

Combinatorial Semantics is Computed in the Left Anterior Insula and is Modular

Yosef Grodzinsky^{1,2}, Galit Agmon¹, Yonatan Loewenstein¹ and Isabelle Deschamps³

[1] The Hebrew University of Jerusalem, Israel

[2] Forschungszentrum Jülich, Germany

[3] Université Laval



Goal:

To study the temporal dynamics and neural relation between 2 worlds –
the **perception of quantity** and the **processing of quantity expressions**

Theoretical tools

Weber's Law and the analysis of natural language quantifiers

Experimental Paradigm

Verification with quantifiers and analogous non-linguistic symbols

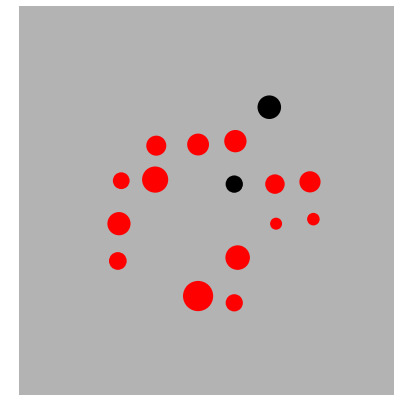
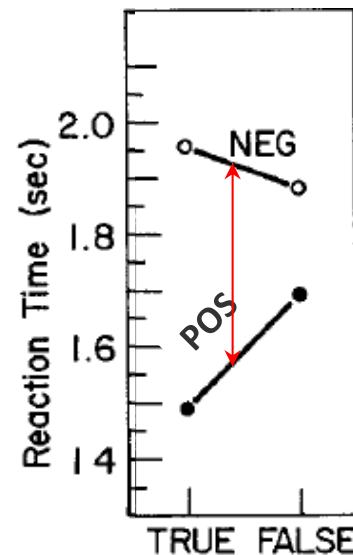
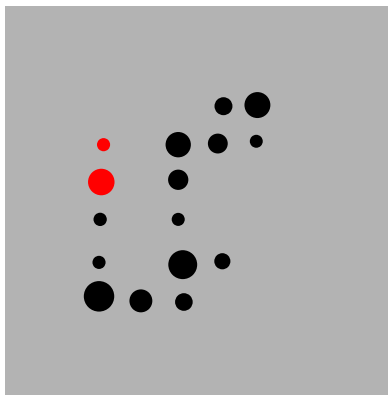
Multi-Modal Measurements

RT, error rates in Broca's aphasia, fMRI signal intensity

Take home message

Extreme language/math Modularity is found in the brain in both health and
brain disease

*The linguistic landscape:
Verification with degree quantifiers and numerosity-containing scenarios*



(1) a. **Many** of the dots are black

≈

b. **Few** of the dots are red

J&C:

- *Decomposition*

Many dots are red

NEG(few) dots are red

NEG(many) dots are red

Few of the dots are red

Arguments for the claim that **few**=NEG(**many**):

“Negative”, but not “Positive” quantifiers reverse entailment patterns

(2) a. **Many** of the students worked hard \Rightarrow b. **Many** of the students worked

(3) a. **Few** of the students worked hard \Leftarrow b. **Few** of the students worked

“Negative” but not “positive” quantifiers license NPIs

(4) a. **Less-than-half** of the students *ever*_{NPI} climbed Mount Everest **good**

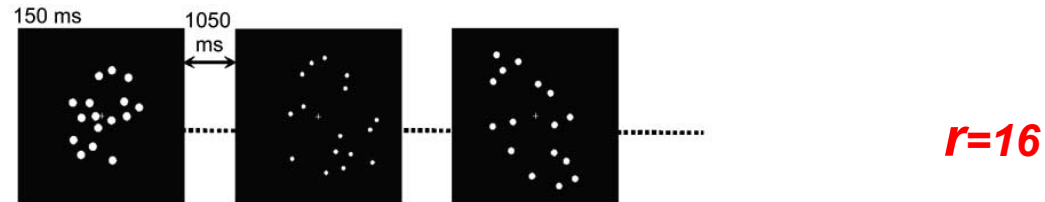
b. **More-than-half** of the students *ever*_{NPI} climbed Mount Everest **odd**

(5) a. **Less-than-half** of the students *lifted a finger*_{NPI} to help me **good**

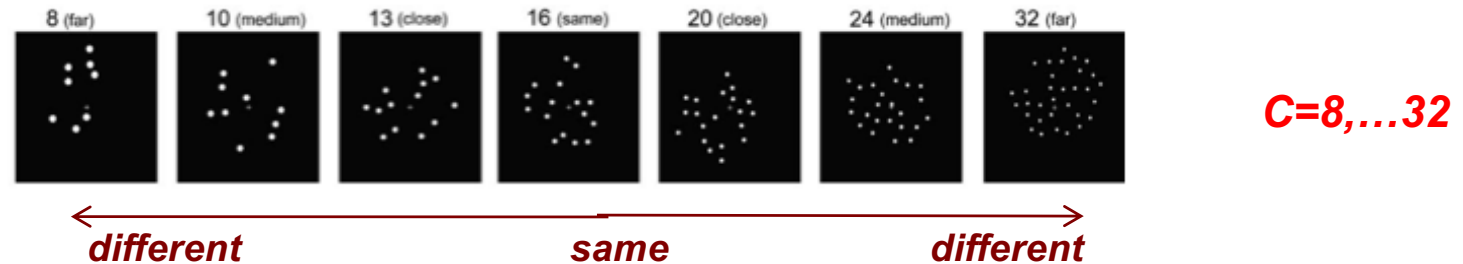
b. **More-than-half** of the students *lifted a finger*_{NPI} to help me **odd**

The numerosity landscape: Verification of variable quantities

a. Stream of habituation of *reference* stimuli



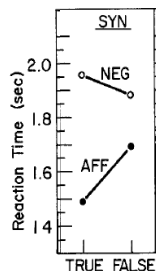
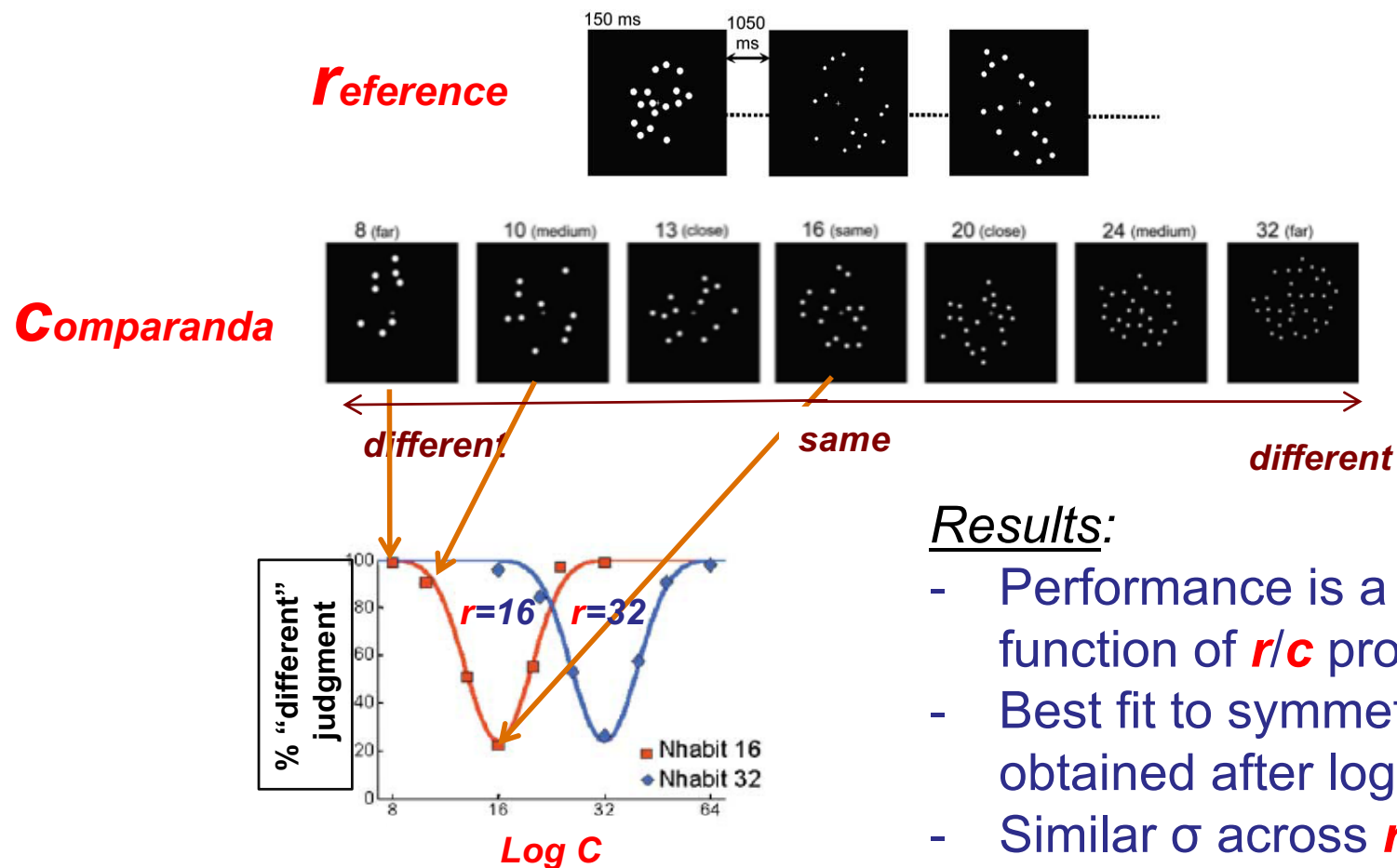
b. Occasional deviant *Comparandum* stimulus of varying numerosity



- c. Instructions: *indicate whether the fourth set was*
(global)
- *larger or smaller than the preceding ones*
 - *same as the preceding ones*
 - *different from the preceding ones*

- d. Expectations: - *performance in keeping with Weber's Law*
- *no effect of instructions on performance: $r > c < r$*

An example experiment



But instructions DO matter!

questions

- Is the “negative” quantifier processing effect general?
- Is it specific to language?
- What is the source of the contrast?

Structure of the experimental argument

- Extend the linguistic domain – **generality of effect**
- Set up parallel linguistic and non-linguistic instructions – **specificity**
- Set up a verification paradigm where scenarios depict variable proportions
– **perceptual-linguistic interactions**
- Seek the neural substrate for these computations

An RT experiment with the Parametric Proportion Paradigm (PPP)

(with Isabelle Deschamps, McGill. Galit Agmon & Yonatan Loewenstein, HUJI)



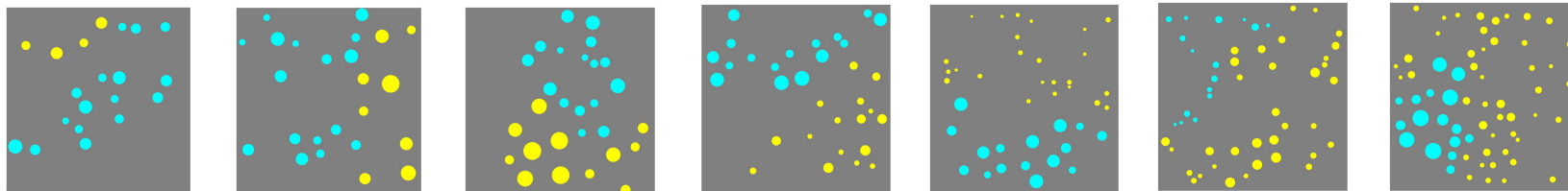
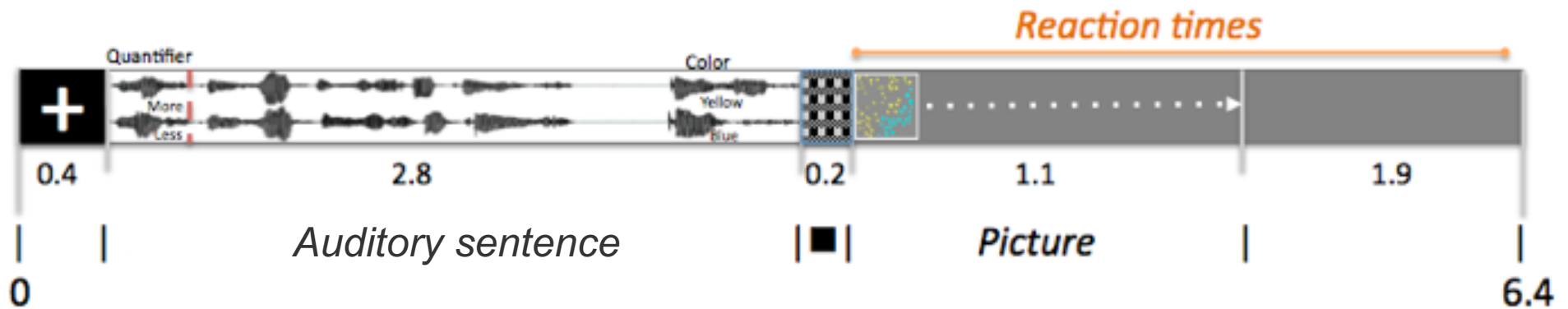
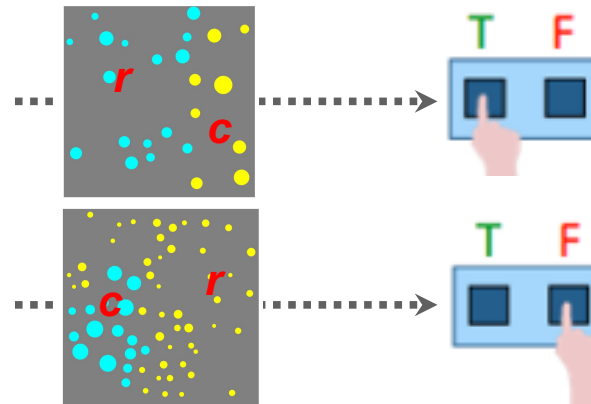
POS:

More-than-half of the circles are blue



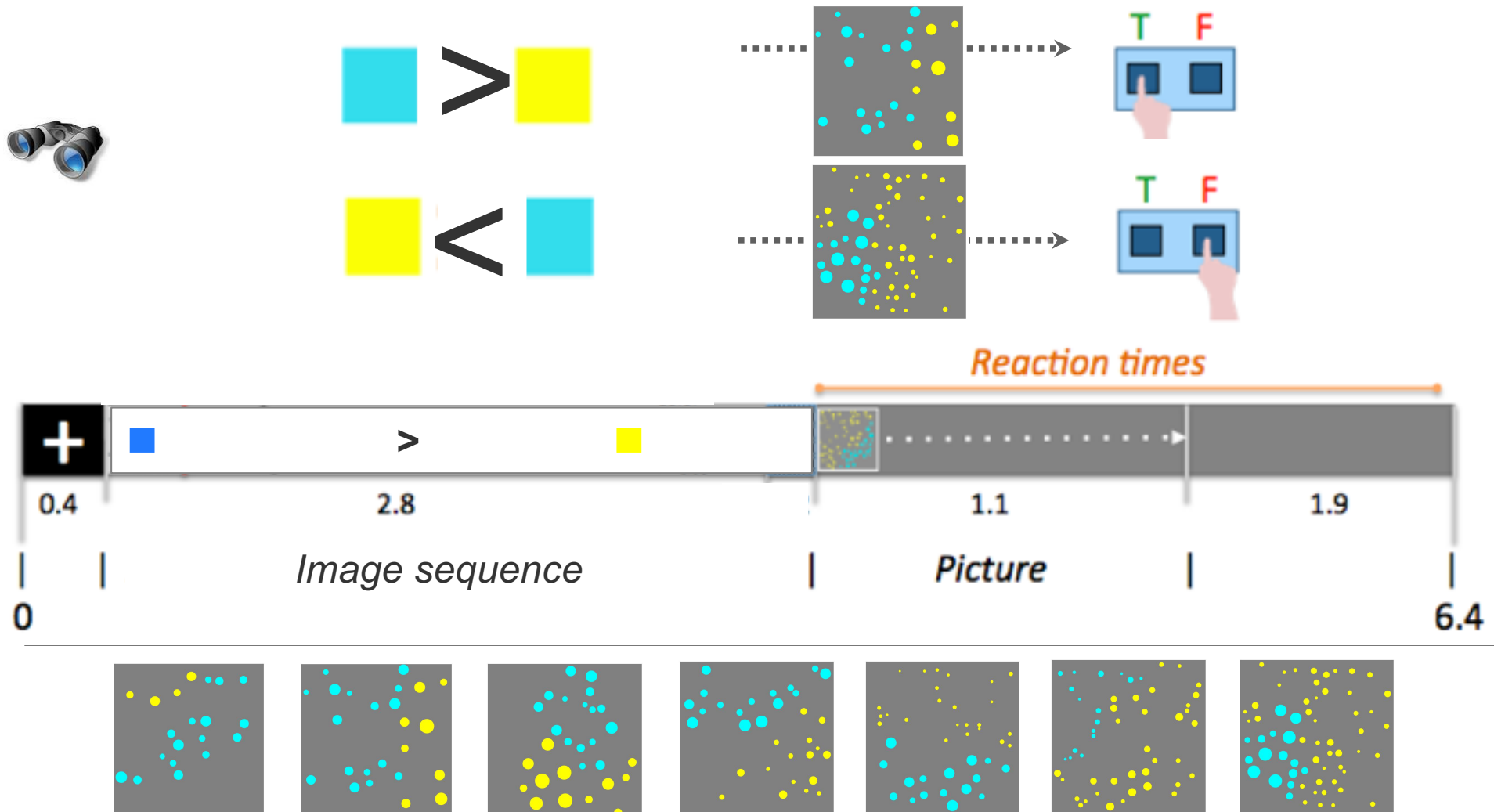
NEG:

Less-than-half of the circles are yellow



A non-verbal PPP: verification with symbols

“Your task is to determine whether the instruction matches the scenario in the image, and do so as quickly as you can”



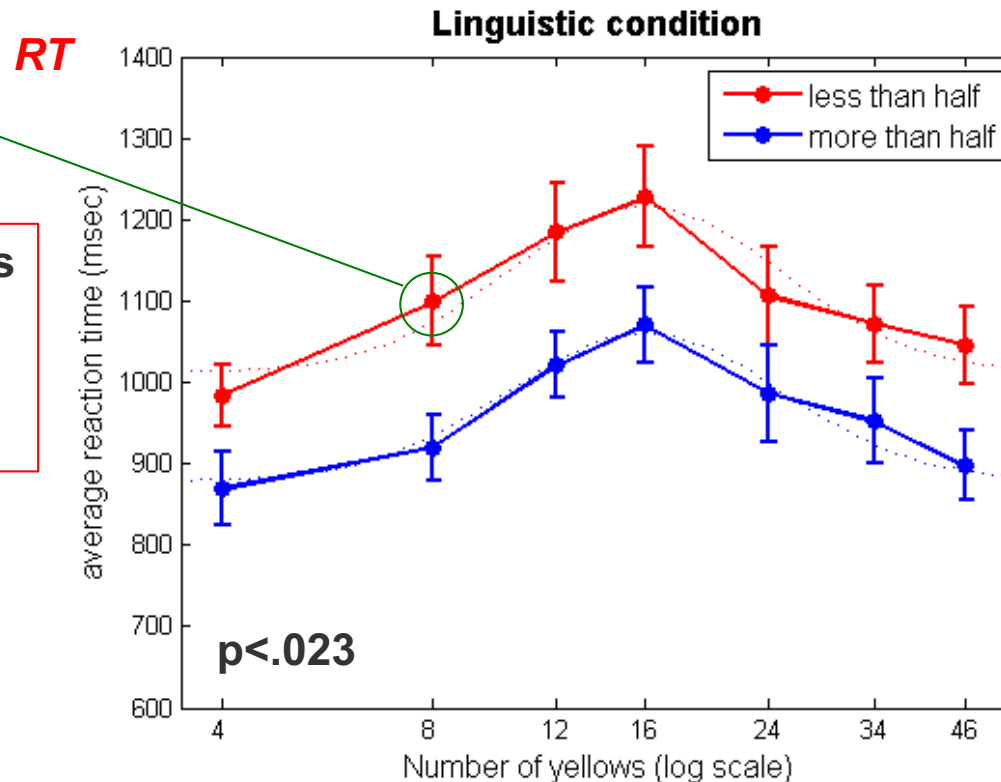
First PPP result: Polarity matters – RT functions

Splitting the
previous graph:
17 subjects X 2
quantifiers X 16
T/F 272= trials

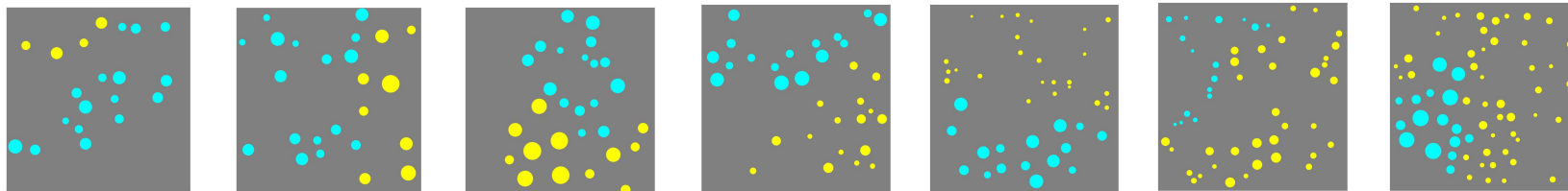
NB: same results
for $r=24$, and for
the *many/few*
contrast

Less than half of the circles are blue

More than half of the circles are blue



#yellow/16 Blue

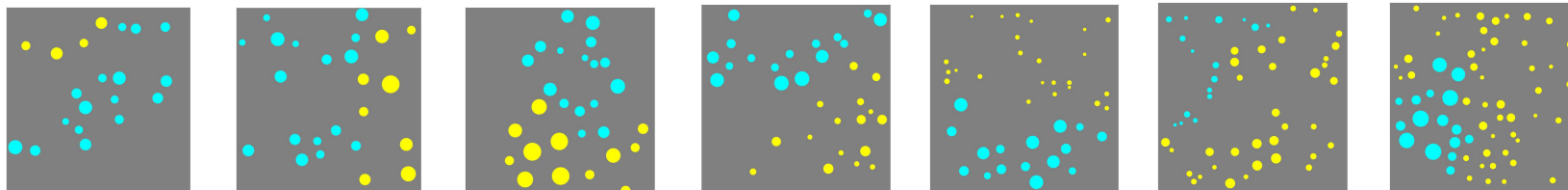
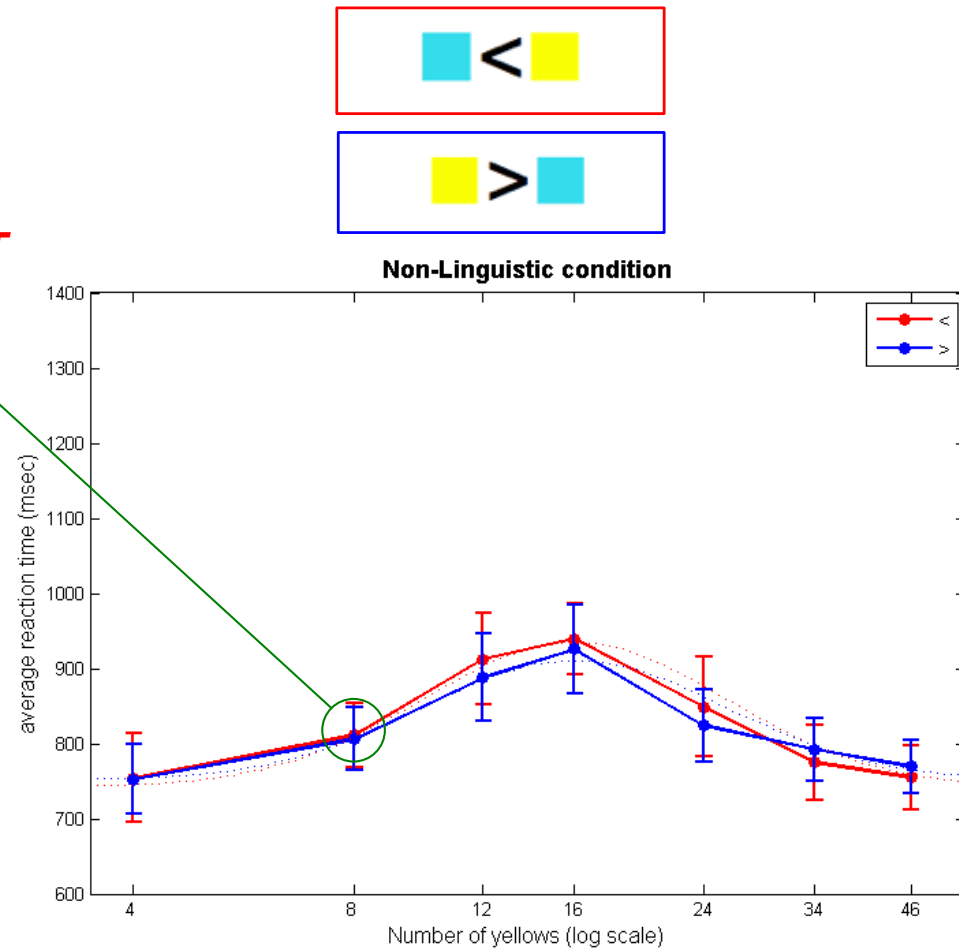


Second PPP result: verification with analogous symbols

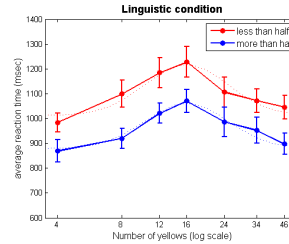
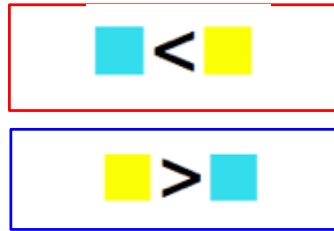
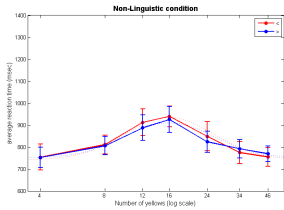
272 trials

RT

NB: same results
for $r=24$

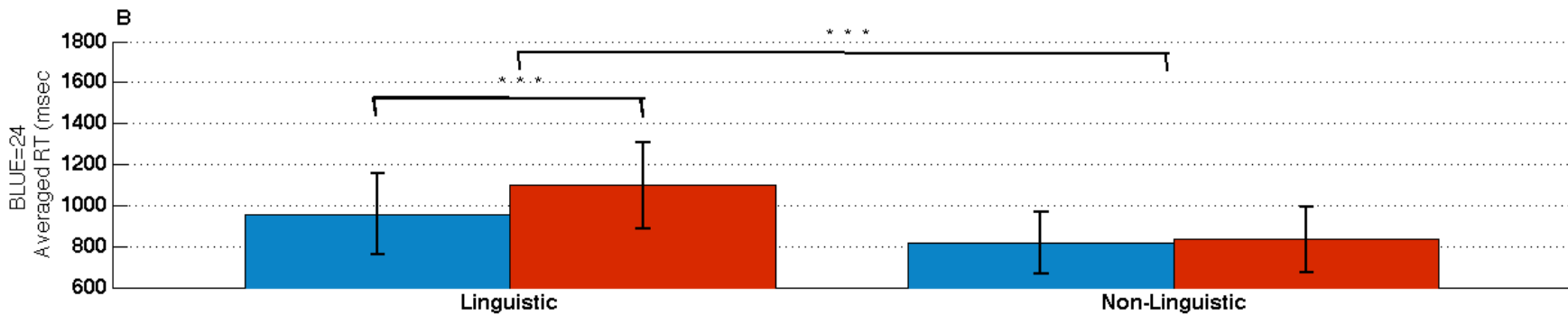
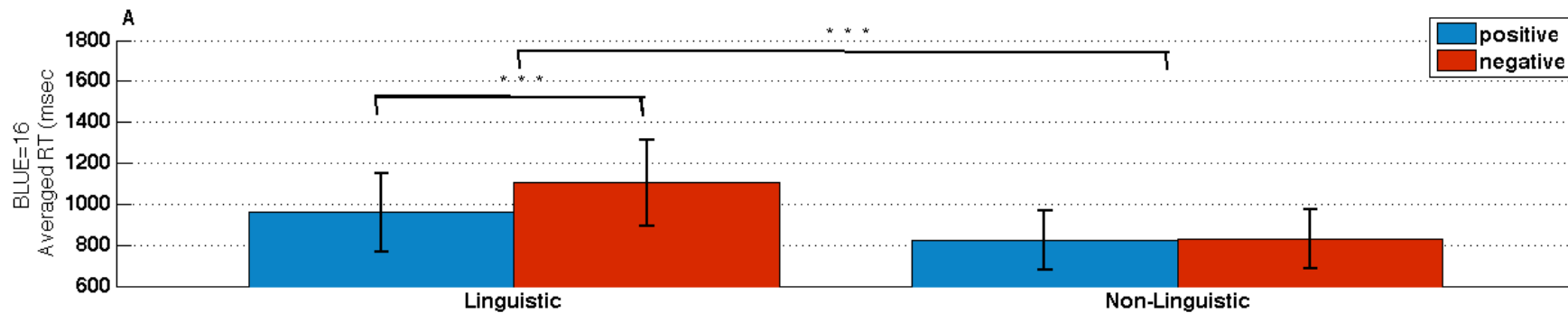


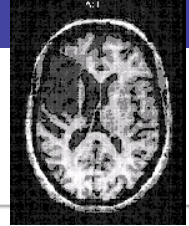
Third PPP result: Polarity \times linguistic interaction



Less than half of the circles are blue

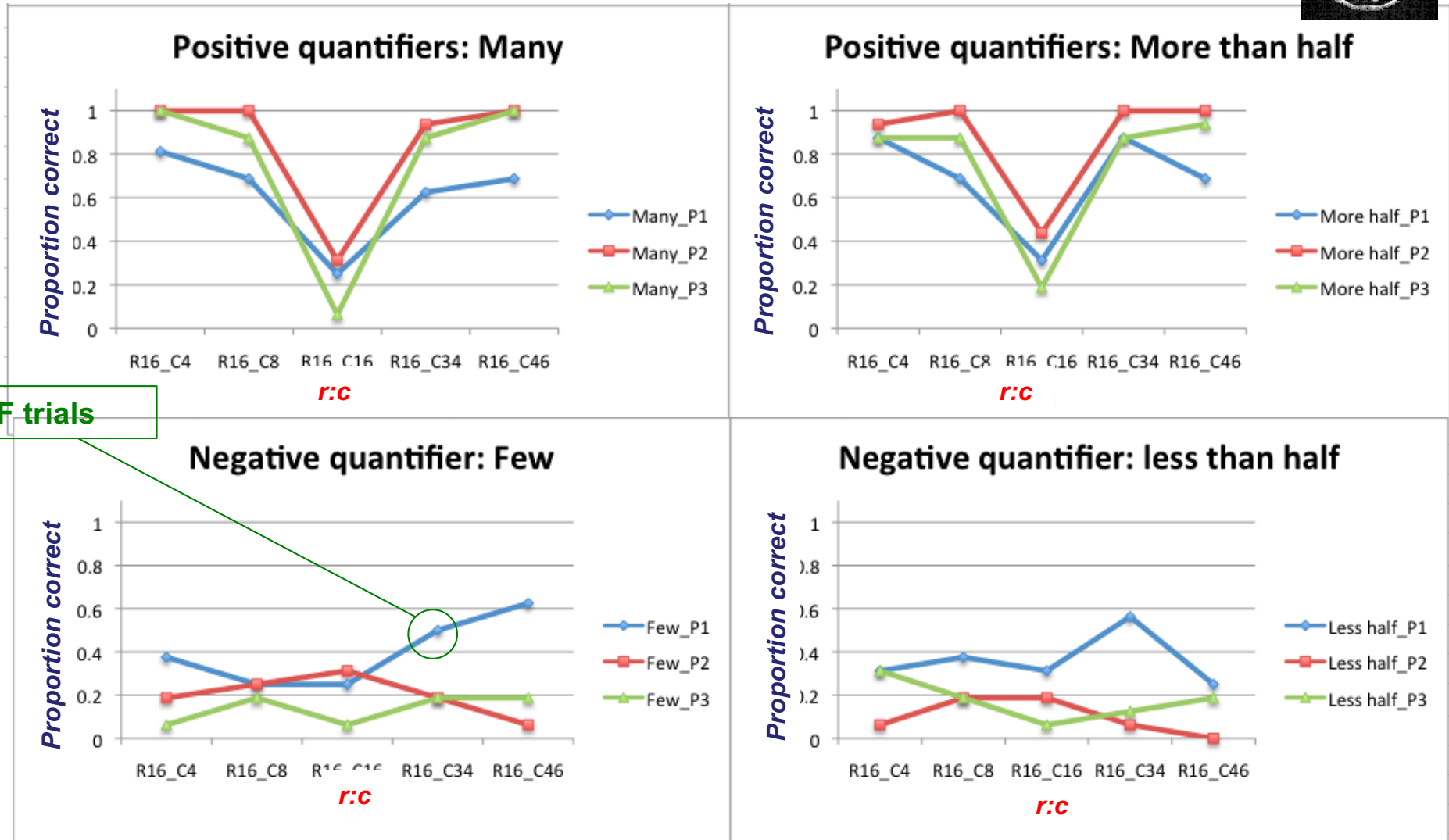
More than half of the circles are blue





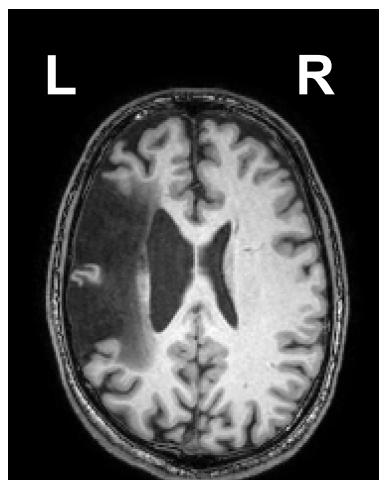
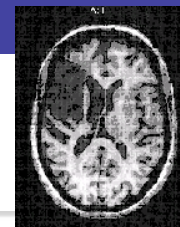
The PPP in Broca's aphasia

(with Virginia Jaichenco, Martin Fuchs, UBA, Isabelle Deschamps, Laval)

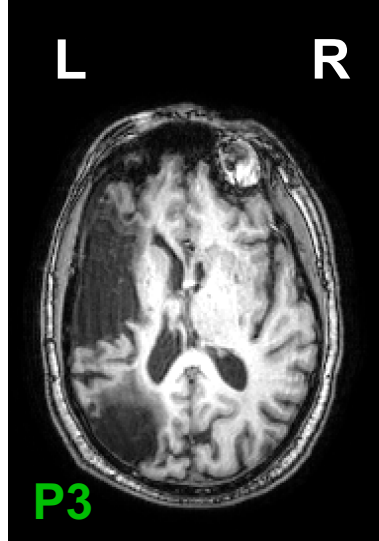


Individual patients' error pattern subsequent to a lesion in **Broca's region**

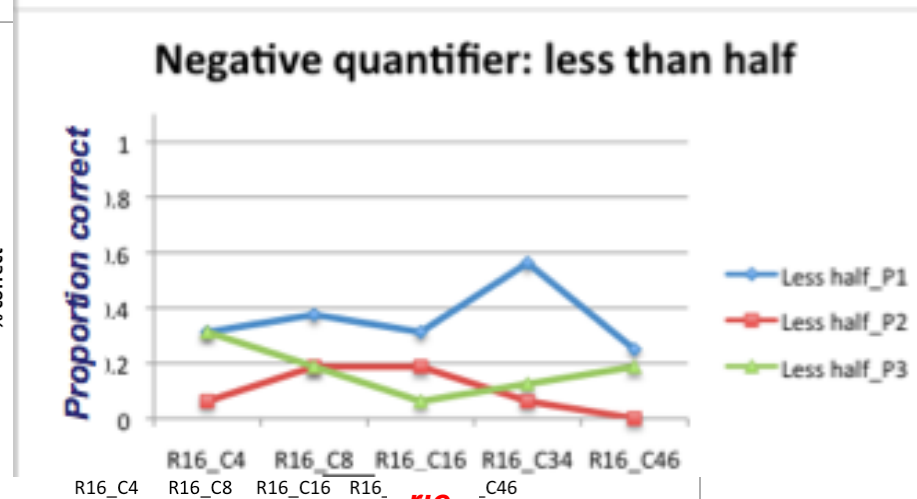
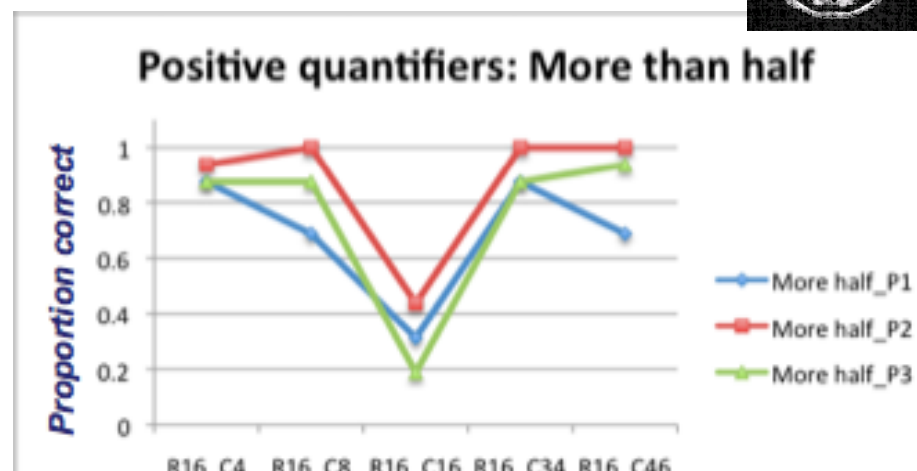
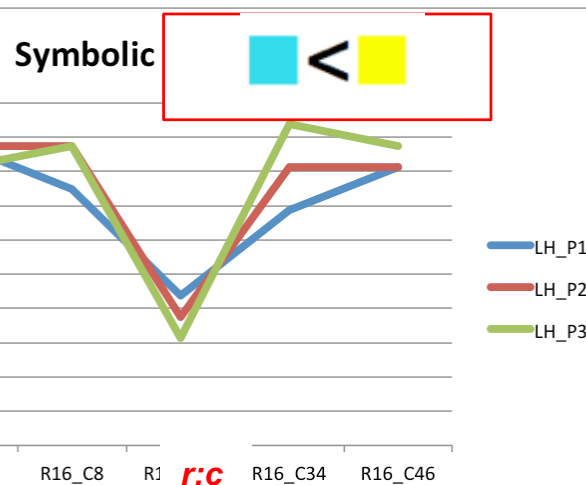
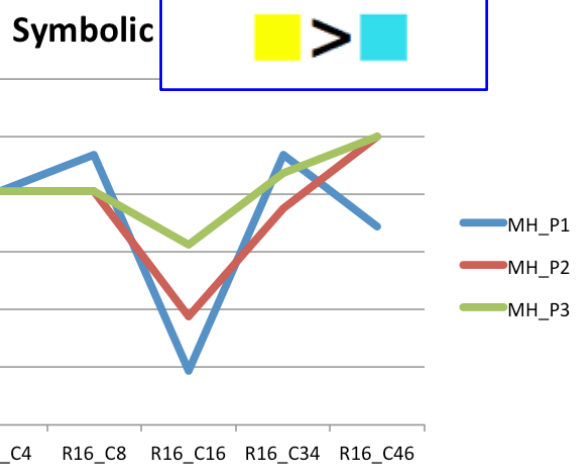
The PPP in Broca's aphasia – 3 patients



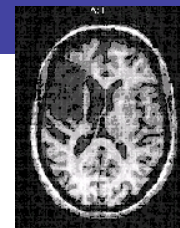
P2



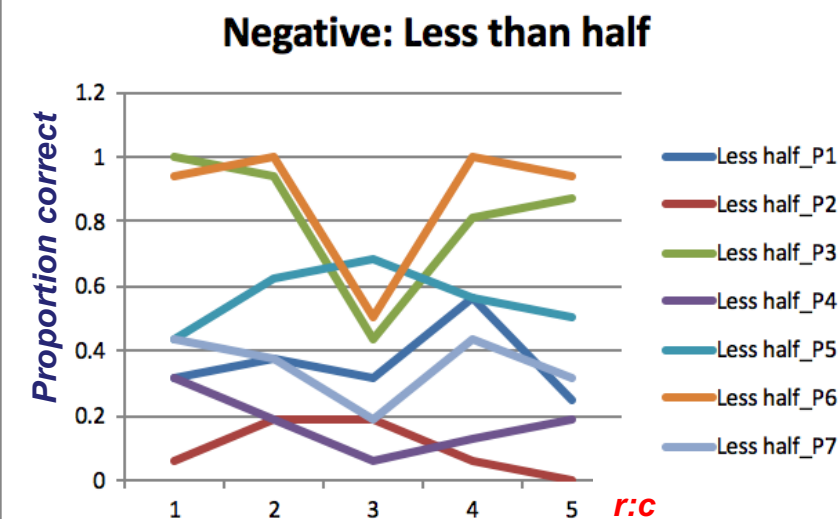
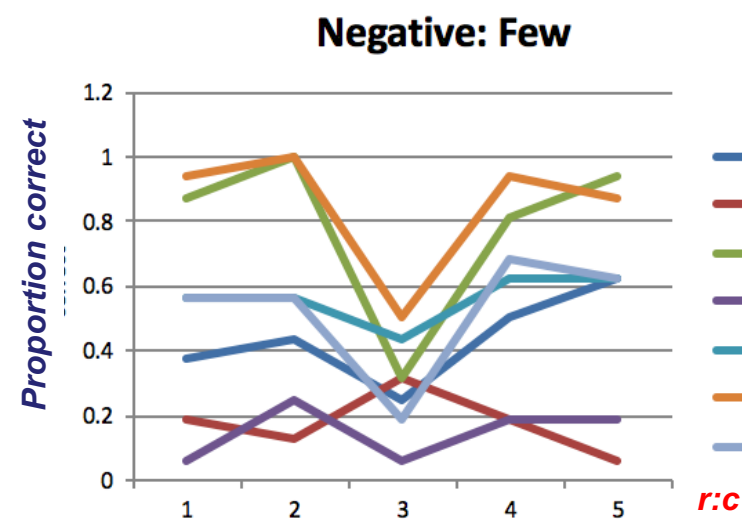
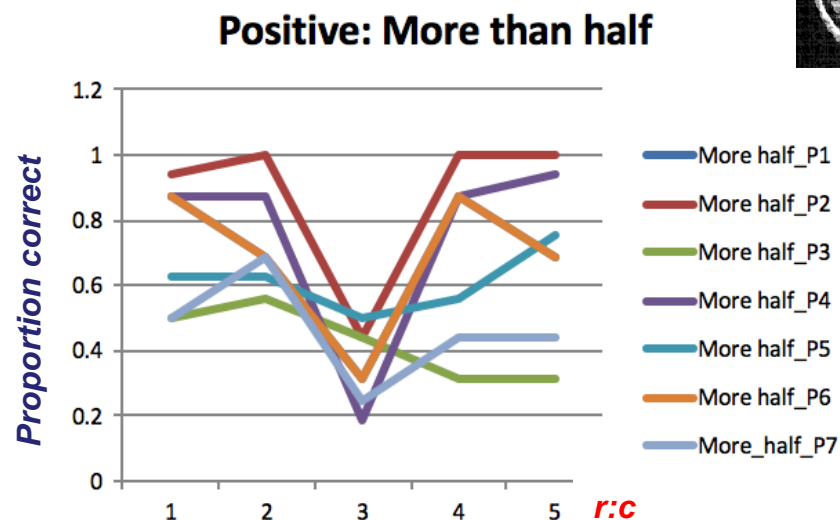
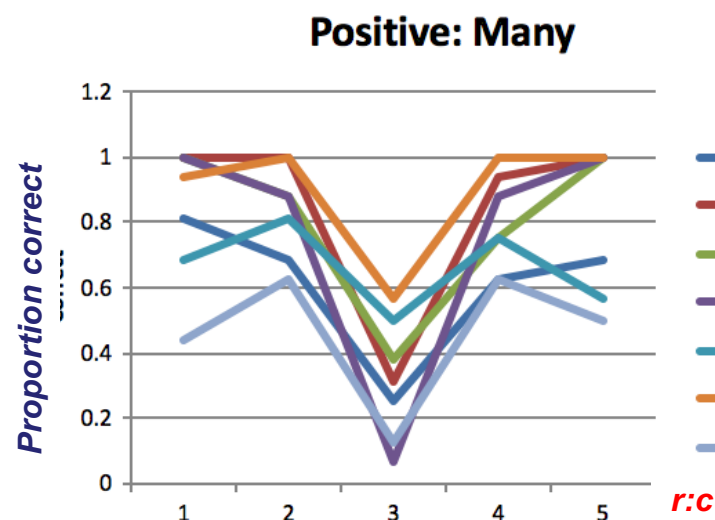
P3



Individual patients' error pattern subsequent to a lesion in **Broca's region**

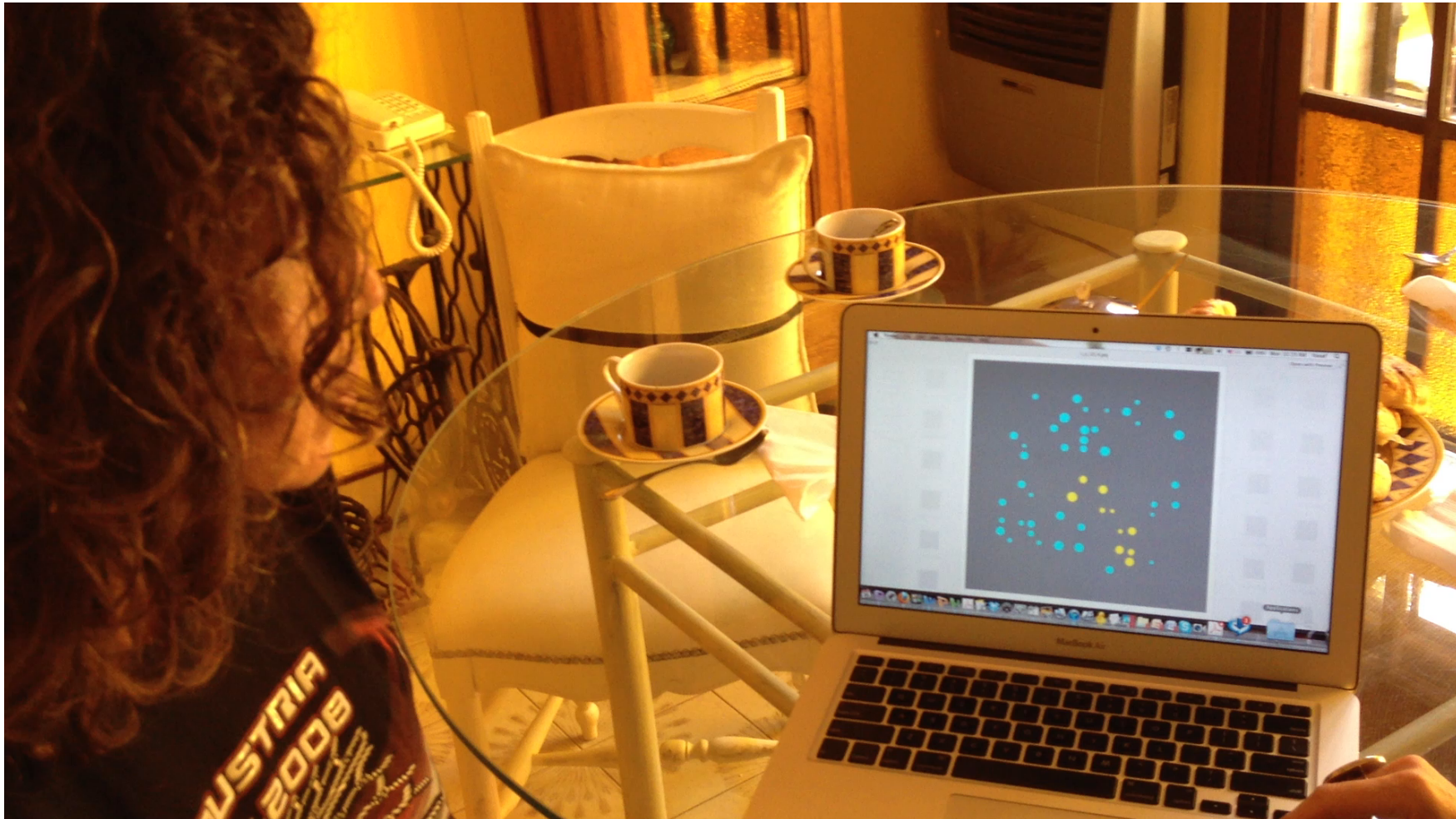


The PPP in Broca's aphasia – 7 patients



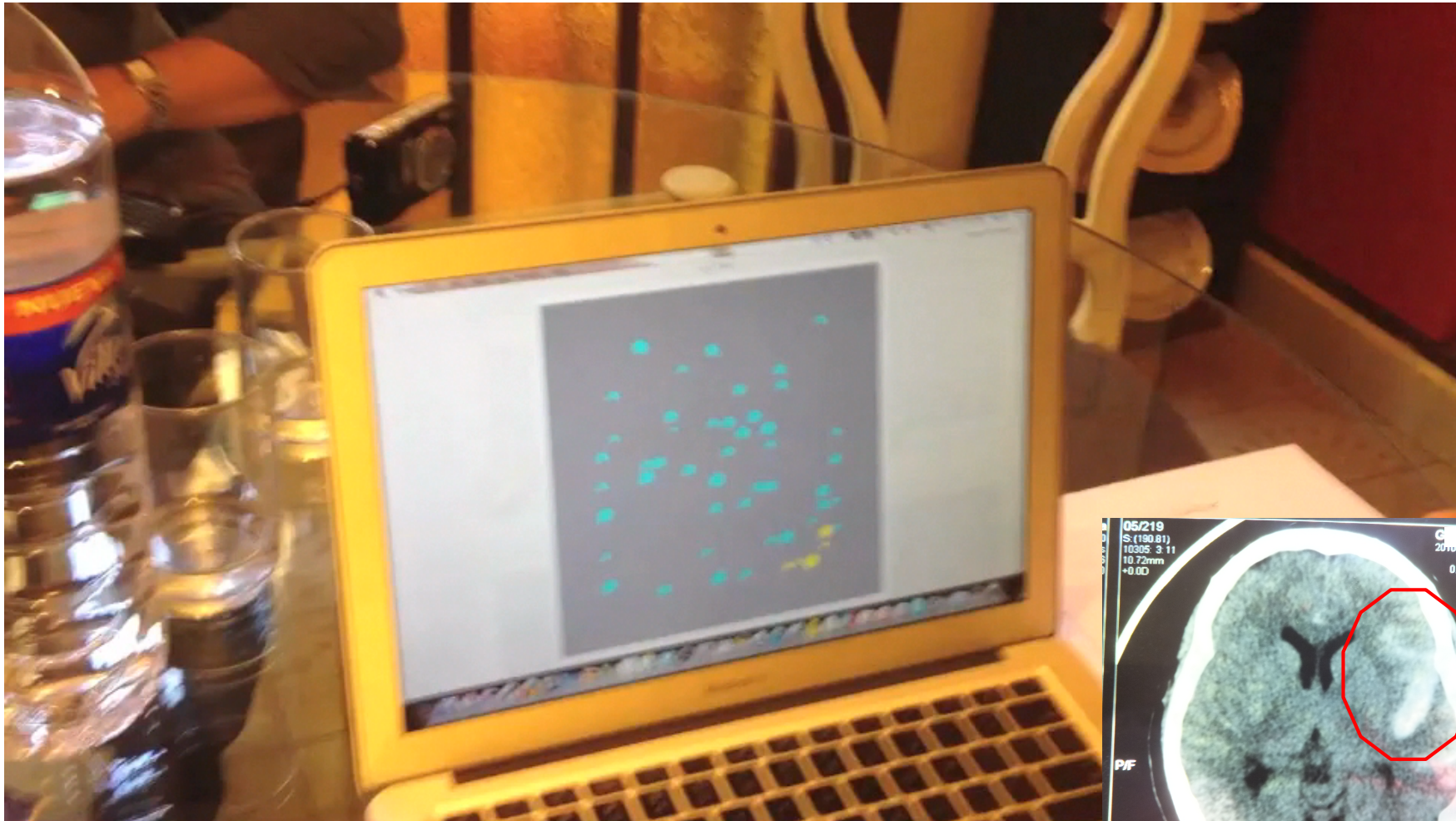
Individual patients' error pattern subsequent to a lesion in **Broca's region**

Patient demo – many (Spanish)



Many of the circles are blue (“YES”)

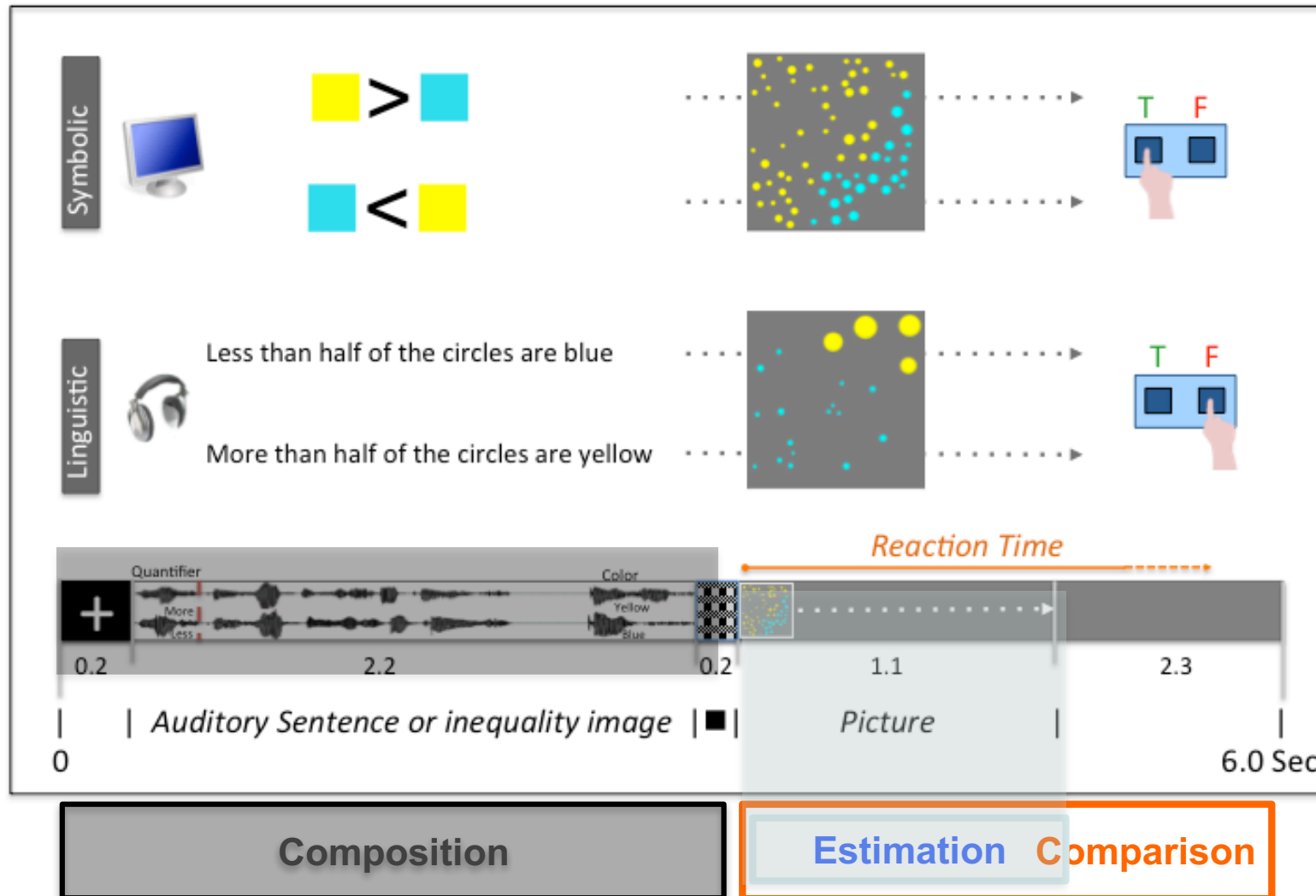
Patient demo – few (Spanish)



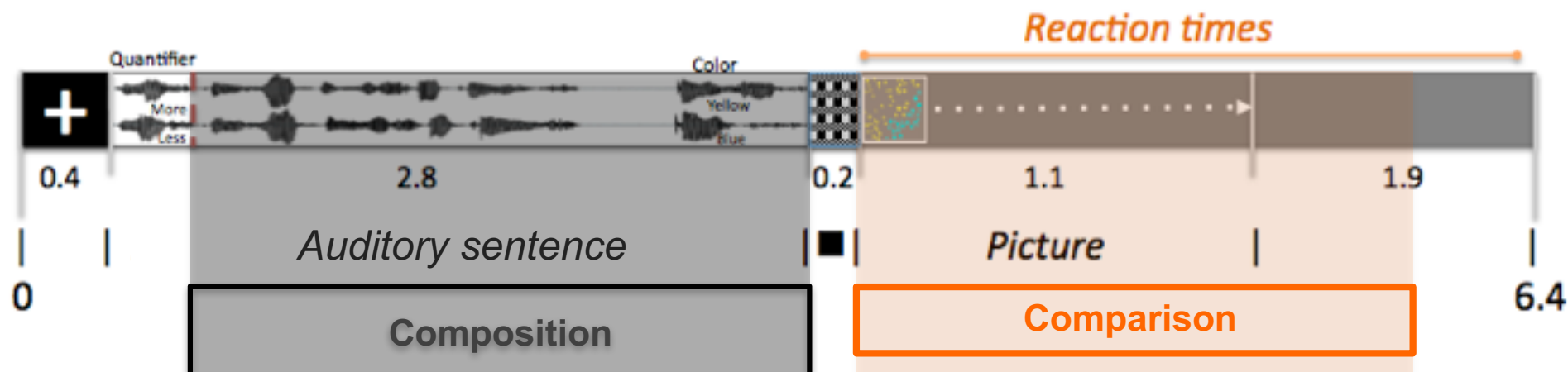
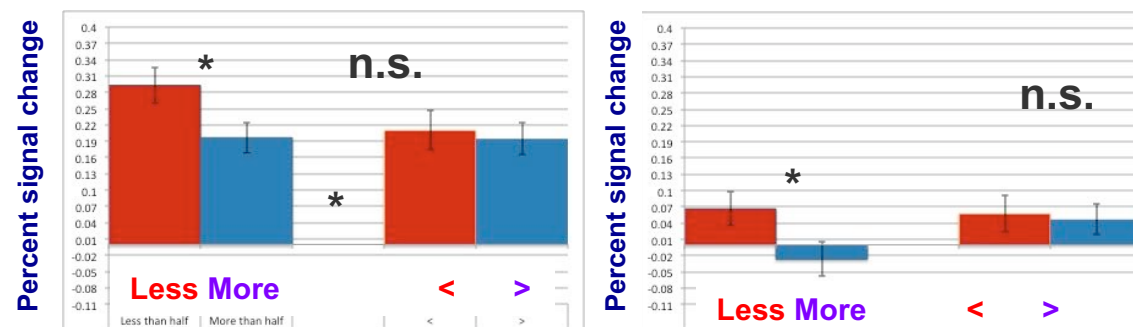
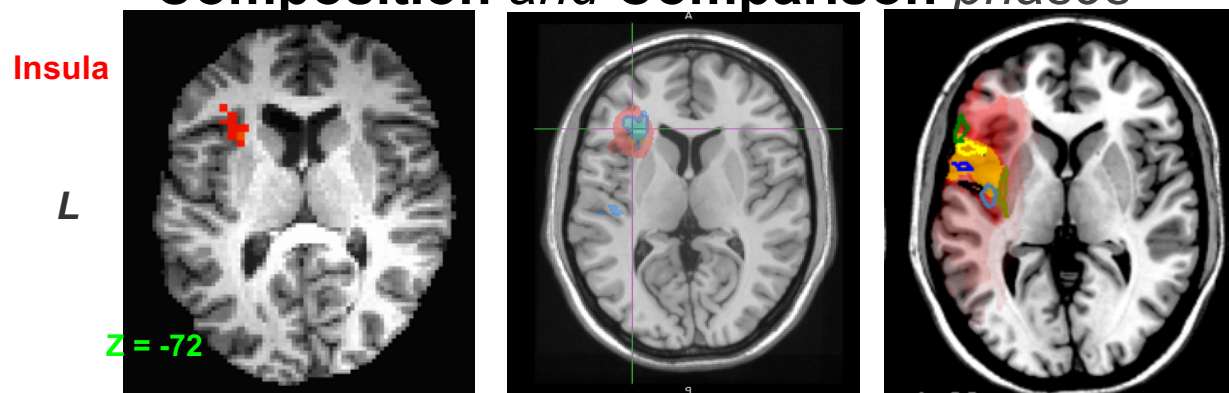
Few of the circles are blue (“

Modeling the HRF for each phase

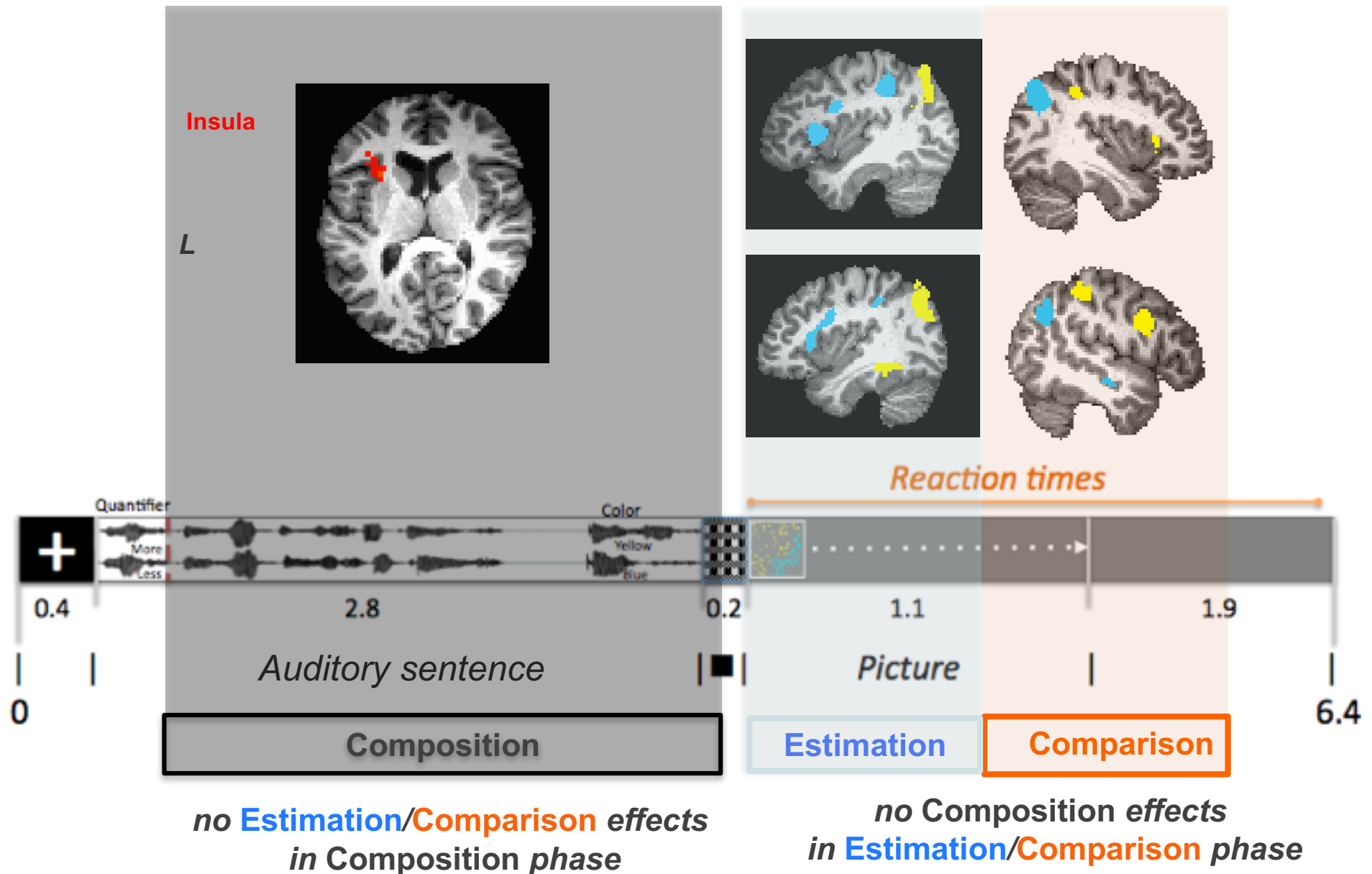
(with Isabelle Deschamps, McGill, Galit Agmon & Yonatan Loewenstein, HUJI)



Where we find **Instructions X Polarity** Interaction during the **Composition** and **Comparison** phases



*Strict Neural Modularity - **no** Language/math interactions:*



implications

- Our brains do arithmetic and talk about it in distinct ways, and distinct neural substrates
- A new locus for specialized linguistic activity is uncovered, supporting the processing of

the end

yosef.grodzinsky@mail.huji.ac.il

Funding:

NIH (NIDCD)

Canada Research Chairs (CRC)

SSHRC Canada

Humboldt Foundation

Research Award

Forschungszentrum Jülich

Israel Science Foundation

ELSC, HUJI



Collaboration:

Katrin Amunts, Stefan Heim,

Peter Pieperhoff

FZ Jülich

Virginia Jaichenco, Martin Fuchs,

María Elína Sanchez, Yamila Sevilla

UBA

Lew Shapiro, Tracy Love

UCSD-SDSU