

**If so many are "few", how
few are "many"?**

Stefan Heim

The eleventy-first birthday

*"I don't know half of you half as well as I should like;
and I like less than half of you half as well as you
deserve"*

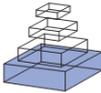
J.R.R. Tolkien 2007

Research questions

1. How are quantifiers processed?
2. Can quantifier semantics be manipulated?
3. How does the brain process quantifiers?
4. How does the brain process such changes?

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The language–number interface in the brain: a complex parametric study of quantifiers and quantities

Stefan Heim^{1,2,3,4*}, Katrin Amunts^{1,2,4}, Dan Drai⁵, Simon B. Eickhoff^{1,2,4,6}, Sarah Hautvast² and Yosef Grodzinsky^{2,7,8}

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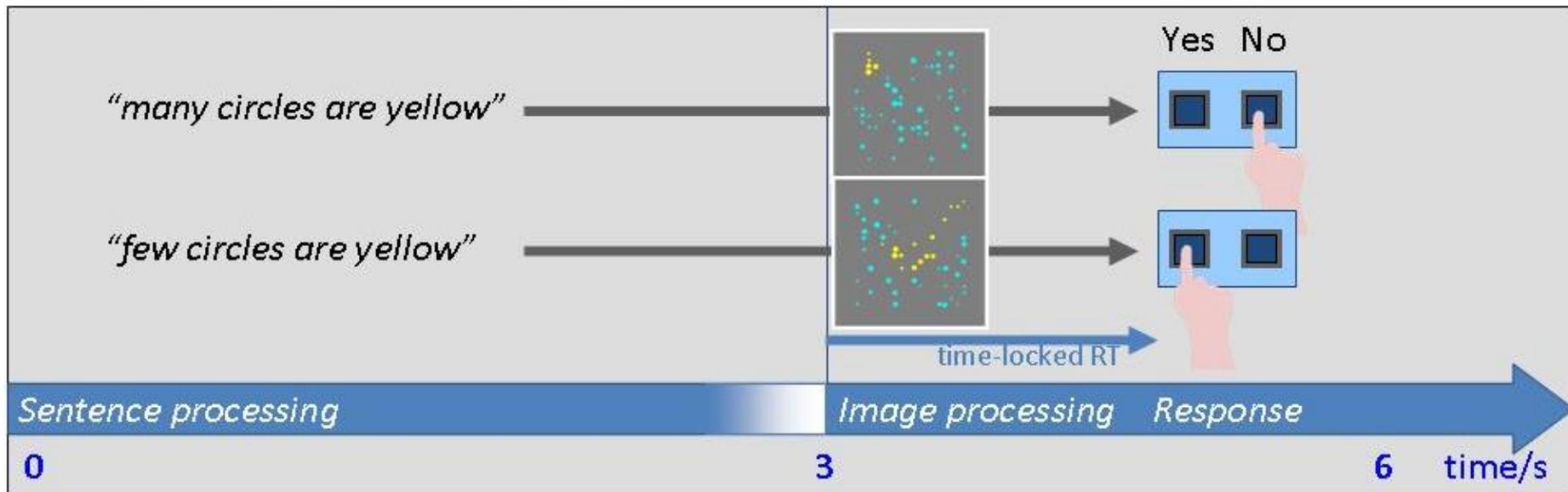
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⁶ Institut für Klinische Neurowissenschaften und Medizinische Psychologie, Heinrich-Heine Universität, Düsseldorf, Germany

⁷ Department of Linguistics, McGill University, Montreal, QC, Canada

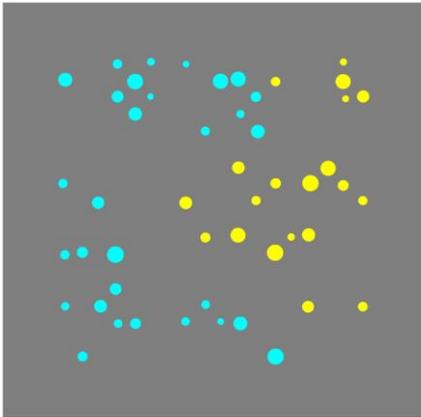
⁸ Department of Neurology/Neurosurgery, McGill University, Montreal, QC, Canada

A truth value judgement paradigm



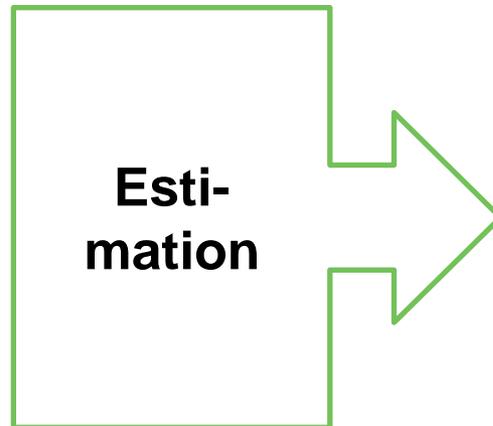
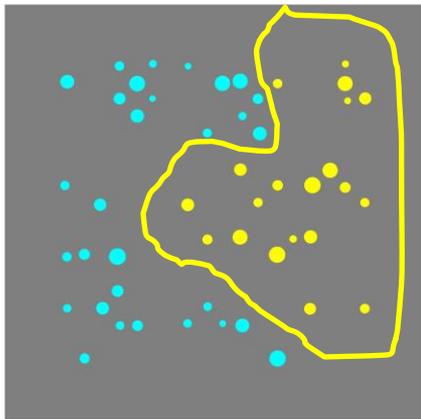
Quantifier processing

„most of the circles are yellow“



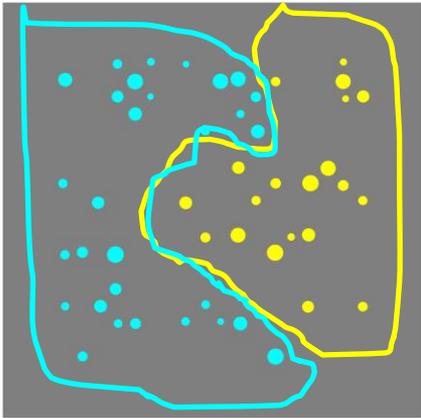
Quantifier processing

„most of the circles are yellow“



Quantifier processing

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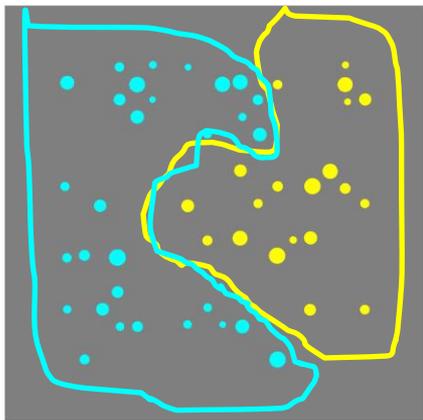


**Esti-
mation**

**Compa-
rison**

Quantifier processing

„most of the circles are yellow“



**Esti-
mation**

**Compa-
rison**

**Semantic
Evaluation**

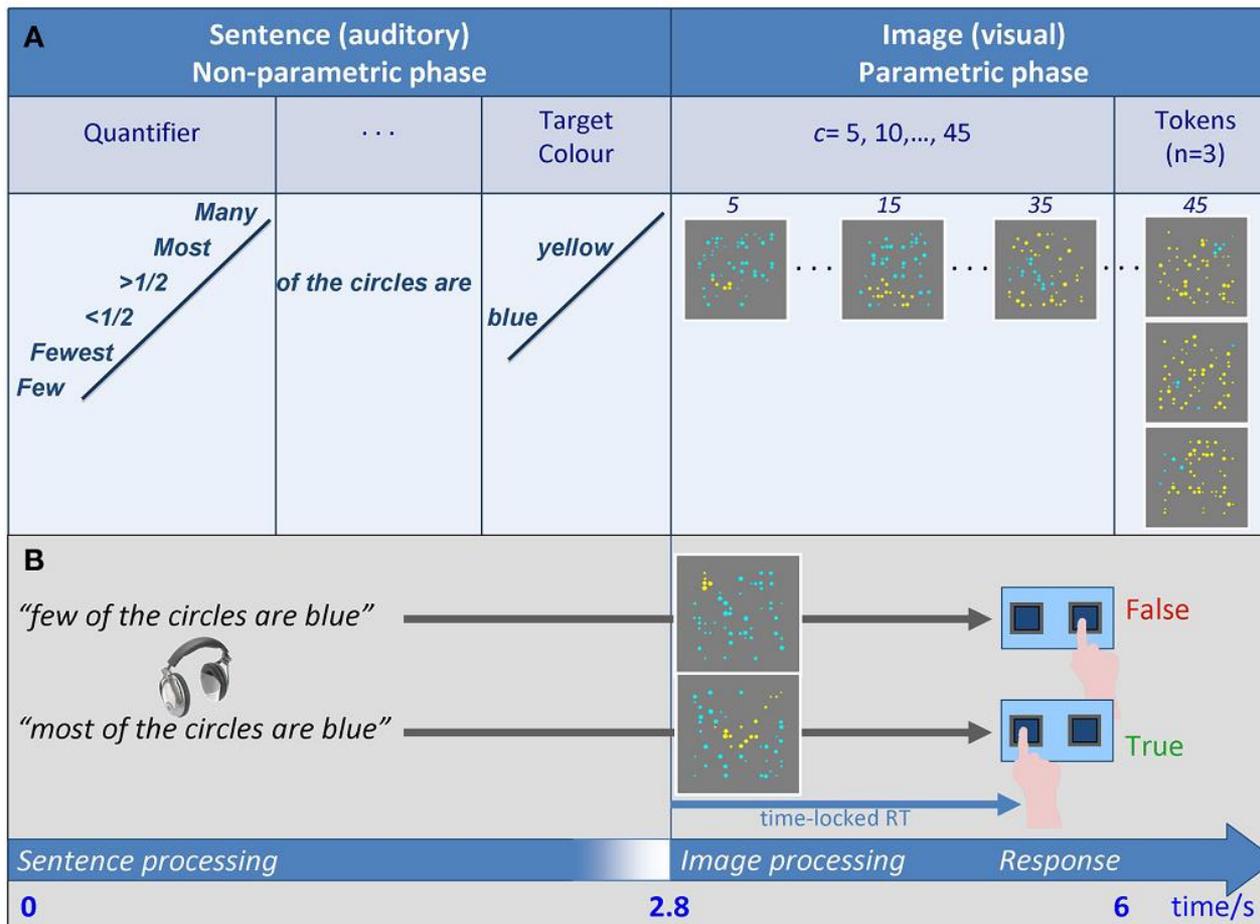


FIGURE 1 | Experimental design. (A) Overall design: Auditory sentence stimuli were of the form “*Quantifier* of the circles are *color*,” where *Quantifier* was one of six proportional quantifiers, and *color* was blue or yellow. Each of the 12 resulting sentences was followed by a visual array of a fixed numerosity $T = 50$ blue and yellow circles, in which blue/yellow ratio was varied parametrically: the comparandum numerosity c of circles in the *TarCol* was a parameter, taking the values 5, 10, ..., 45. As T was fixed, the numerosity of circles in the other color r varied accordingly (45,

40, ..., 5 out of 50). Three different tokens were generated for each proportion, and combined with the sentences. **(B)** Time course of a trial: The auditory part was 2.8 s long (sentence duration was ≤ 2.8 s). Subsequently, an image was presented (1.2 s). Participants were asked to make a truth-value judgment by a button press. RTs were time-locked to the visual phase of the trial, where overall trial duration was 6 s. Speeded responses were mostly < 2 s, which enabled a short rest period before the next trial began.

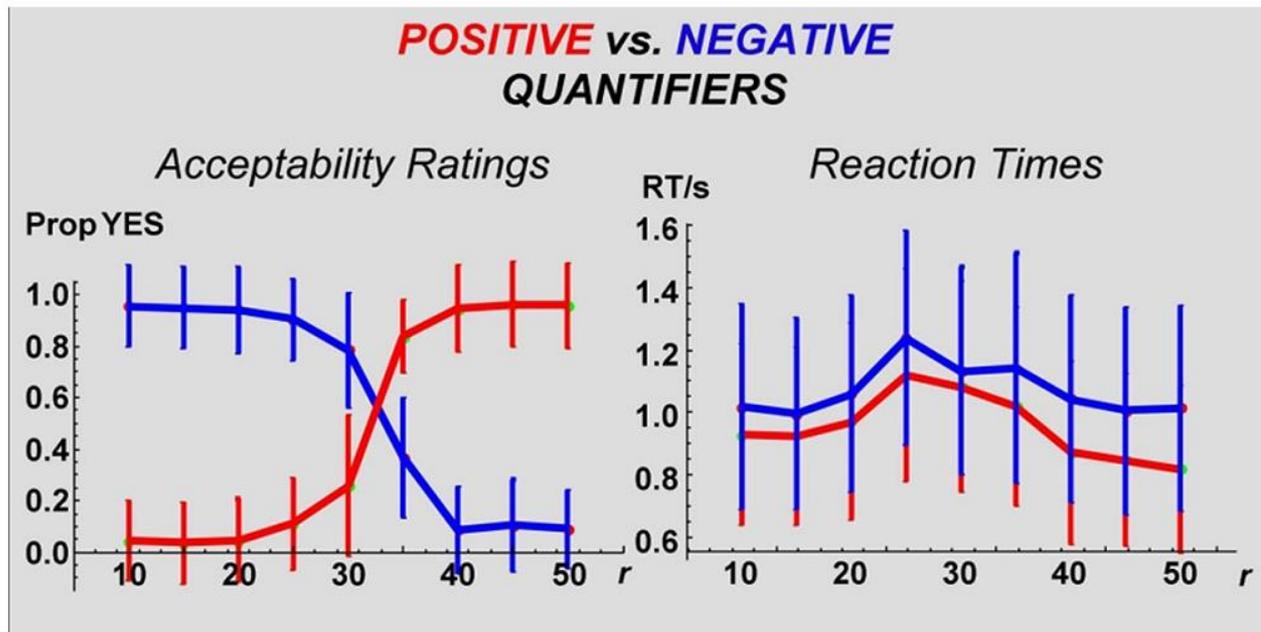
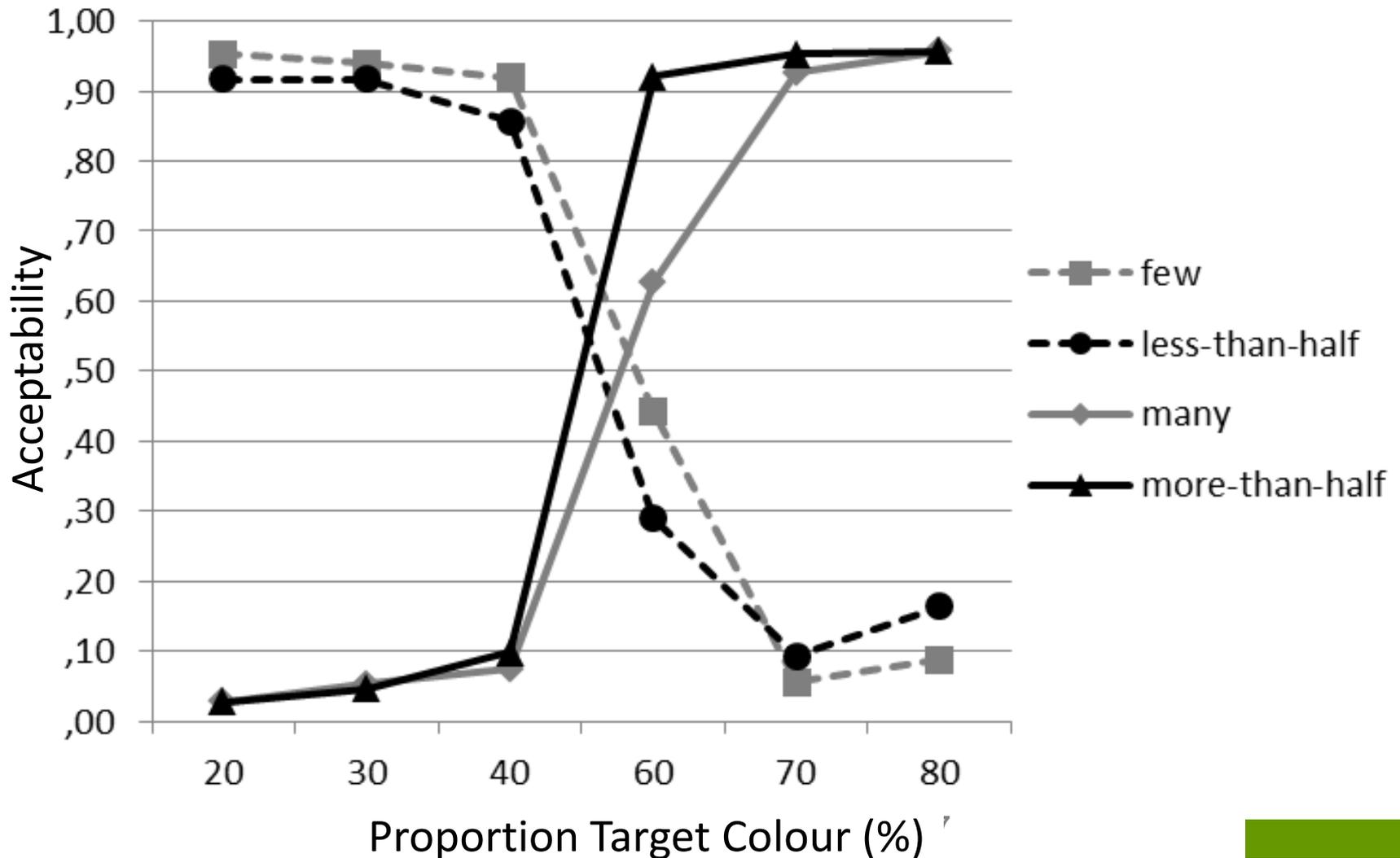


FIGURE 2 | Response accuracy and response time: Accuracy: Probabilities of “YES” responses by *TarCol* proportion per quantifier.

NB: Quantifiers are clustered by Polarity (positive vs. negative). In both cases, a step-function is evident. Moreover, positive and negative quantifiers reveal a mirrored pattern – an image that makes a sentence with a positive quantifier true falsifies its negative counterpart. RT: Mean RTs by *TarCol* proportion per quantifier. NB: Quantifiers are clustered by Polarity. Negative quantifiers produce longer *RTs* (for statistical analysis see text). In all cases, a non-monotonic function is evident (see The Mapping Between the Current PPP and Standard Numerosity Experiments in Supplementary Material for mathematical details).

Vague vs. precise quantifiers – Variable vs. fixed degree



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Processing of Numerical and Proportional Quantifiers

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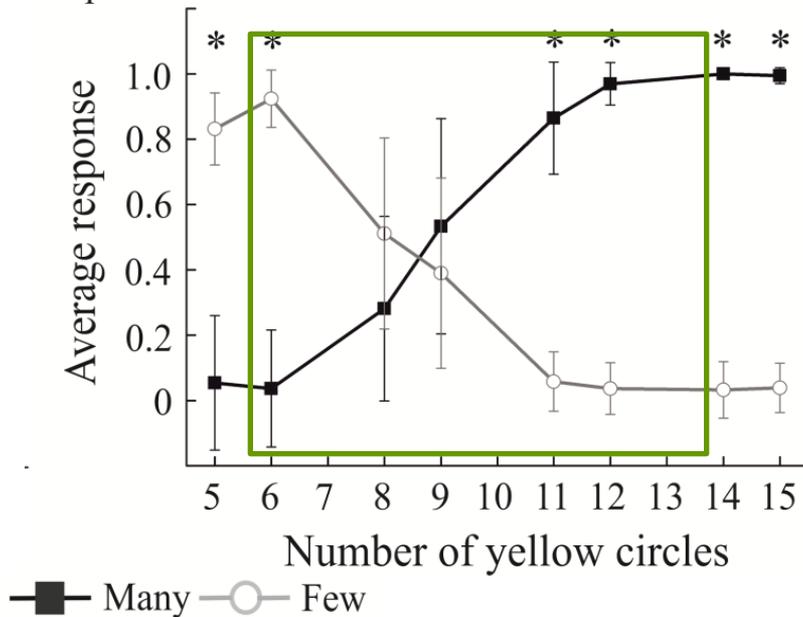
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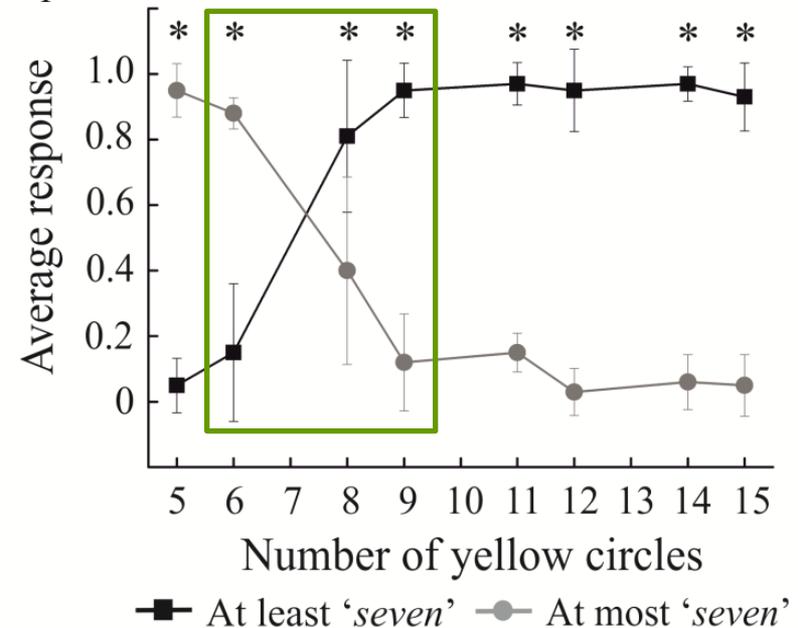
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Variable vs. fixed degree

Proportion ACCEPT



Proportion ACCEPT



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Preferential use of quantifiers

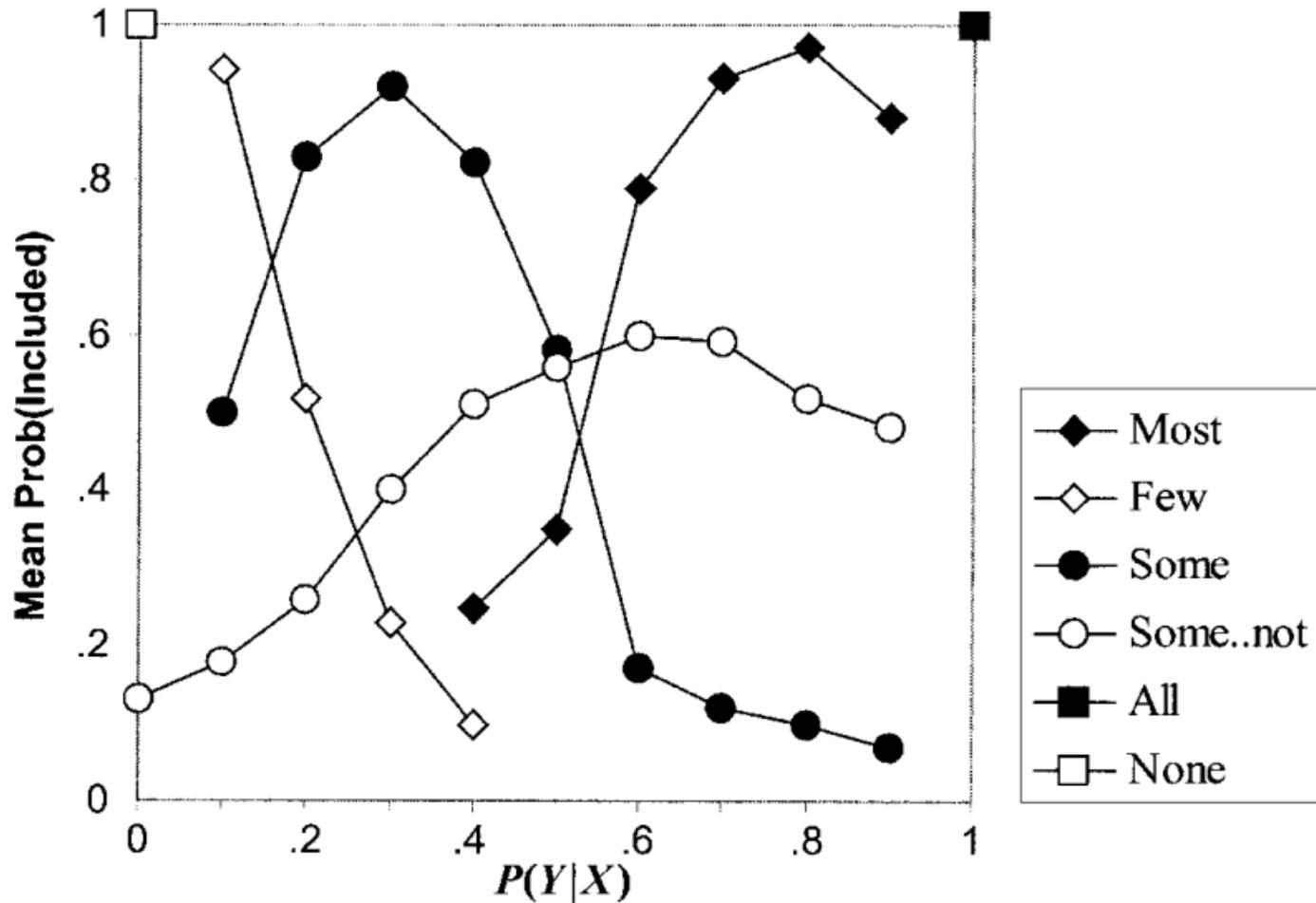


Figure 2 from Oaksford et al. 2002 Mem Cogn

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THE PSYCHOLOGICAL REVIEW

ADAPTATION-LEVEL AS A BASIS FOR A QUANTITATIVE
THEORY OF FRAMES OF REFERENCE

BY HARRY HELSON

Bryn Mawr College

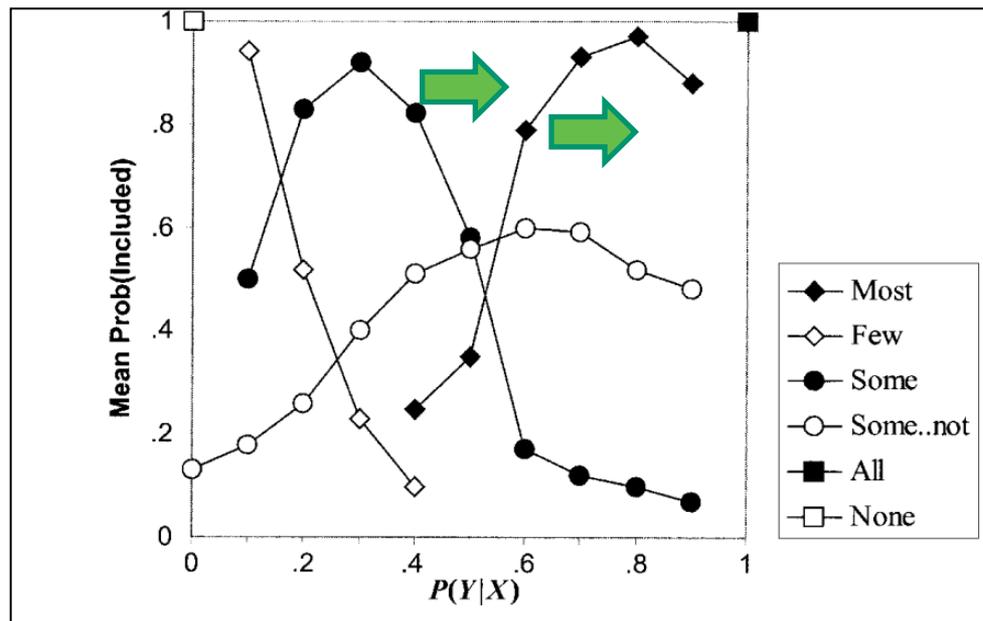


Figure 2 from Oaksford et al. 2002 Mem Cogn

If so many are “few,” how few are “many”?

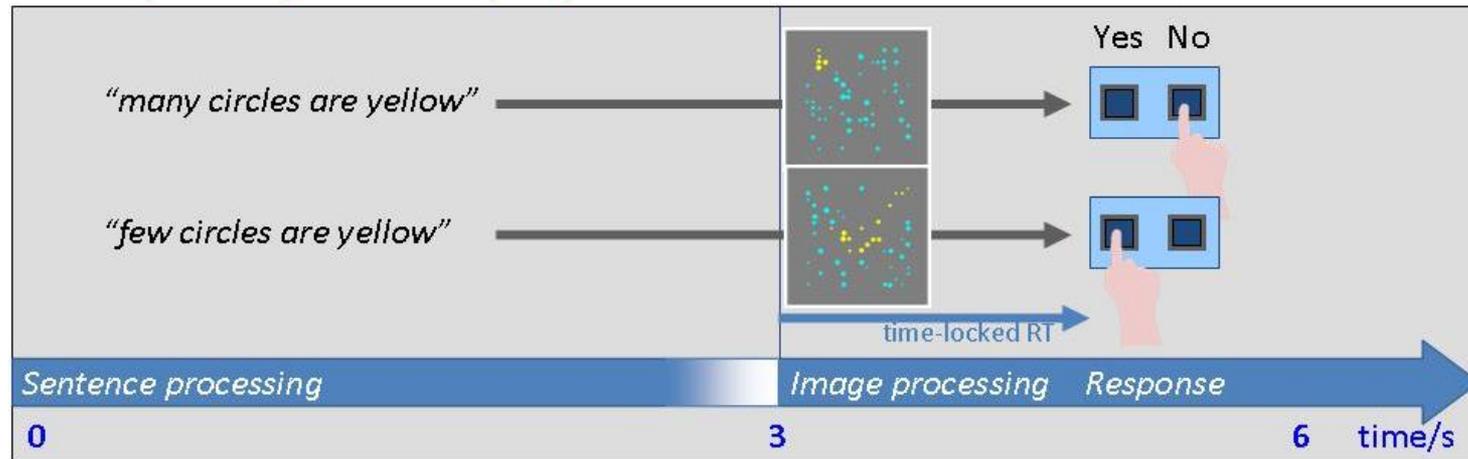
Stefan Heim^{1,2,3*}, Corey T. McMillan⁴, Robin Clark⁵, Stephanie Golob⁴, Nam E. Min⁴, Christopher Olm⁴, John Powers⁴ and Murray Grossman⁴

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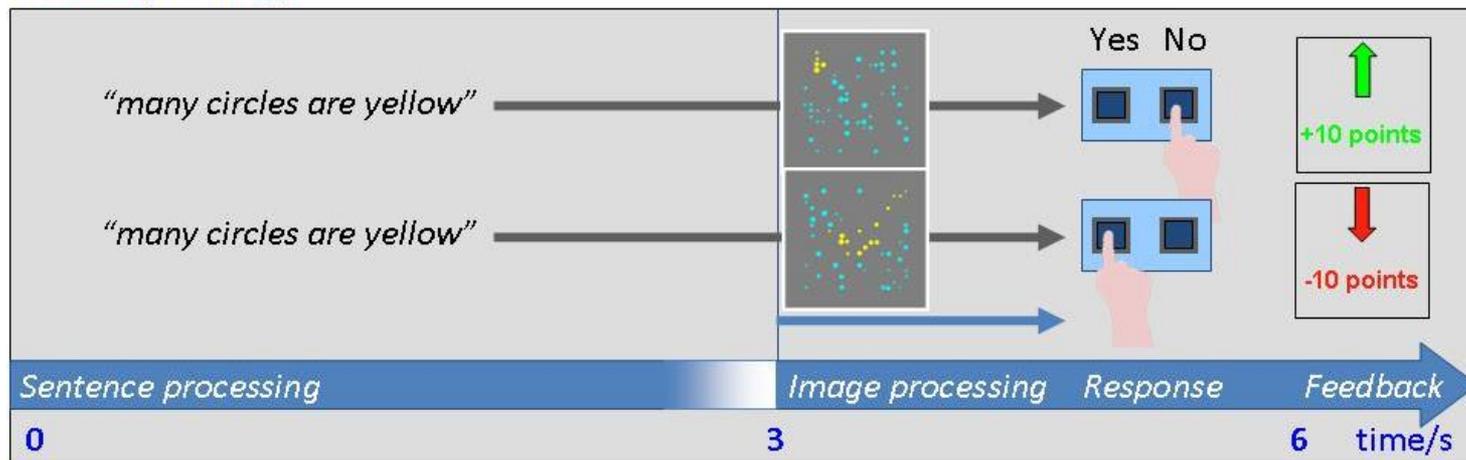
1. Assessing the degree

Block 1 (Baseline) and Block 3 (Test)



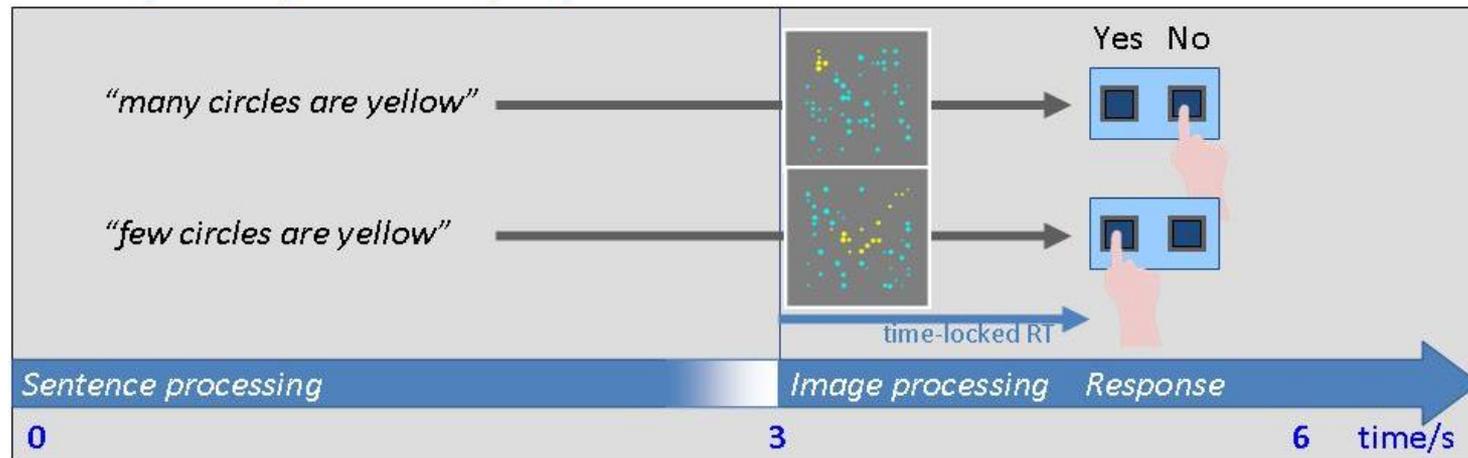
2. Training a new degree

Block 2 (Training)



3. Assessing the degree again

Block 1 (Baseline) and Block 3 (Test)



Method

- **Experiment 1:**
 - Training for „many“ at degree 40%
 - No training for „few“
- **Experiment 2:**
 - Training for „few“ at degree 50%
 - No training for „many“

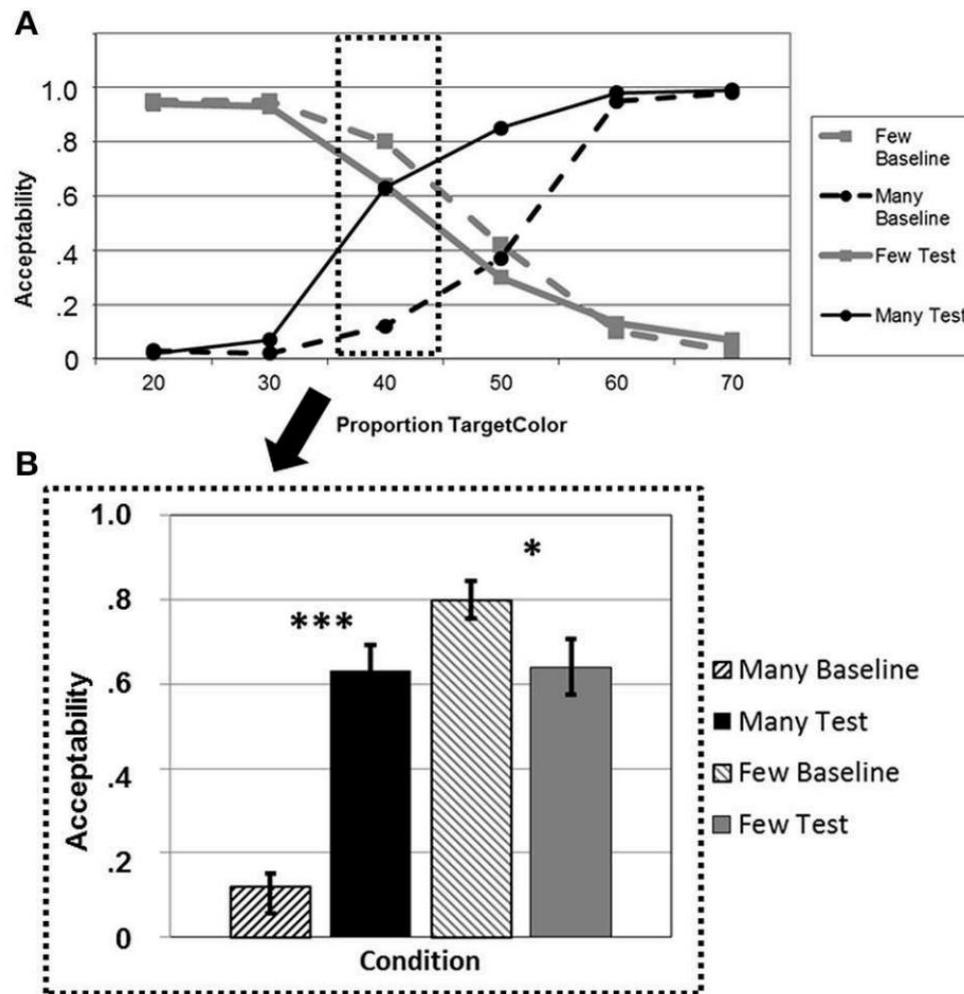
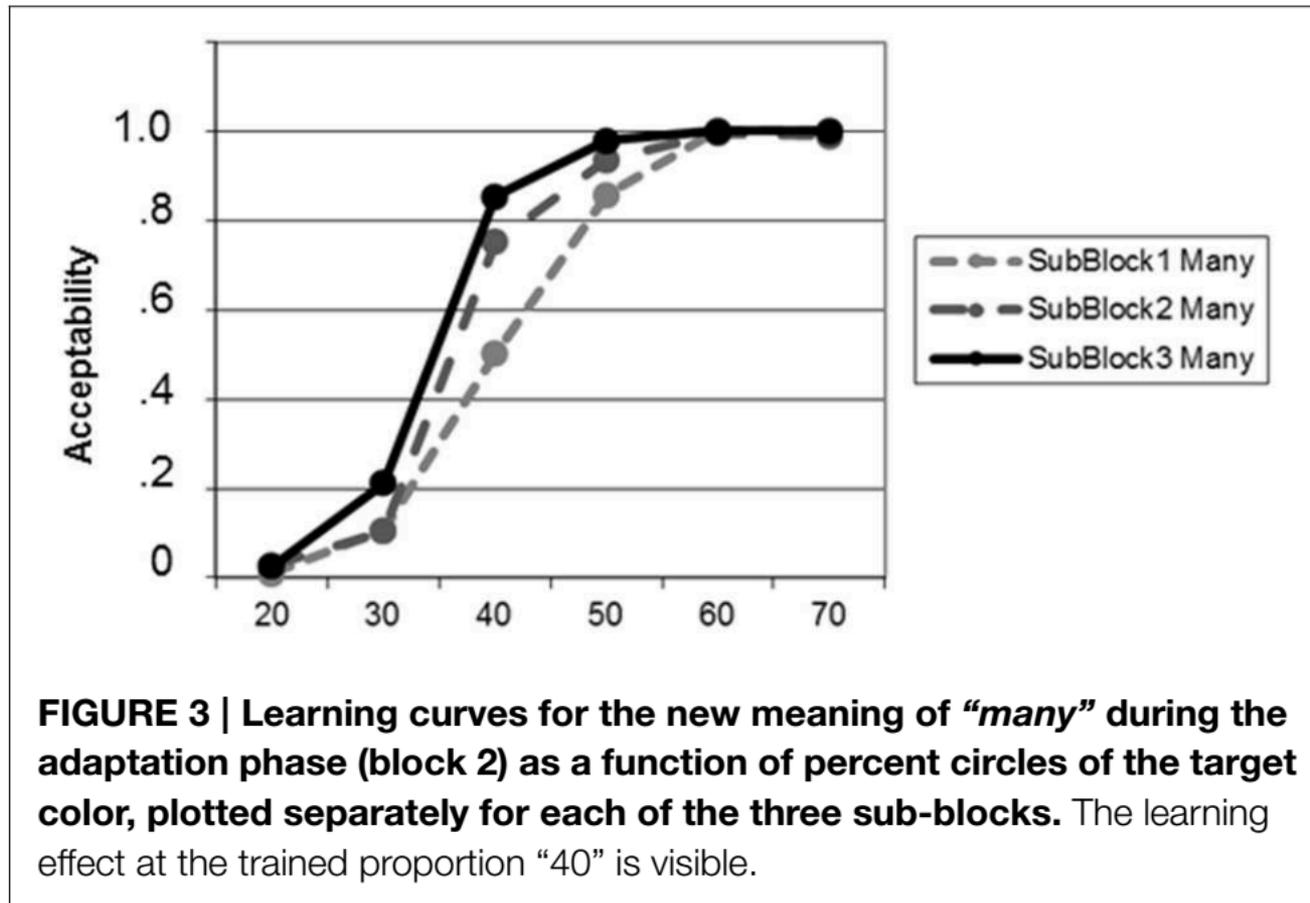


FIGURE 2 | (A) Average acceptability ratings for a given proportion of circles of the mentioned color, plotted separately for the quantifiers “many” (black lines) and “few” (gray lines) in the baseline blocks (dashed lines) and the test blocks after adaptation (solid lines). **(B)** Average acceptability ratings for a critical proportion of circles of the mentioned color, plotted separately for “many” (black bars) and “few” (gray bars) in the baseline blocks (dashed bars) and the test blocks after adaptation (solid bars). * $p < 0.05$, *** $p < 0.001$.



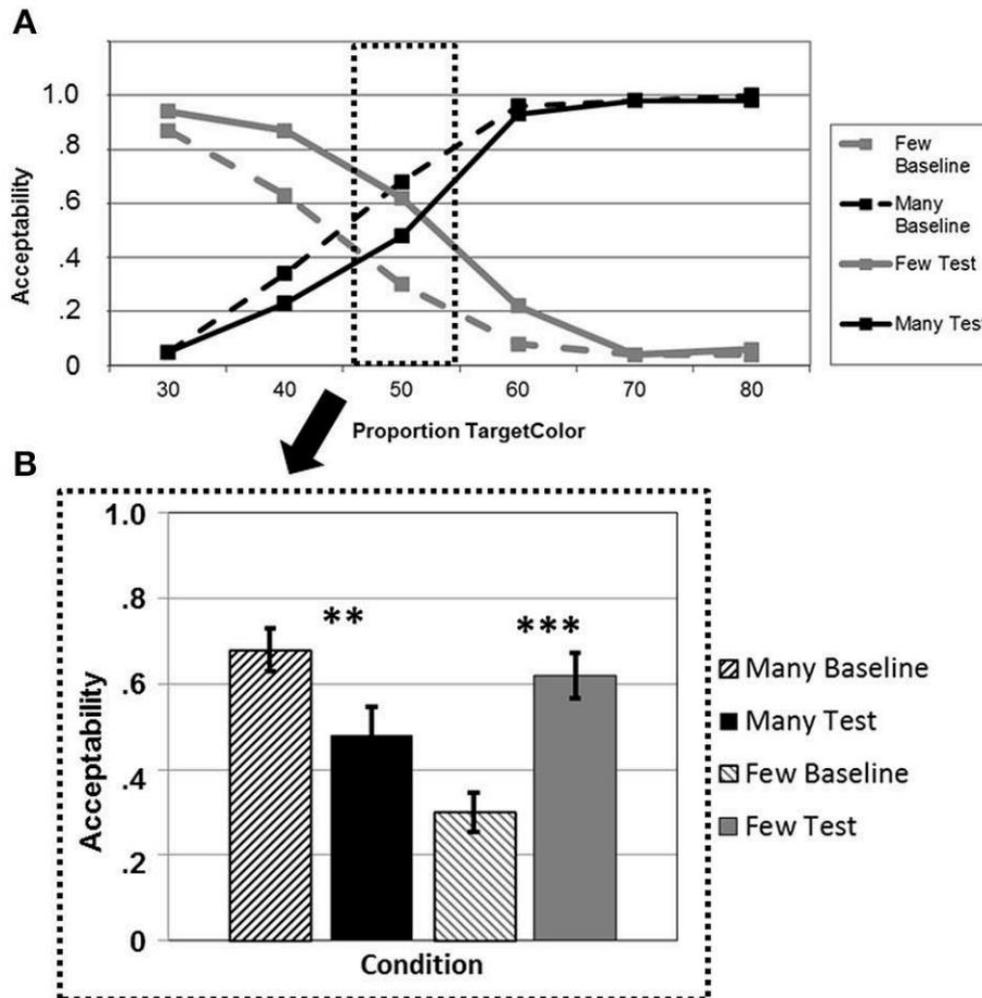
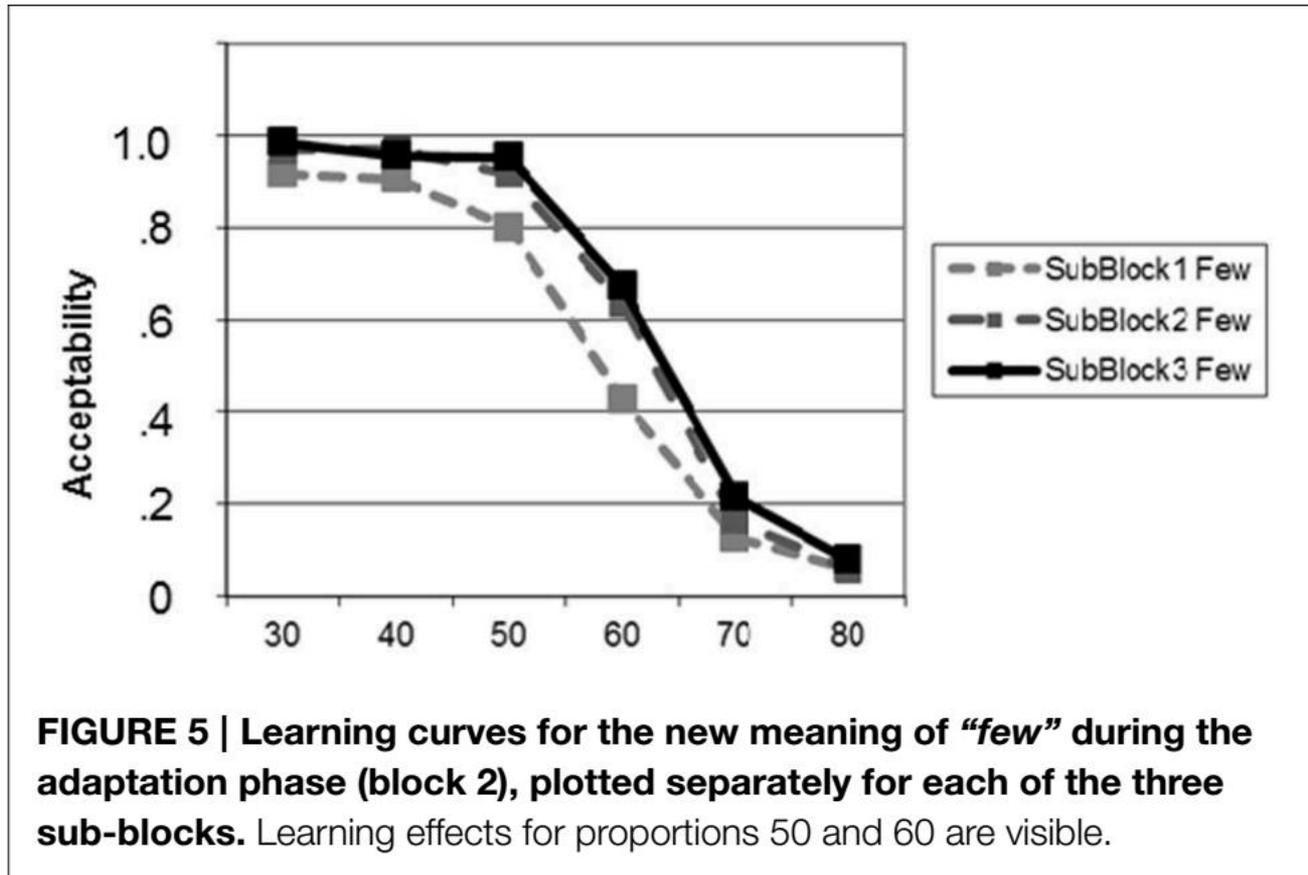
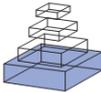


FIGURE 4 | (A) Average acceptability ratings for a given proportion of circles of the mentioned color, plotted separately for the quantifiers “many” (black lines) and “few” (gray lines) in the baseline blocks (dashed lines) and the test blocks after adaptation (solid lines). **(B)** Average acceptability ratings for a critical proportion of circles of the mentioned color, plotted separately for “many” (black bars) and “few” (gray bars) in the baseline blocks (dashed bars) and the test blocks after adaptation (solid bars). $**p < 0.01$, $***p < 0.001$.



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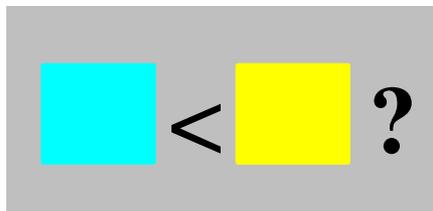
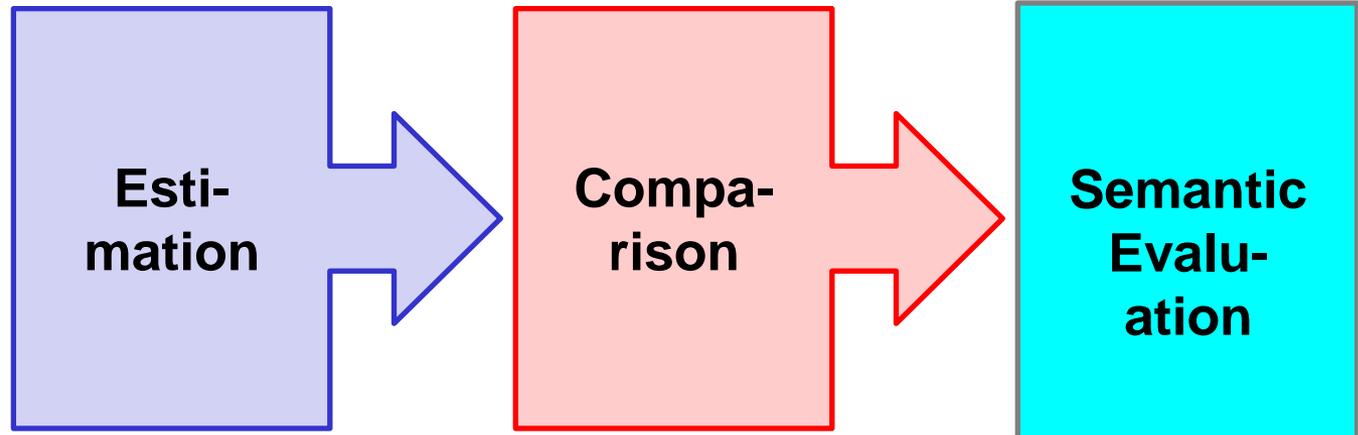
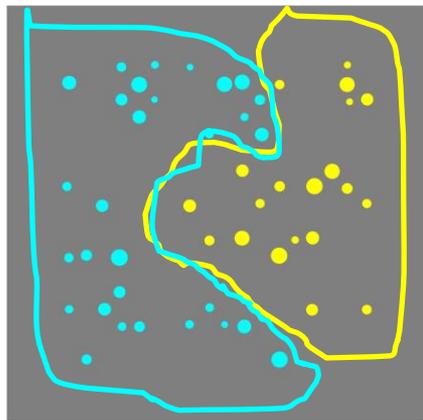
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Quantifier processing

„most of the circles are yellow“



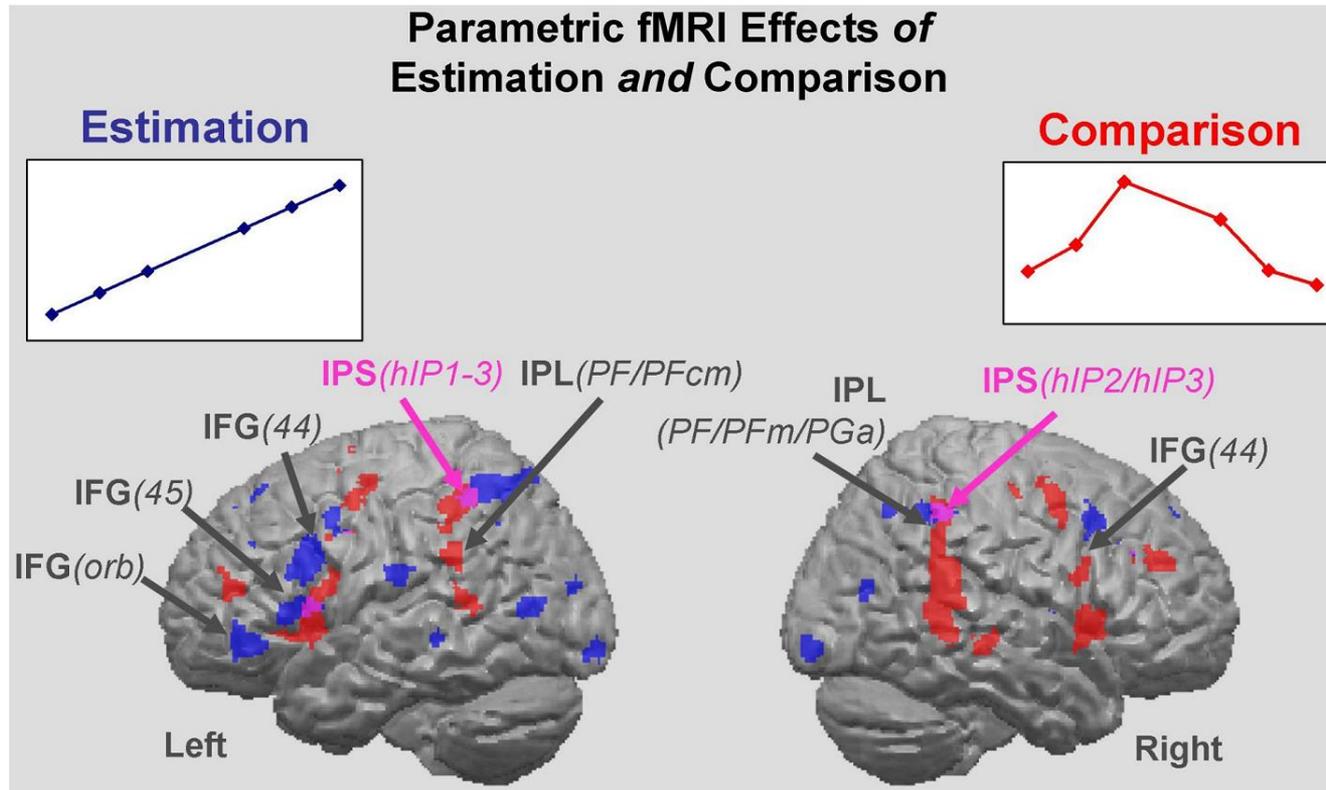


FIGURE 3 | Estimation and Comparison regions. Parametric effects for the Estimation of the numerosity of circles in target color (blue areas), and for the Comparison as manifest through RT (red areas). All effects are main effects over the six quantifiers. Estimation clusters: brain regions in which the BOLD signal intensity co-varies with the linearly increasing number of circles in

target color (F -test). Comparison clusters: brain regions in which the BOLD signal intensity co-varies with RT – a reflection of processing difficulty. Regions commonly tapped by the Estimation and Comparison parameters are shown in purple (red plus blue). IPS, intraparietal sulcus; IFG, inferior frontal gyrus; IFG/orb, pars orbitalis of the IFG.

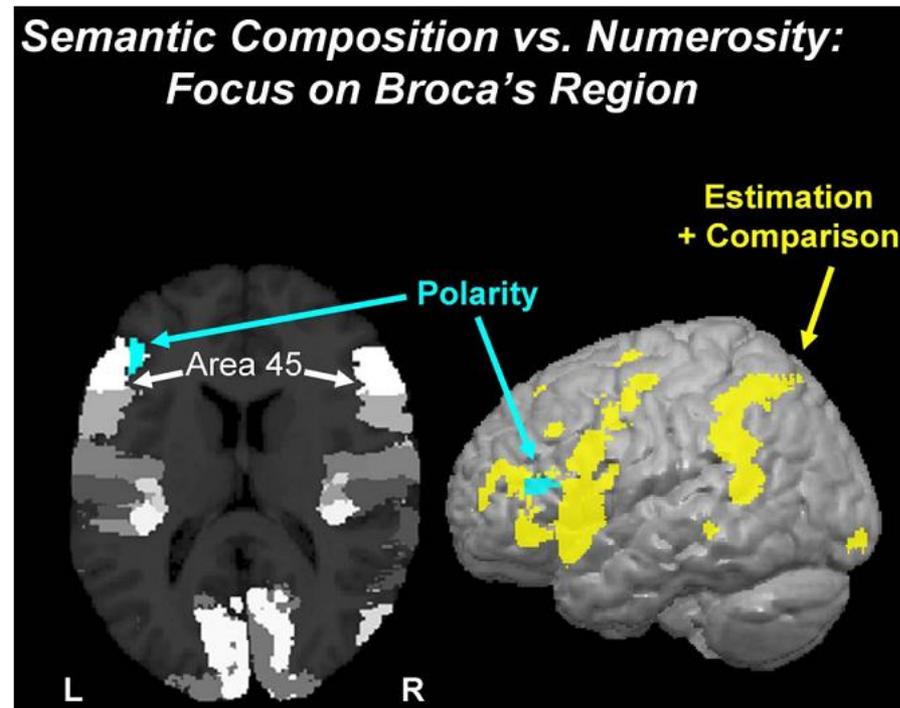


FIGURE 4 | Semantics of quantification: polarity. The effect of Polarity (negative vs. positive quantifiers; turquoise blob) was observed in Broca's region in the left inferior frontal gyrus. The effect, which is clearly non-numeric but semantic in nature, overlaps with cytoarchitectonic area 45 (white). The surface rendering shows that this Polarity effect is predominant in the left inferior frontal cortex, whereas the numerosity network (yellow) comprising both areas for Estimation and Comparison (from **Figure 3**) taps widely into a fronto-parietal network.

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How the brain learns how few are “many”: An fMRI study of the flexibility of quantifier semantics



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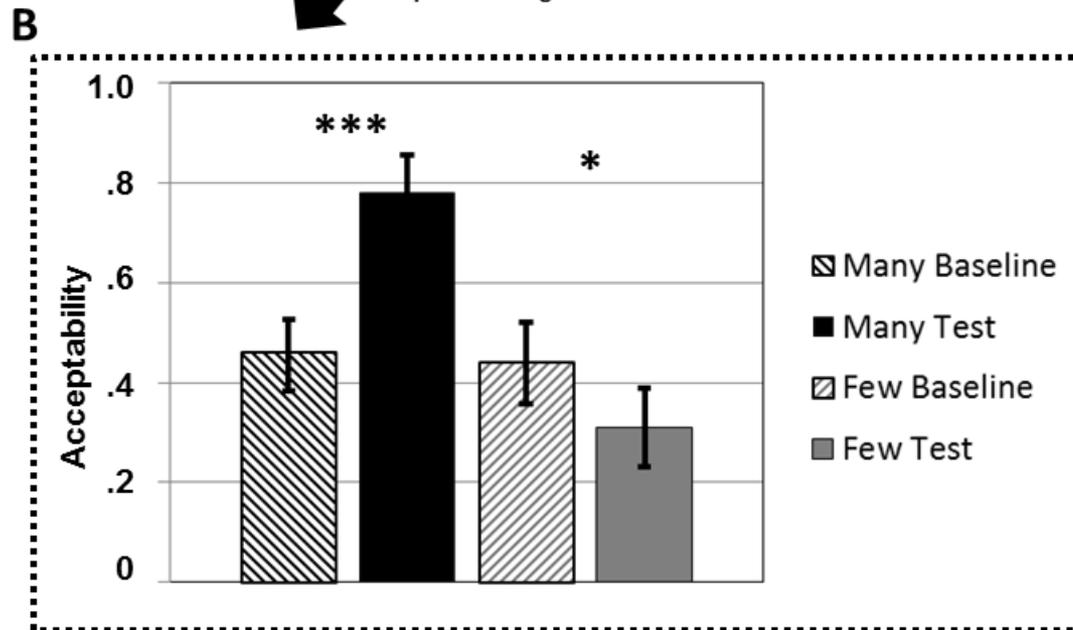
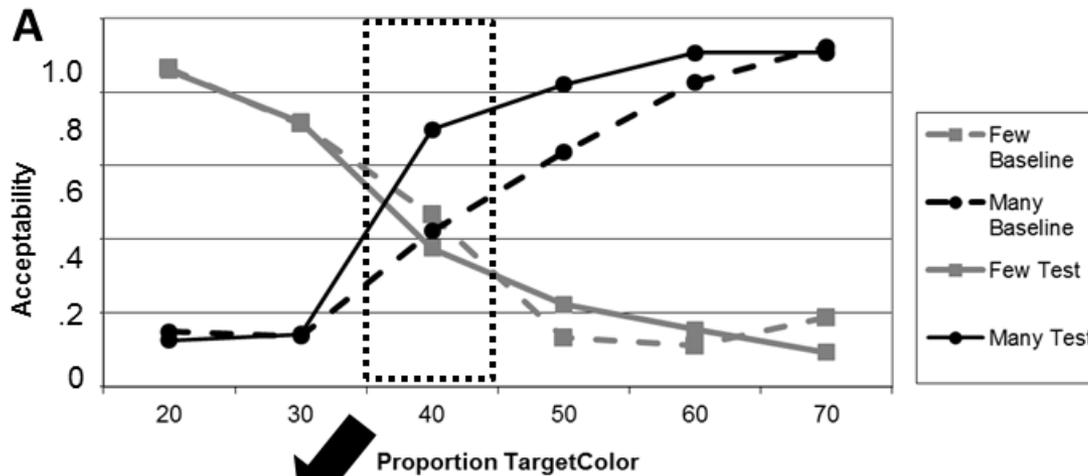
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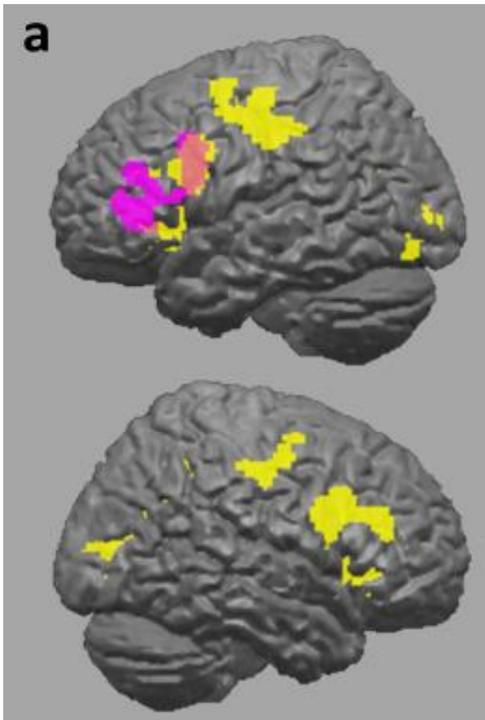
^e University of Pennsylvania, Department of Linguistics, USA

Training for „many“

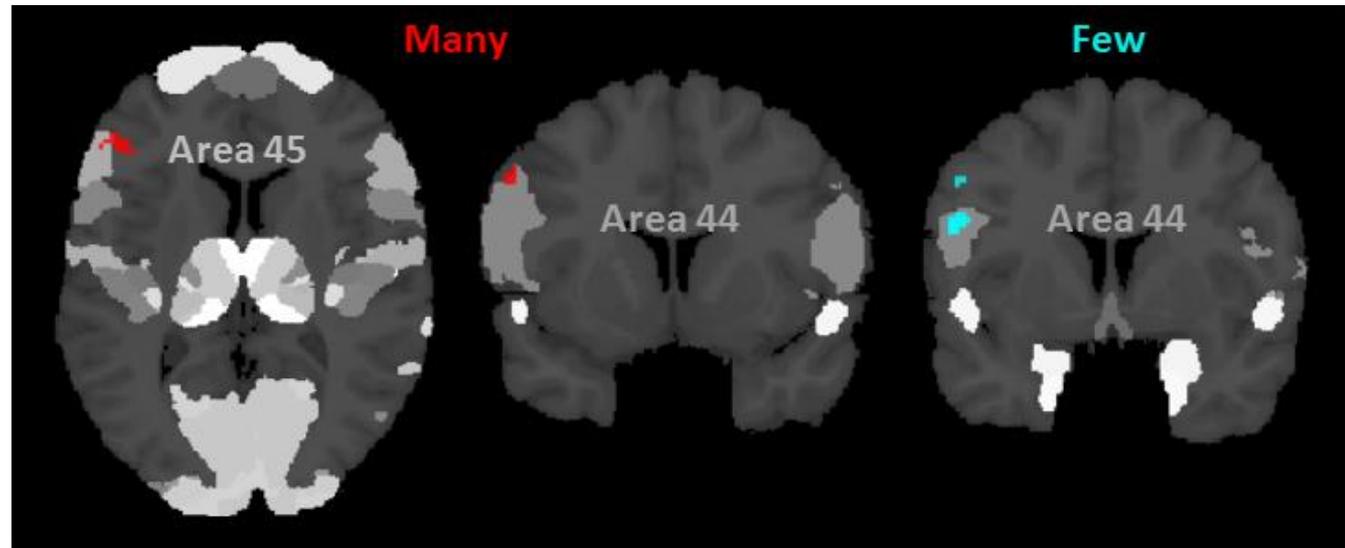


Quantifier learning in the brain

General changes
Block 1 vs. 3



Specific changes for degree 40% vs. others
Block 1 vs. 3



from Heim et al. 2015 Neuroimage

Images: <https://www.ncbi.nlm.nih.gov/pubmed/26481678>

Conclusion

For quantifiers with a non-fixed degree ...

- ... can this degree be modified
- ... can this modification carry over onto other quantifiers, even and in particular to the polar opposite

The brain processes quantifier semantics ...

- ... specifically in Broca's region in the LIFG
- ... and in particular for the change of degree, for trained and untrained quantifiers

Credits to ...

Overall cooperation:

Yosef Grodzinsky

Learning paradigm, FTD patients:

Murray Grossman, Corey McMillan

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Stefan Heim