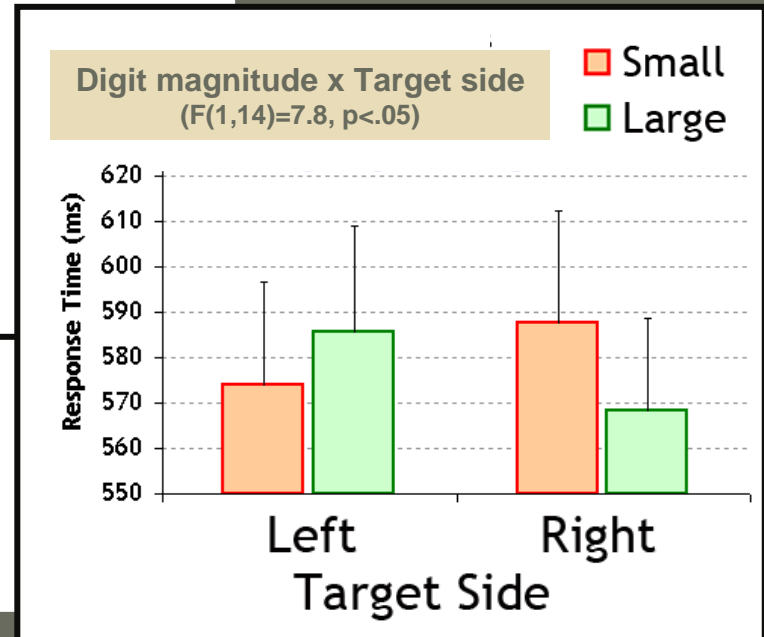
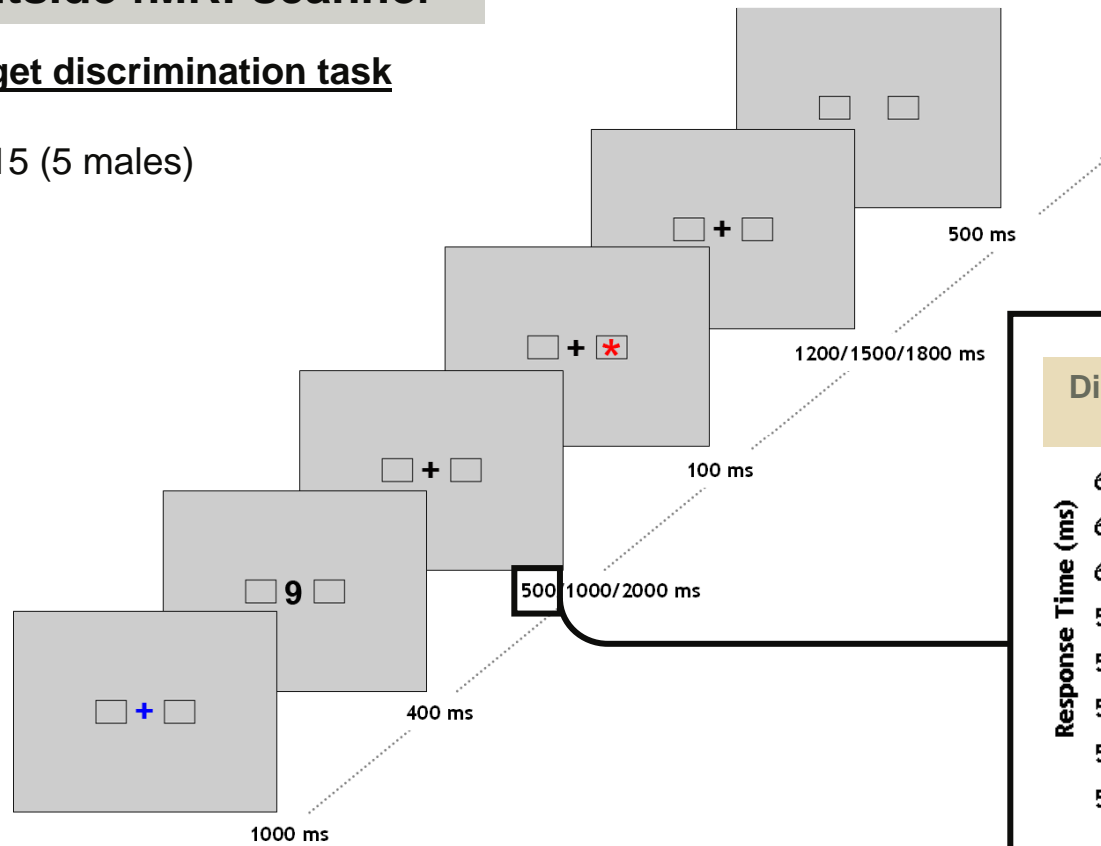
Neuro-functional evidence for a close connection between numbers and space

METHODS & Behavioral RESULTS

- Outside fMRI-scanner -

Target discrimination task

N= 15 (5 males)



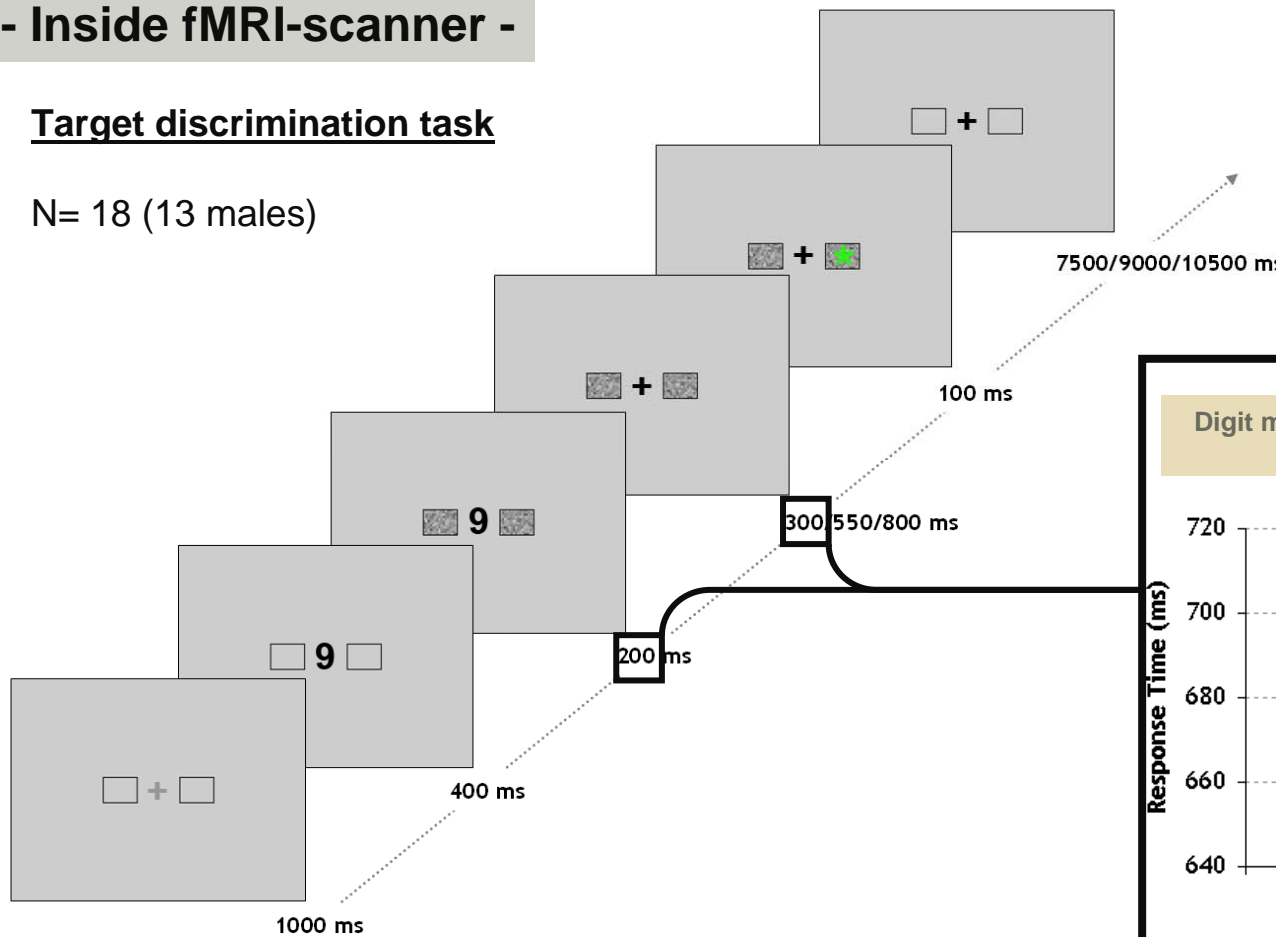
Neuro-functional evidence for a close connection between numbers and space

METHODS & Behavioral RESULTS

- Inside fMRI-scanner -

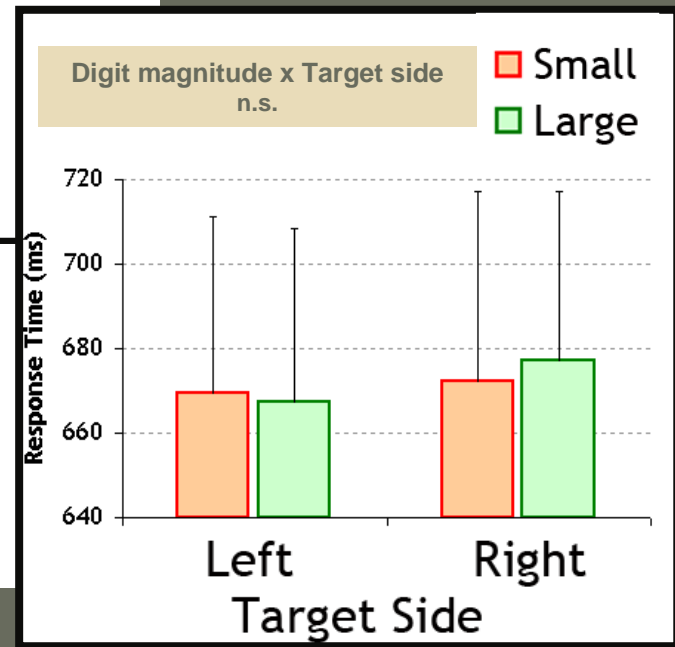
Target discrimination task

N= 18 (13 males)



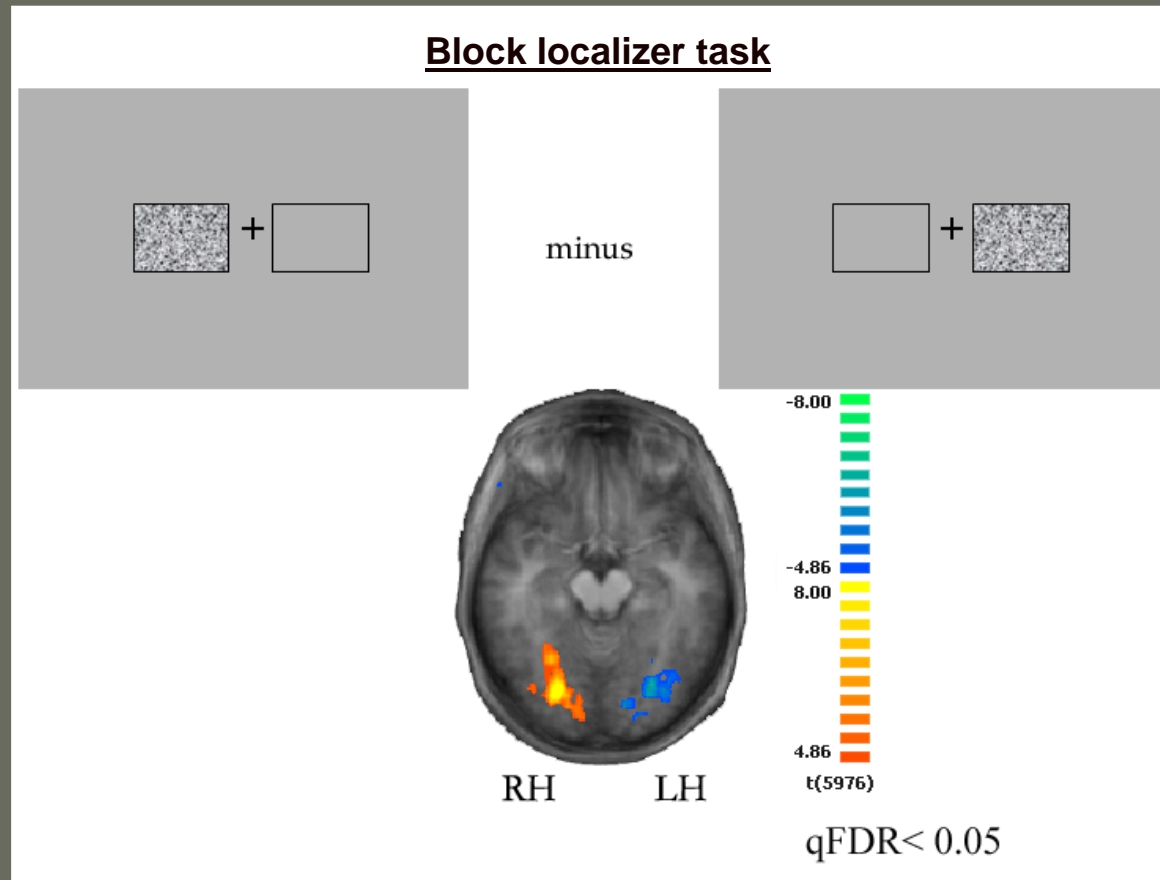
3T fMRI (MBIC, UniMaas)

- 25 slices of 5 mm
- TR 1500 ms



Neuro-functional evidence for a close connection between numbers and space

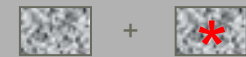
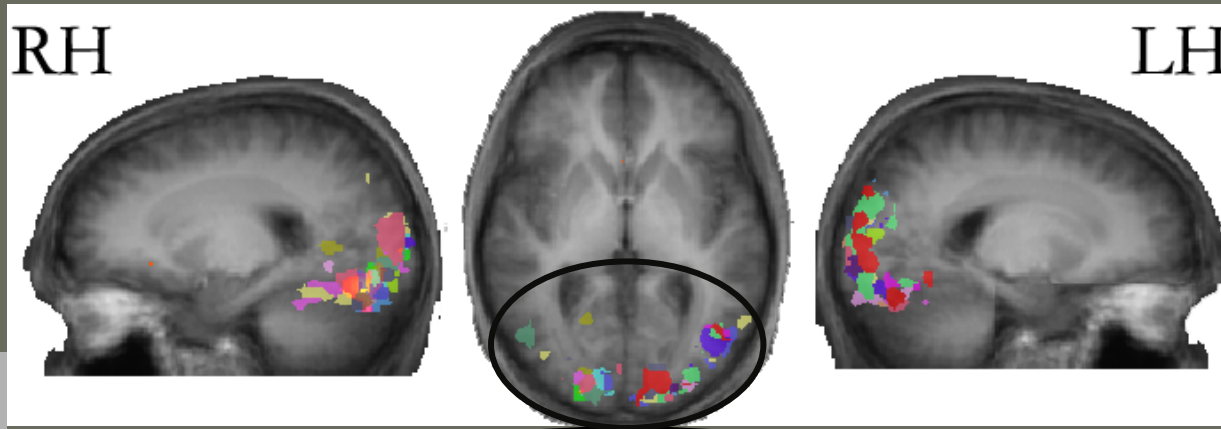
METHODS: Individual occipital ROIs



Visual ROIs responding to the contra-lateral visual stimulation
(qFDR < 0.05 , size > 4 voxels)

Neuro-functional evidence for a close connection between numbers and space

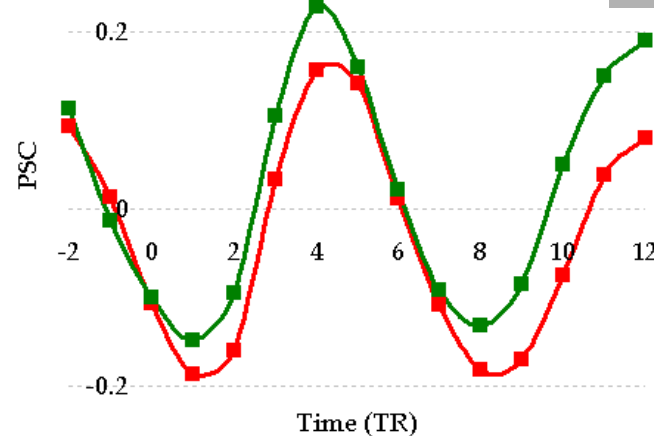
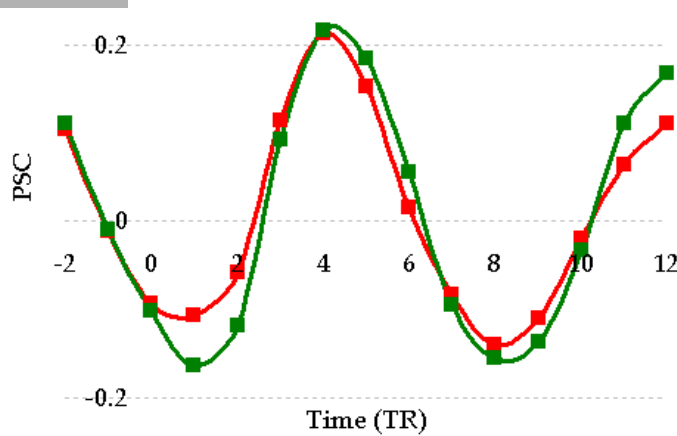
RESULTS: Attentional enhancement of occipital BOLD response by Arabic digits



Left target

—■ Small Digit (1, 2)
—■ Large Digit (8, 9)

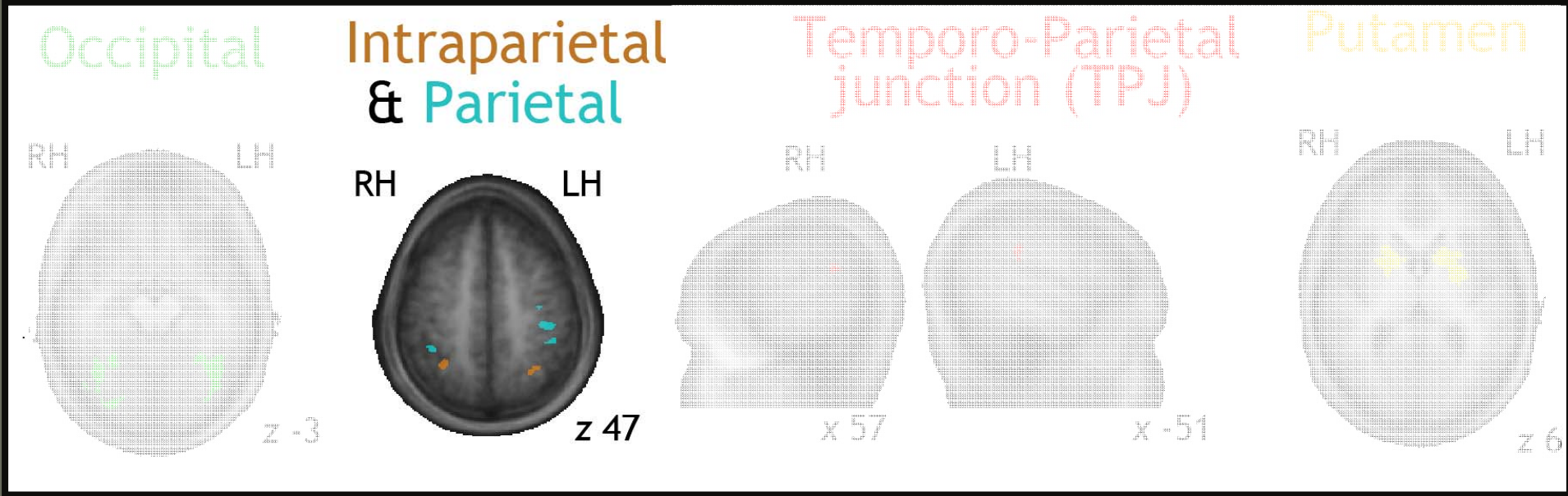
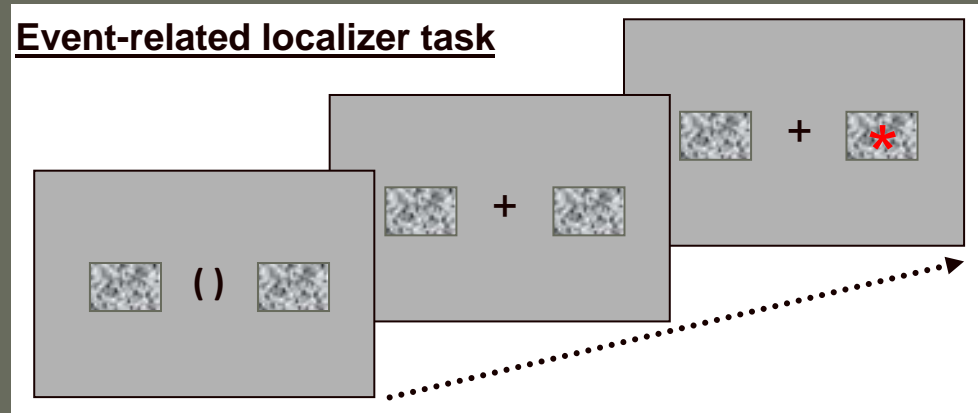
Right target



Digit magnitude x Target side ($F(1,15)=4.5, p<.05$)

Neuro-functional evidence for a close connection between numbers and space

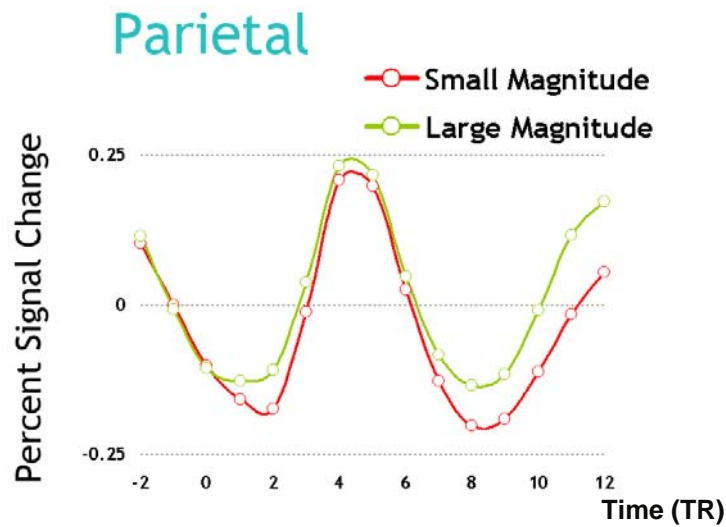
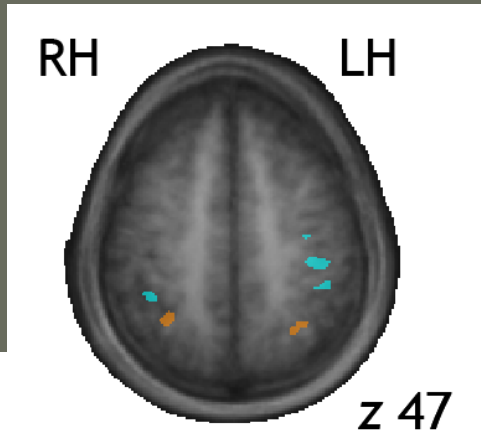
METHODS: ROIs related to target discrimination



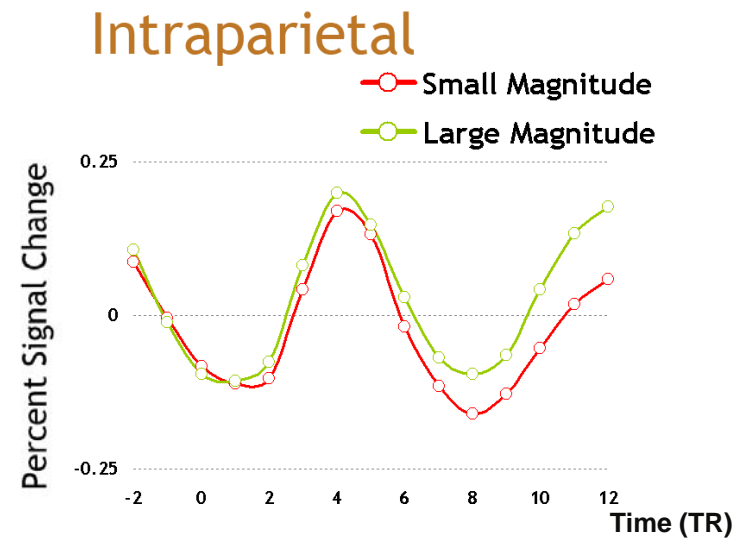
ROIs activated by target discrimination task (p uncor < 0.0001 , size > 4 voxels)

Neuro-functional evidence for a close connection between numbers and space

RESULTS: Magnitude modulation of parietal BOLD response



8,9 > 1,2



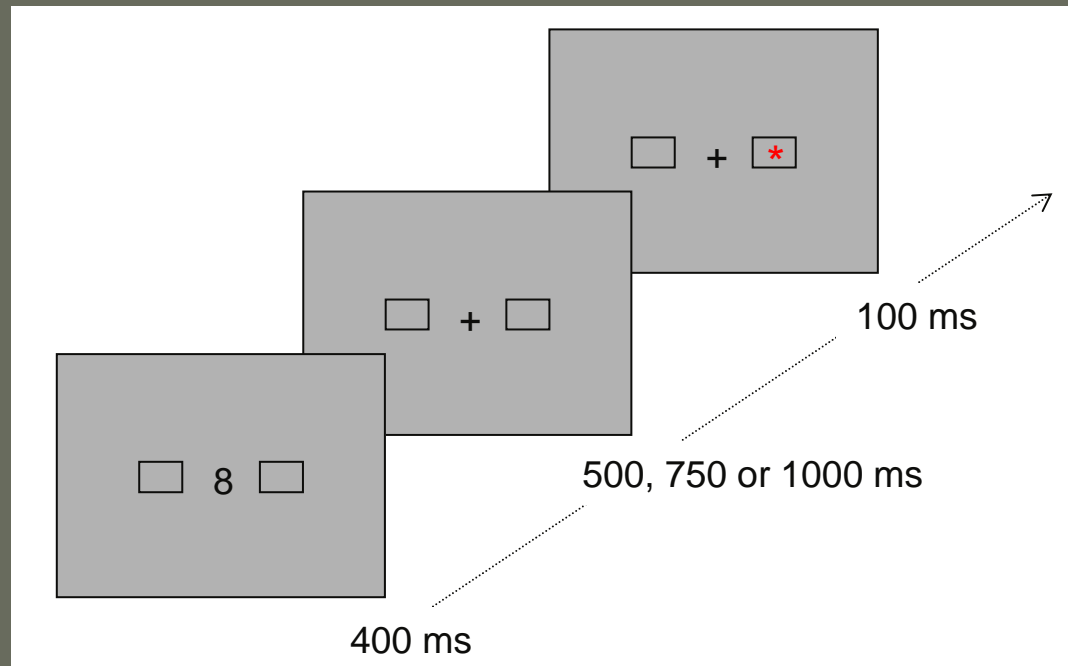
Main effect of Digit Magnitude ($F(1,13)=5.555, p<.05$)

Neuro-functional evidence for a close connection between numbers and space

Automatic magnitude processing (in parietal cortex)

→ induces unintentional visuo-spatial attention shifts

→ that result in enhanced visual responses (in occipital cortex)



Lateral target detection/discrimination task

Evidence for a close connection between numbers and space

DISCUSSION

- **Number-space association** revealed in the present paradigm:
 - Is a default mode that arises unintentionally
 - That can easily be affected by :
 - Task context and instructions (cf. Ristic et al., 2006)
 - Developmental stage (cf. Van Galen and Reitsma, 2008)
 - Personal talent and training with numbers?
- **Future questions:**
 - How specific to numbers vs. other types of ordered sequences?
(cf. Dodd et al., 2009)
 - What is the critical role of working memory?
(Previtali et al., 2010; Van Dijk and Fias, 2011)

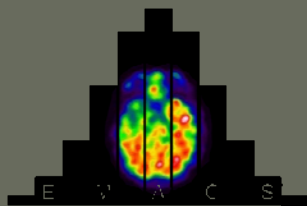
Sehen ist Denken *

(Richard Serra)



* To see is to think

Thank you for your attention



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