# Space to Reason

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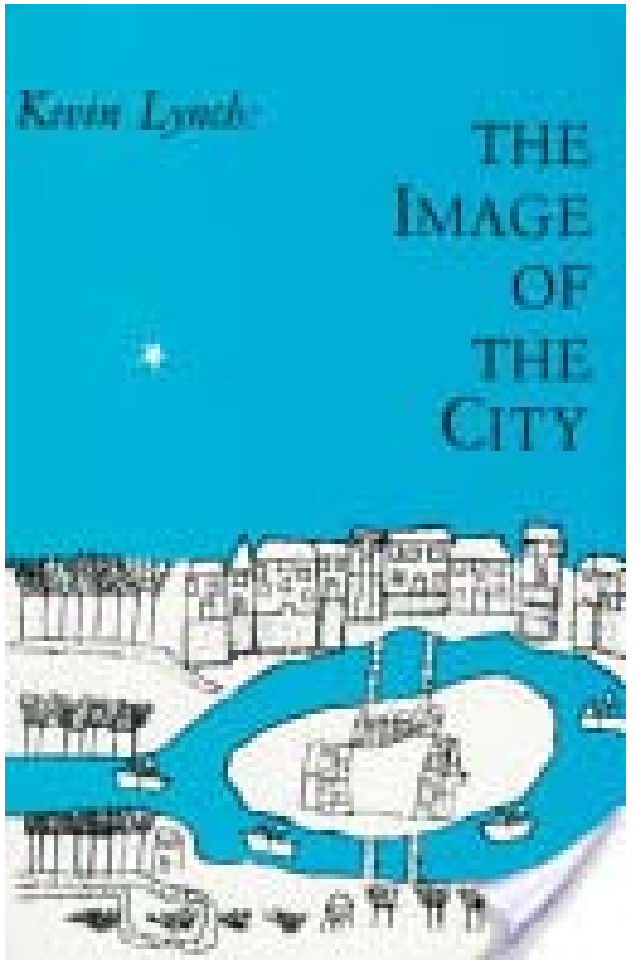
For every complex problem, there is an answer that is clear, simple, and wrong.

*H.L. Mencken (1880 - 1956)*

# Imageability and City Planning

- What does the city's form actually mean to the people who live there? What can the city planner do to make the city's image more vivid and memorable to the city dweller? To answer these questions, Lynch, formulates a new criterion-imageability-and shows its potential value as a guide for the building and rebuilding of cities.



# Visual imagery and reasoning

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- Visual imagery helps to reason: Huttenlocher (1968), Shaver, Pierson, and Lang (1976), Clement and Falmagne (1986), and many others
- Visual imagery does not help: Sternberg (1980), Richardson (1987), Johnson-Laird, Byrne and Tabossi (1989), Newstead, Pollard, and Griggs (1986), and many others

# The core idea ..

- … to re-examine the orthodox visual theory of reasoning, to reject it, and to propose a spatial theory of reasoning in its stead.
- … to show that not visual images, but rather the ability to mentally construct and inspect more abstract spatial representations is critical for reasoning.
- .. to show that by means of behavioral reasoning experiments, experiments using functional MRI, and computational modeling.

# The visual-impedance hypothesis



Knauff & Johnson-Laird (2002). *Memory & Cognition*, 30, 363-371.

- Orthodox hypothesis: visual relations help to construct visual images and thus support the process of reasoning
- Alternative hypothesis: visual relations elicit irrelevant visual images and thus impede the process of reasoning
  = **visual-impedance hypothesis**


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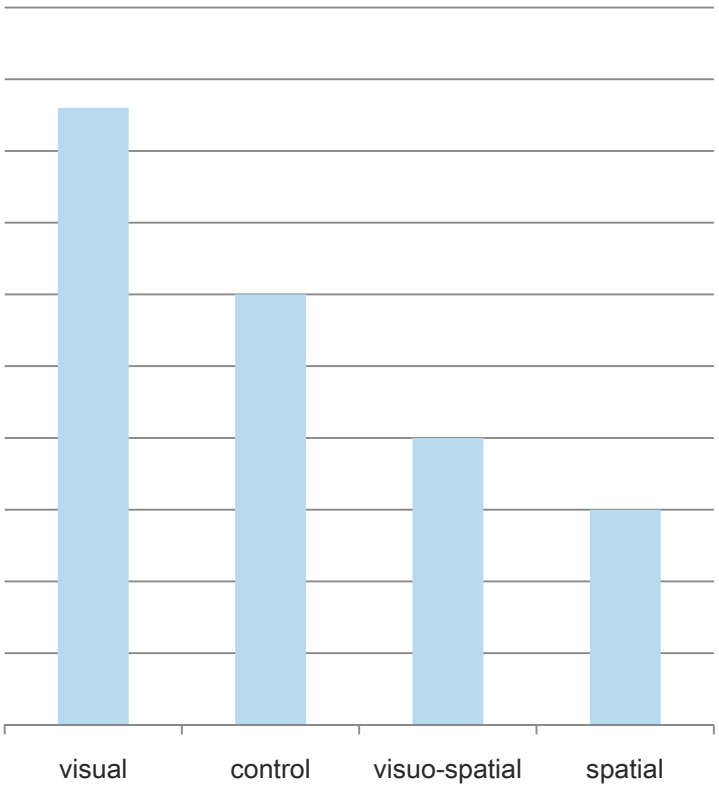
# Reasoning and imageability

- Four sorts of problems:
  - visual problems – e.g. cleaner-dirtier
  - visuo-spatial problems – e.g. above-below
  - spatial problems – e.g. to the north-to the south
  - control problems – e.g.better-worse
- Participants solved reasoning problems with the four sorts of relations

# Response latencies



Knauff & Johnson-Laird (2002). *Memory & Cognition*, 30, 363-371.




- visual problems were significantly slower than the other problems (Wilcoxon test $z = 3.07$; $p < .002$)
- No difference between the other sorts of problems
- Imageability does not help; it even impedes reasoning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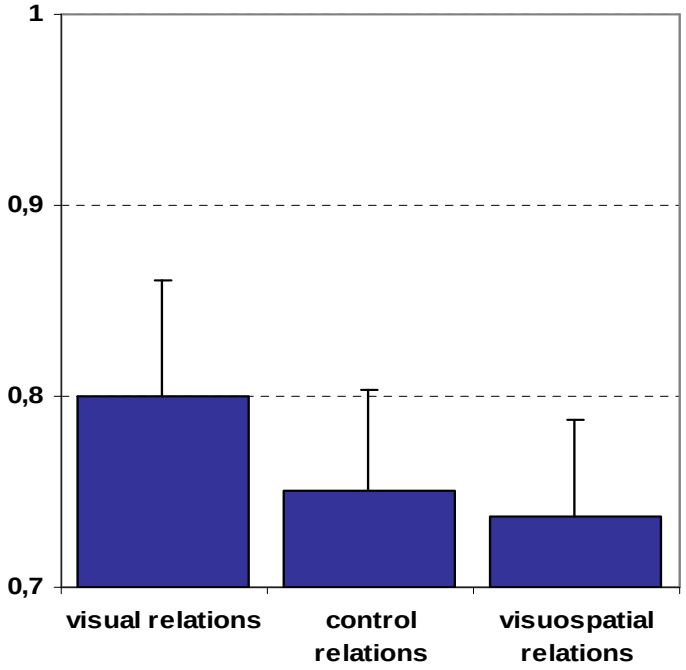
# Congenitally Blind Reasoners

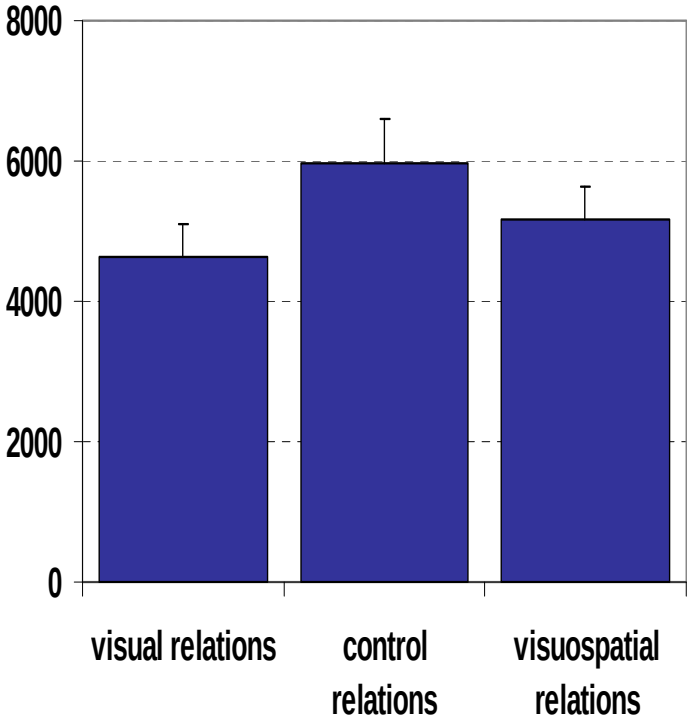


Knauff & May (2006). *Quarterly Journal of Experimental Psychology,* 59, 16-177.

- accuracy [rel. frequency of correct responses]




- response latency [in msec]





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# Sighted Reasoners

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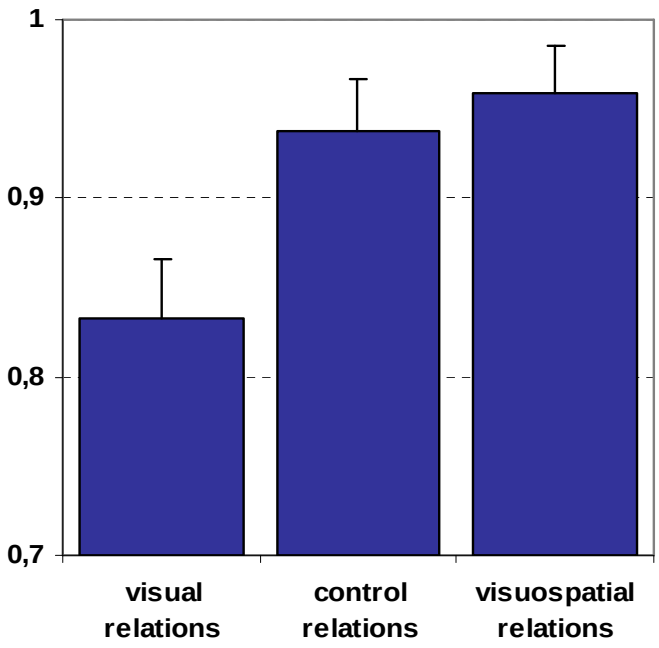
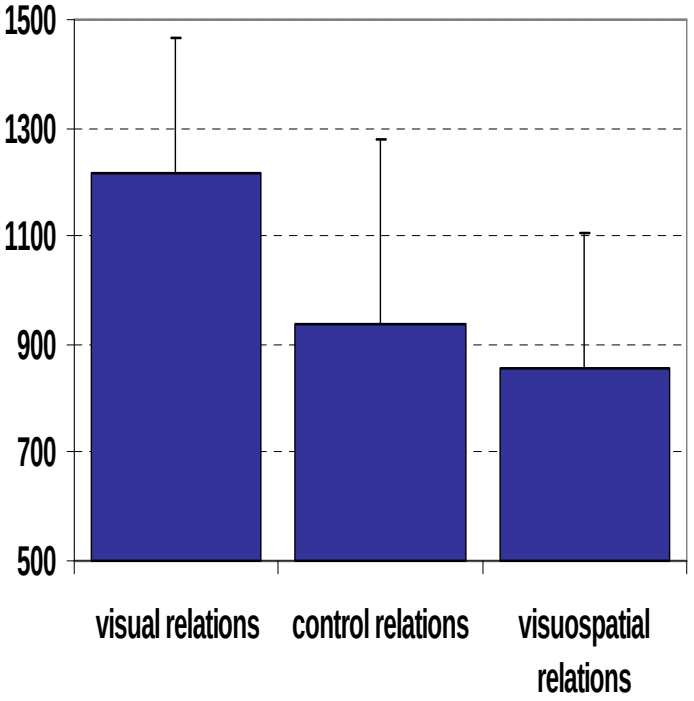
Knauff & May (2006). *Quarterly Journal of Experimental Psychology,* 59, 16-177.

- accuracy [rel. frequency of correct responses]




- response latency [in msec]





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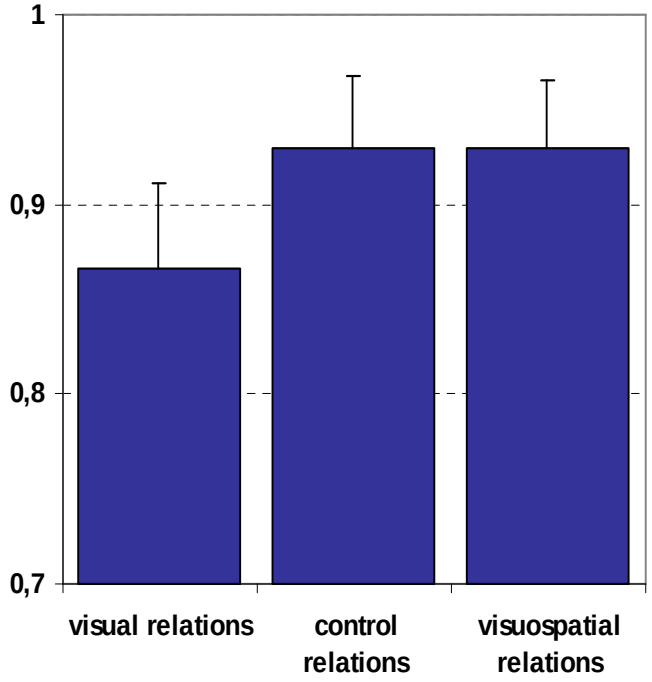
# Blindfolded Sighted Reasoners

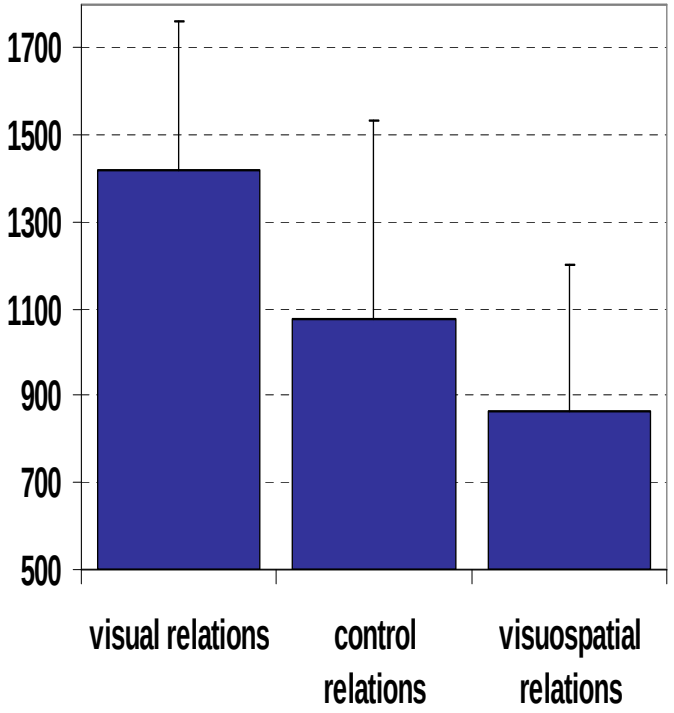
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Knauff & May (2006). *Quarterly Journal of Experimental Psychology,* 59, 16-177.

- accuracy [rel. frequency of correct responses]




- response latency [in msec]





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# Replications and Extensions of the visual impedance effect

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- Dyslexia
  - Bacon, A.M., Handley, S.J., Dennis I. & Newstead, S.E. (2008). Reasoning strategies: the role of working memory and verbal-spatial ability. European Journal of Cognitive Psychology, 20(6), 1065 - 1086.
  - Bacon, A.M., Handley, S.J. and McDonald, E.L. (2007). Reasoning and dyslexia: a spatial strategy may impede reasoning with visually rich information. British Journal of Psychology, 98(1), 79-92.
- Psychopharmacology/ Bezodiaziones:
  - S. Pompéia , G. M. Manzano, M. Pradella-Hallinan and O. F. A. Bueno (2007). Effects of lorazepam on deductive reasoning. *Psychopharmacology*, 527 - 536
- Individual differences
  - DeLeeuv, K. Hegarty, M (2008). What Diagrams Reveal about Representations in Linear Reasoning, and How They Help*. Diagrams,* 89-102.


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# Neural Activity During Reasoning and imageability

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- Four sorts of problems:
  - visual problems – e.g. cleaner-dirtier
  - visuo-spatial problems – e.g. above-below
  - spatial problems – e.g. to the north-to the south
  - control problems – e.g.better-worse

# Activity in ALL problems

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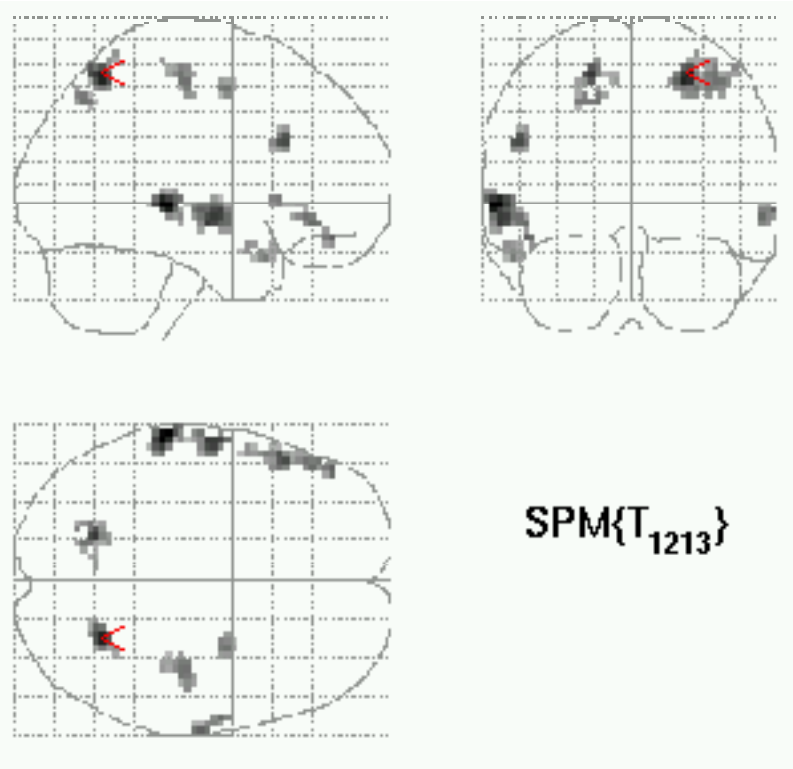
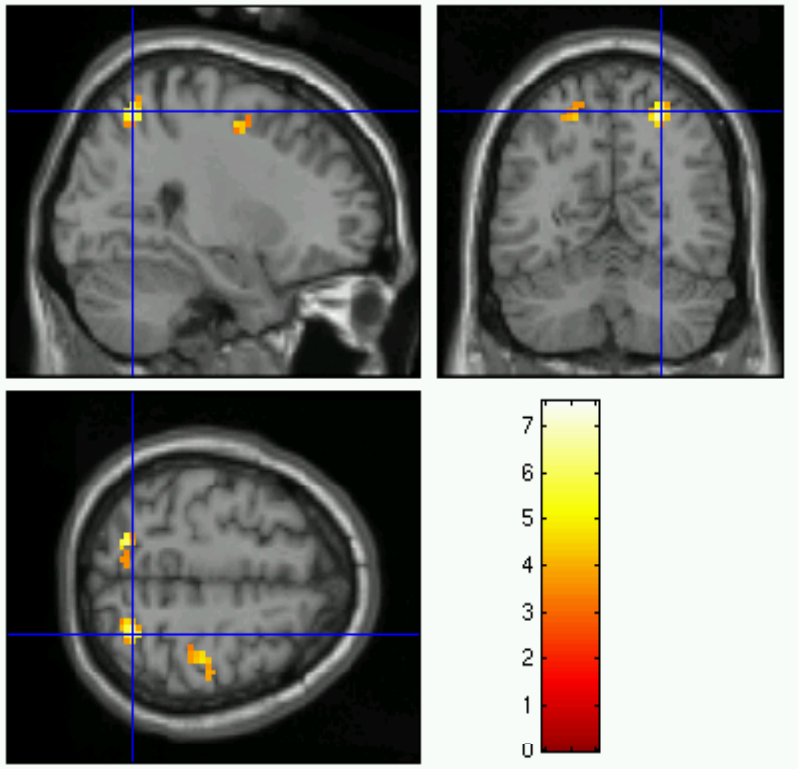
Knauff et al. (2003). *Journal of Cognitive Neuroscience,* 15 (4), 559-573.




Contrast: all problems vs. baseline ($p < .001$)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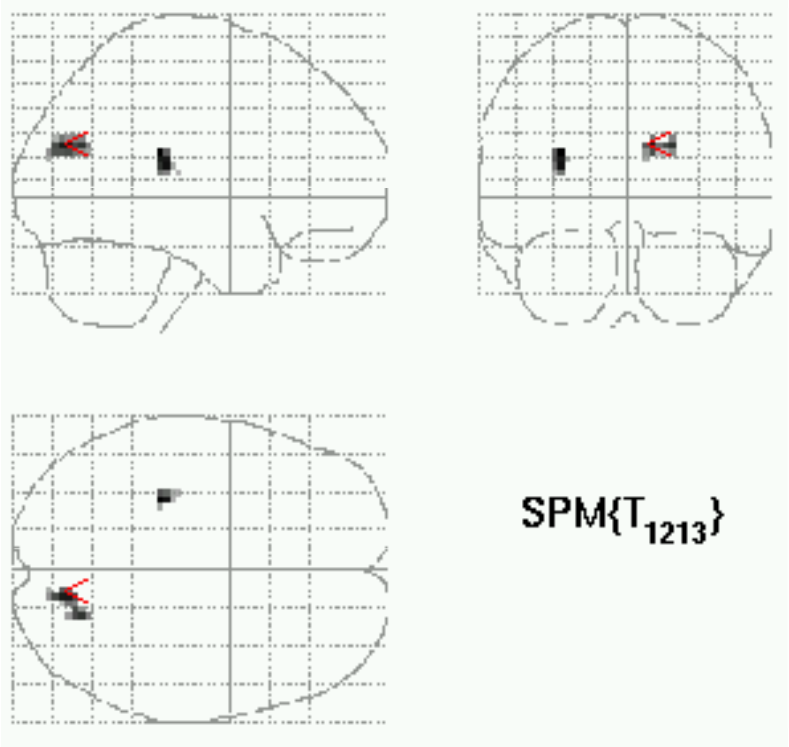
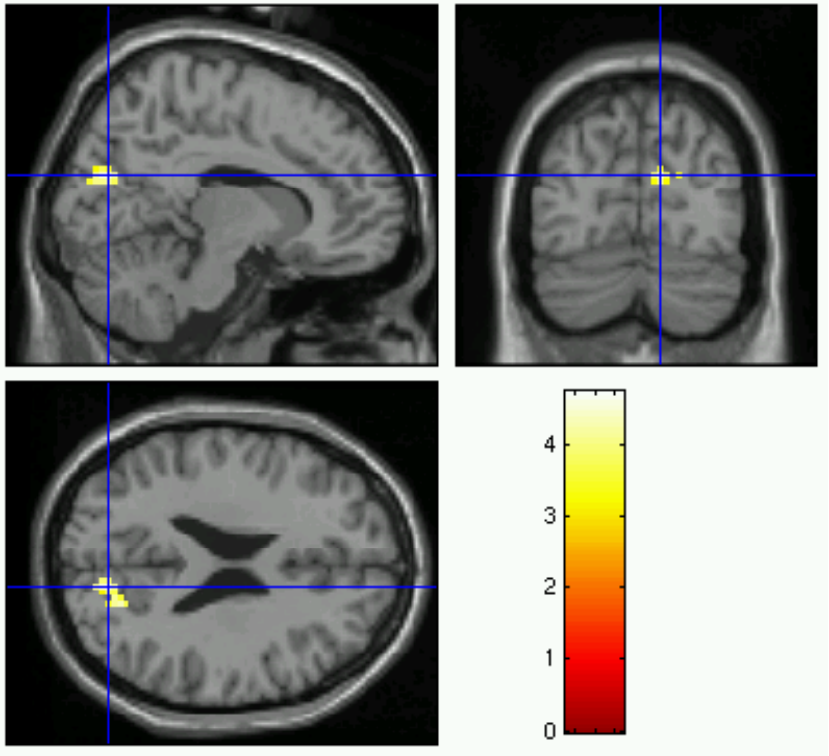
# Activity in visual problems

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Knauff et al. (2003). *Journal of Cognitive Neuroscience,* 15 (4), 559-573.




Contrast: visual problems vs. control problems ($p < .001$)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# Reasoning and working memory

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Knauff et al., (2004*). Spatial Cognition & Computation*, 4, 167-189

- Participants solved transitive inferences (N = 3 X 48) as main task (k = 48)
- Four different secondary tasks were solved concurrently:
  - Visuo-spatial: location of objects (1)
  - visual: brightness of  Objects (2)
  - spatial: location of tones (3)
  - Kontrolle: pitch of tones (4)


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# Problems



The red circle lies to
the left of the green rectangle.

The green rectangle lies to the
left of the blue square.

Does it follow:

The red circle lies to the
left of the blue square?

# Valid Inferences

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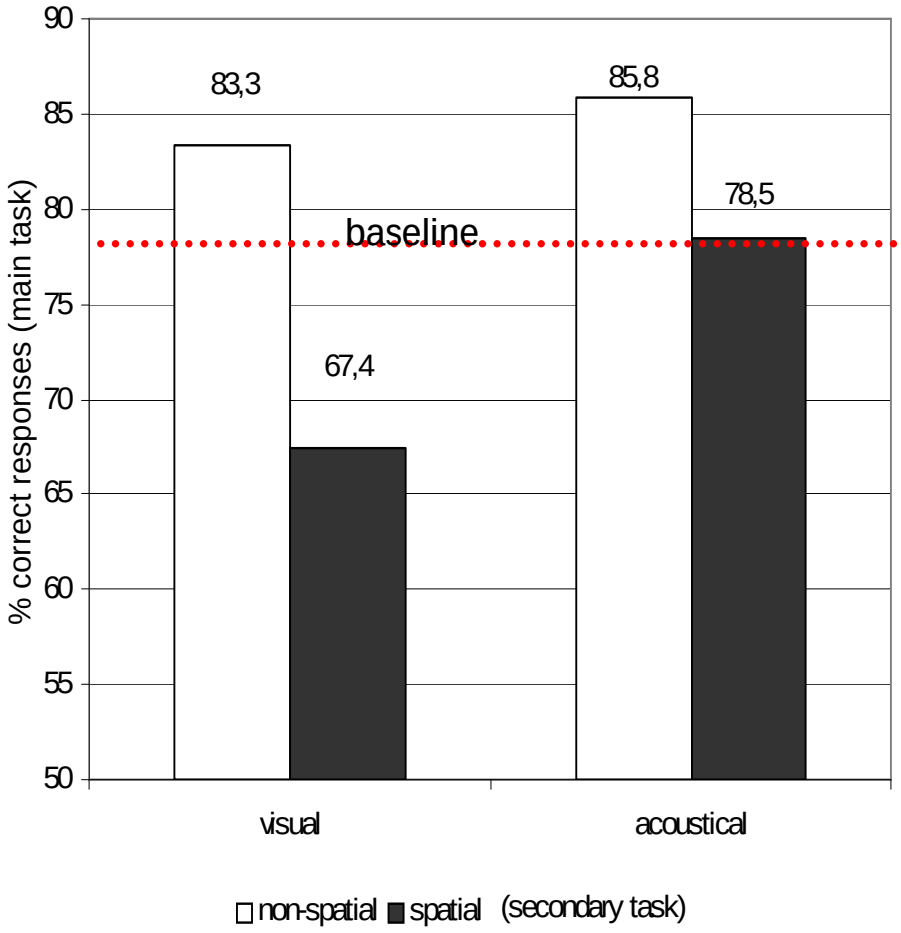
Knauff et al., (2004). *Spatial Cognition & Computation*, 4, 167-189

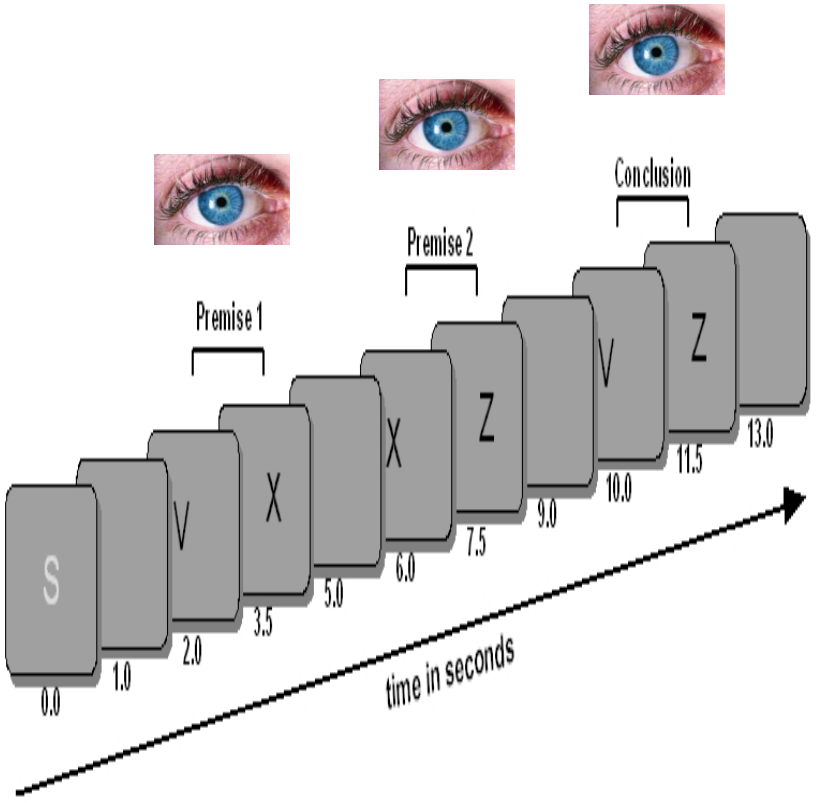



- Visual secondary tasks had no negative effect on reasoning performance
- Spatial secondary tasks had a disrupting effect on reasoning performance (Wilcoxon test $z = 2.19$; $p < .05$)
- Reasoning and spatial secondary tasks are processes in the same spatial subsystem of working memory

# Three phases of an inference…

Fangmeier, Knauff, Ruff, & Sloutsky (2006). *Journal of Cognitive Neuroscience,* 4, 559-573.

- premise processing phase: comprehension and processing of the premises
- integration phase: construction of a single integrated model of the premise information; the premises are no longer represented as separate entities in working memory
- validation phase: evaluation of the logical validity of a presented conclusion





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# “Visual Areas” only in Phase I and II

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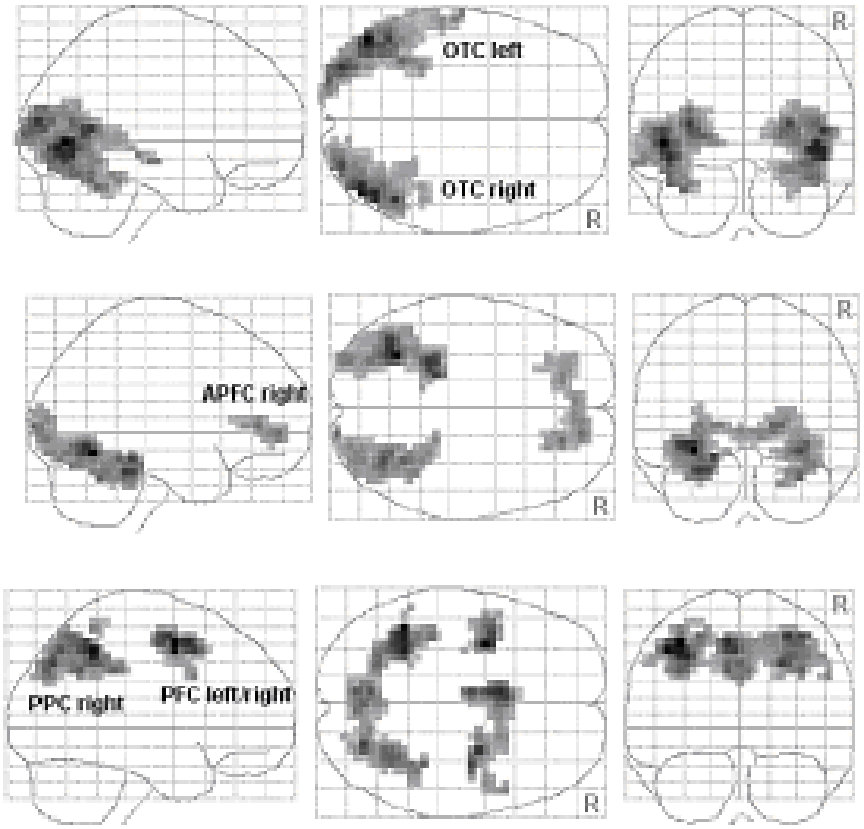
Fangmeier, Knauff, Ruff, & Sloutsky (2006). *Journal of Cognitive Neuroscience,* 4, 559-573.




- *premise processing phase:* middle occipital gyrus, and superior temporal gyrus, bilaterally
- *integration phase:* anterior prefrontal cortex and occipito-temporal gyrus
- *validation phase*: prefrontal gyrus, inferior parietal lobule (L); precuneus (R)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# Acoustical problems

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Fangmeier & Knauff (2009). *Brain Research, 1249, 181-190.*

- premise processing phase: comprehension and processing of the premises
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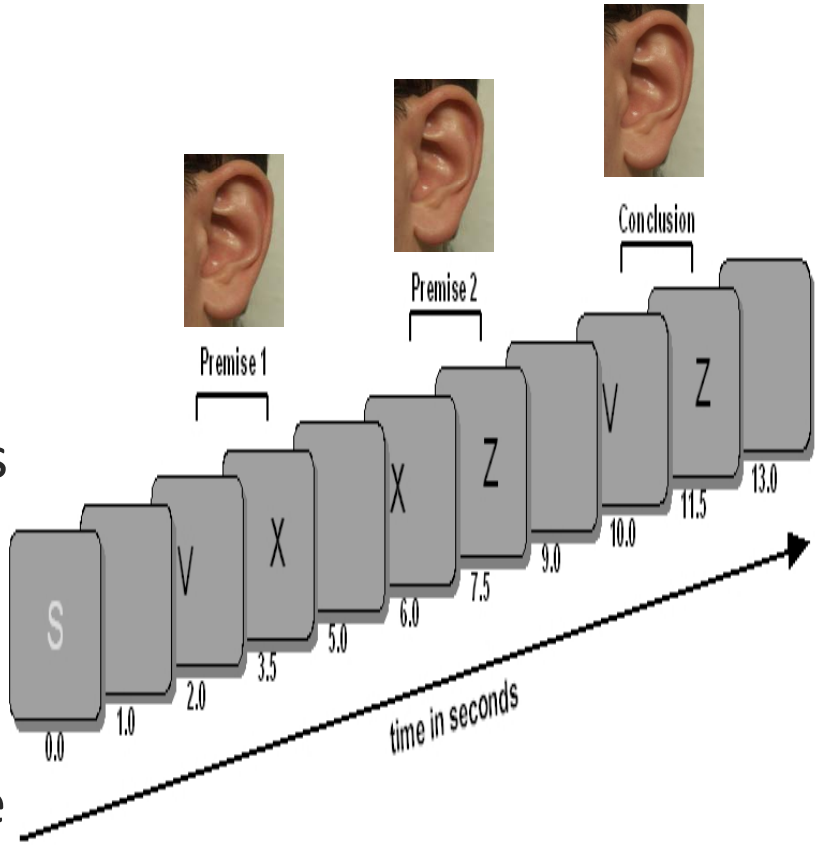



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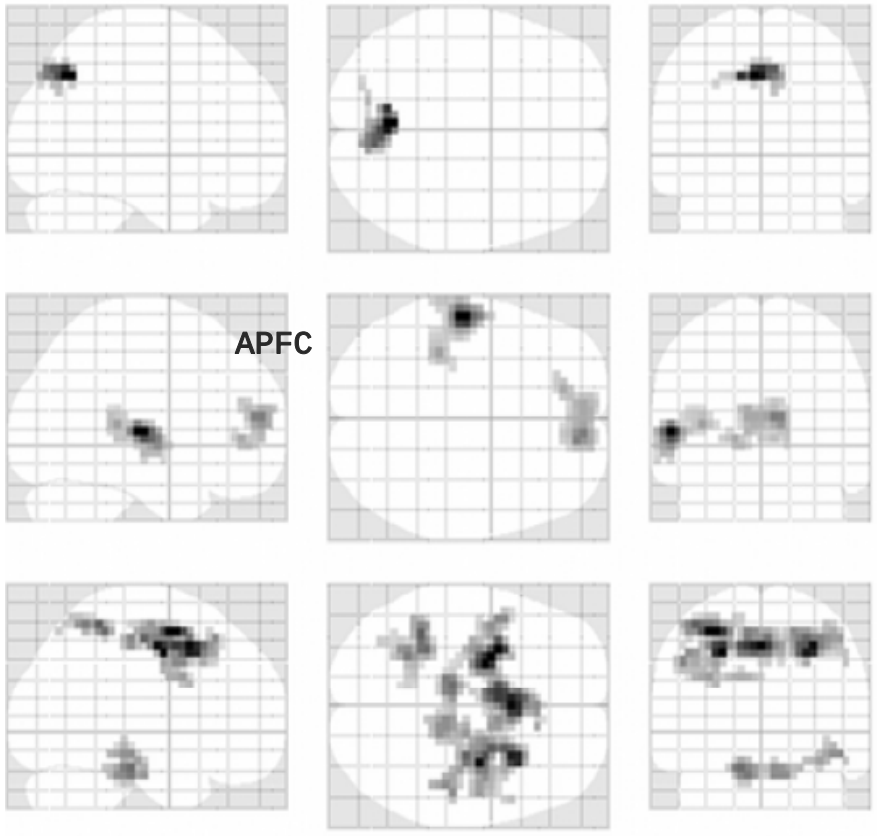
# Acoustical Problems

Fangmeier & Knauff (2009). *Brain Research, 1249, 181-190.*




- *premise processing phase:* superior parietal gyrus, precuneus, bilaterally
- *integration phase:* superior temporal gyrus, anterior heschl gyrus (BA 41 , 42)
- *validation phase*: prefrontal gyrus (L), parietal lobule (L); precuneus (R)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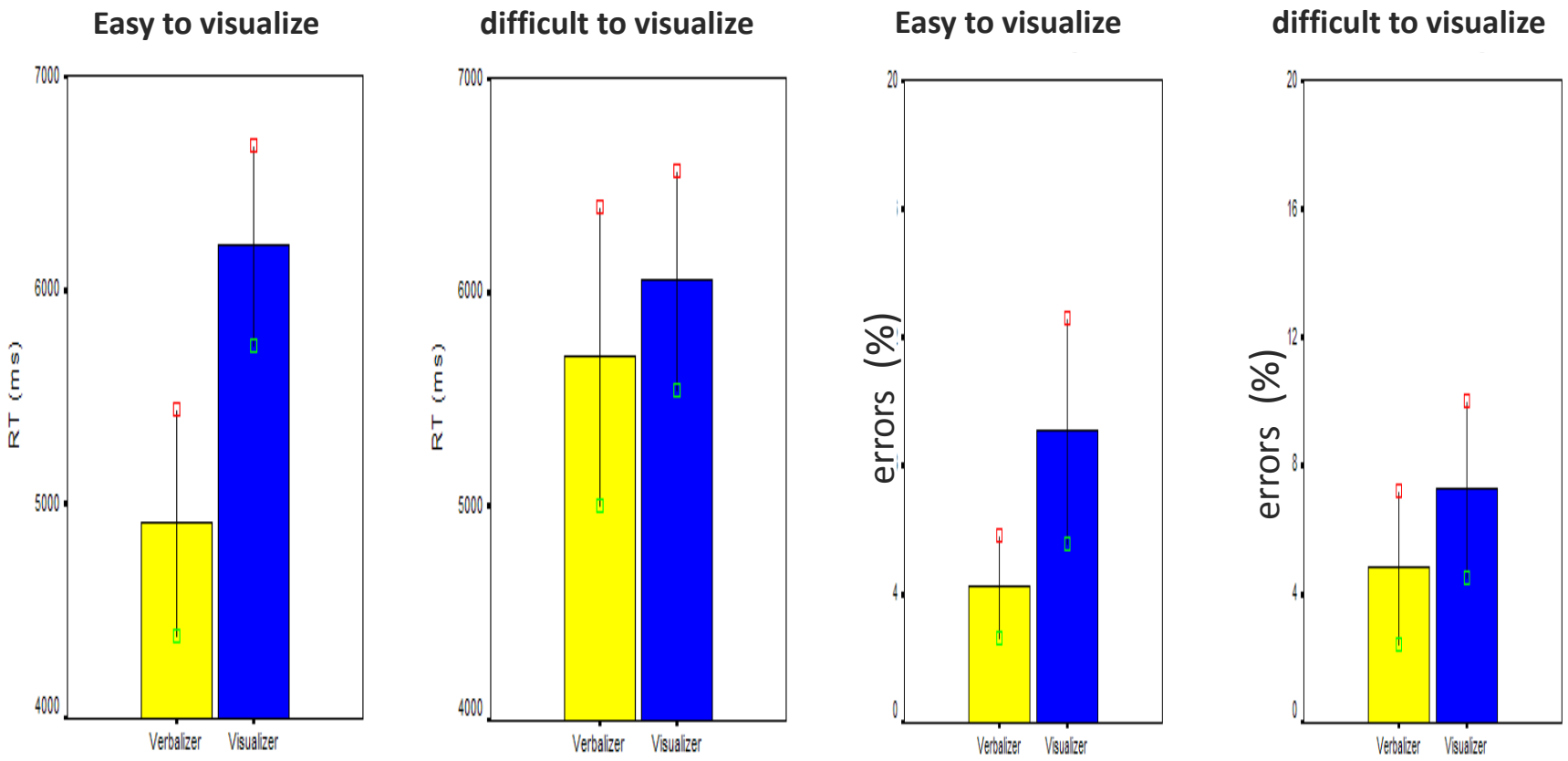
# Verbalizer vs. Visualizer

(Gazzo & Knauff, in prep.)



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# Individual differences and neural activity



Ruff, C. C., Knauff, M., Fangmeier, T., & Spreer, J. (2003). *Neuropsychologia, 41*, 1241-1253

- Participants (N = 12) solved 32 transitive Inferences
- participants spatial-constructive Intelligence were tested with the "Block Design Test" of the German equivalent to the Wechsler Adult Intelligence Scale (HAWIE-91)
  - min: $IQ_{BDT} = 103$
  - max: $IQ_{BDT} = 128$
  - mean: $IQ_{BDT} = 114.$
- positive correlation of spatial-constructive intelligence and number of correct responses ($r = .76$, $p < .01$)


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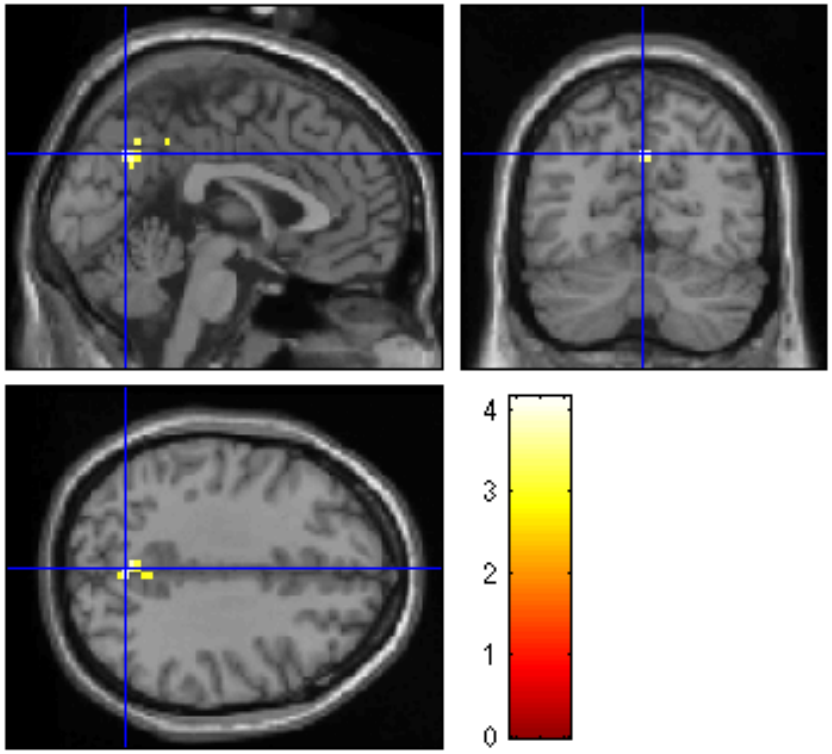
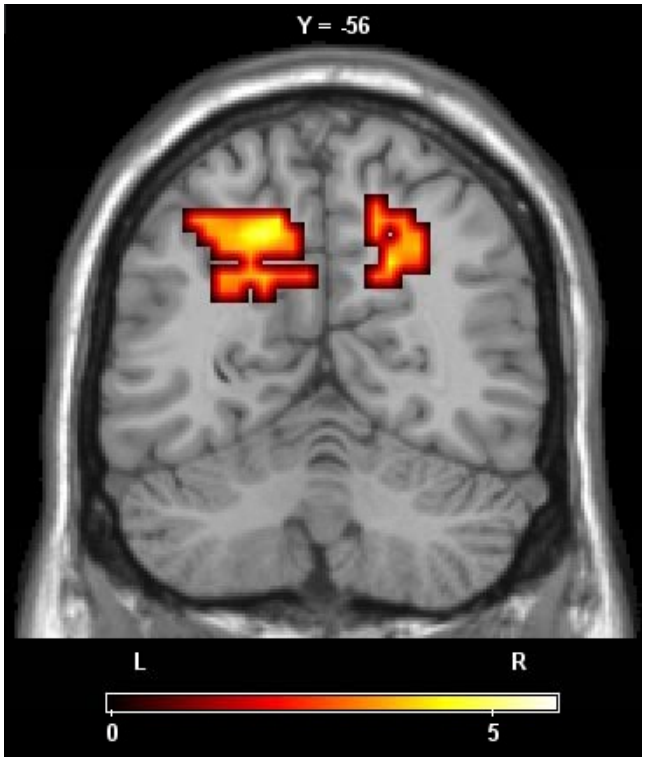
# Negative correlation between BOLD and visuo-spatial IQ

Ruff, C. C., Knauff, M., Fangmeier, T., & Spreer, J. (2003). *Neuropsychologia, 41*, 1241-1253



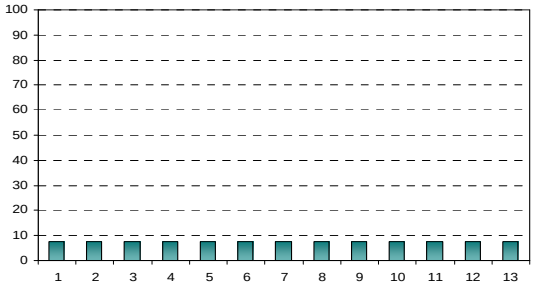

Contrast: all Problems vs. baseline (p < .001) with BDT score as Covariate (x = 0, Y = - 62, z = 36).

# Preferred mental models

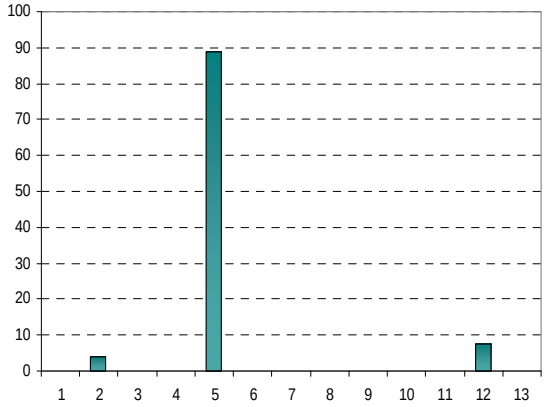


Rauh, R., Hagen, C., Knauff, M., Kuß, T., Schlieder, C., & Strube, G. (2005). *Spatial Cognition & Computation, 5*, 239-26
Jahn, G., Knauff, M. & Johnson-Laird, P. N. (2007). *Memory & Cognition*, *35*, 2075-2087

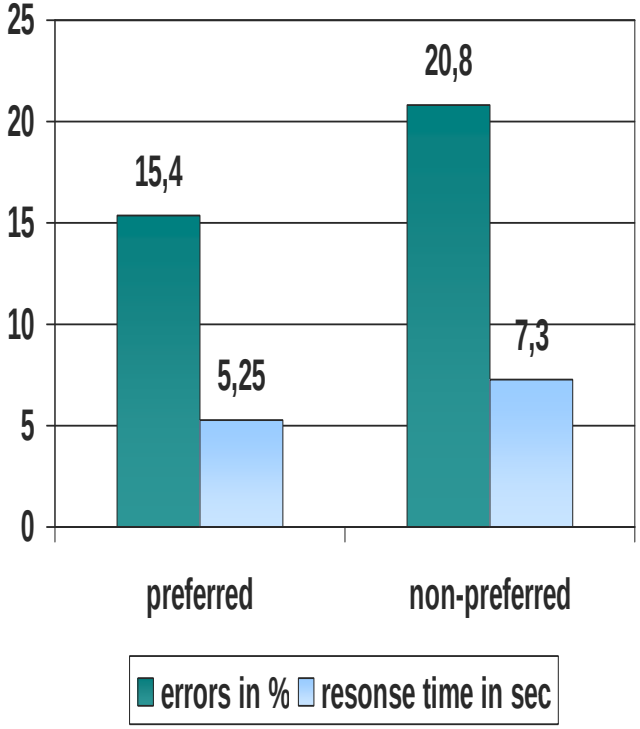
**Logically valid, expected**




**Empirically found**




- Verification: faster and more often correctly





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# Preferred Conclusions in Reasoning: Berendt's "visual account"

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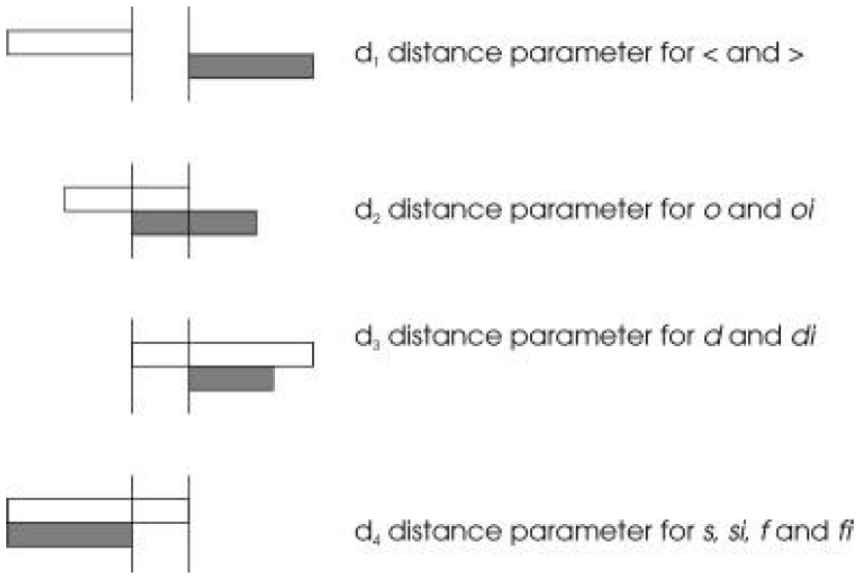


**Figure 18.** An illustration of metrical distance parameters used in reasoning with interval relations as described in Schlieder and Berendt (1998).

# Preferred Conclusions in Reasoning: Schlieder's "spatial account"

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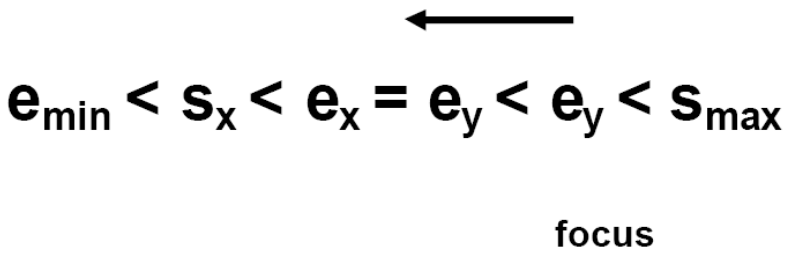


**Figure 21.** Point ordering information of an *X m Y* situation in the computational model by Schlieder (1995, 1999). The < within the gray rectangle is the focussed position *f* and the arrow indicates the scanning direction *d*.

# Modelling results

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- How many preferences can be reconstructed?
- Imagery account: 18 out of 72 preferences unexplained
- Spatial account: 2 out of 72 preferences unexplained
- The spatial account is more parsimonious and can reconstruct more empirically found preferences.

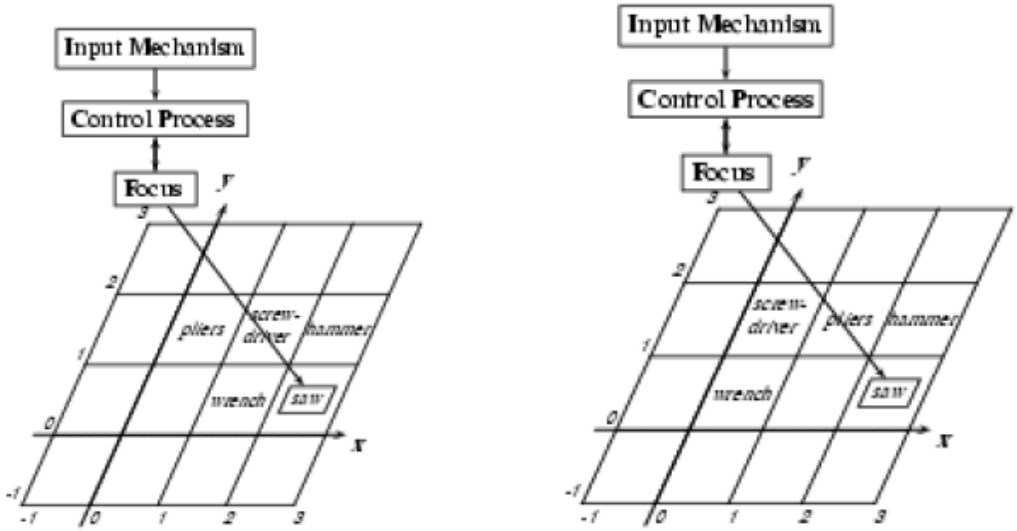
# The PRISM model



Ragni, M. Knauff, M., & Nebel, B. (2005). Proceedings of the 27th Annual Conference of the Cognitive Science Society, (pp. 1797-1802).
Ragni, M., Fangmeier, T., Brüssow, S., & Knauff, M. (submitted).

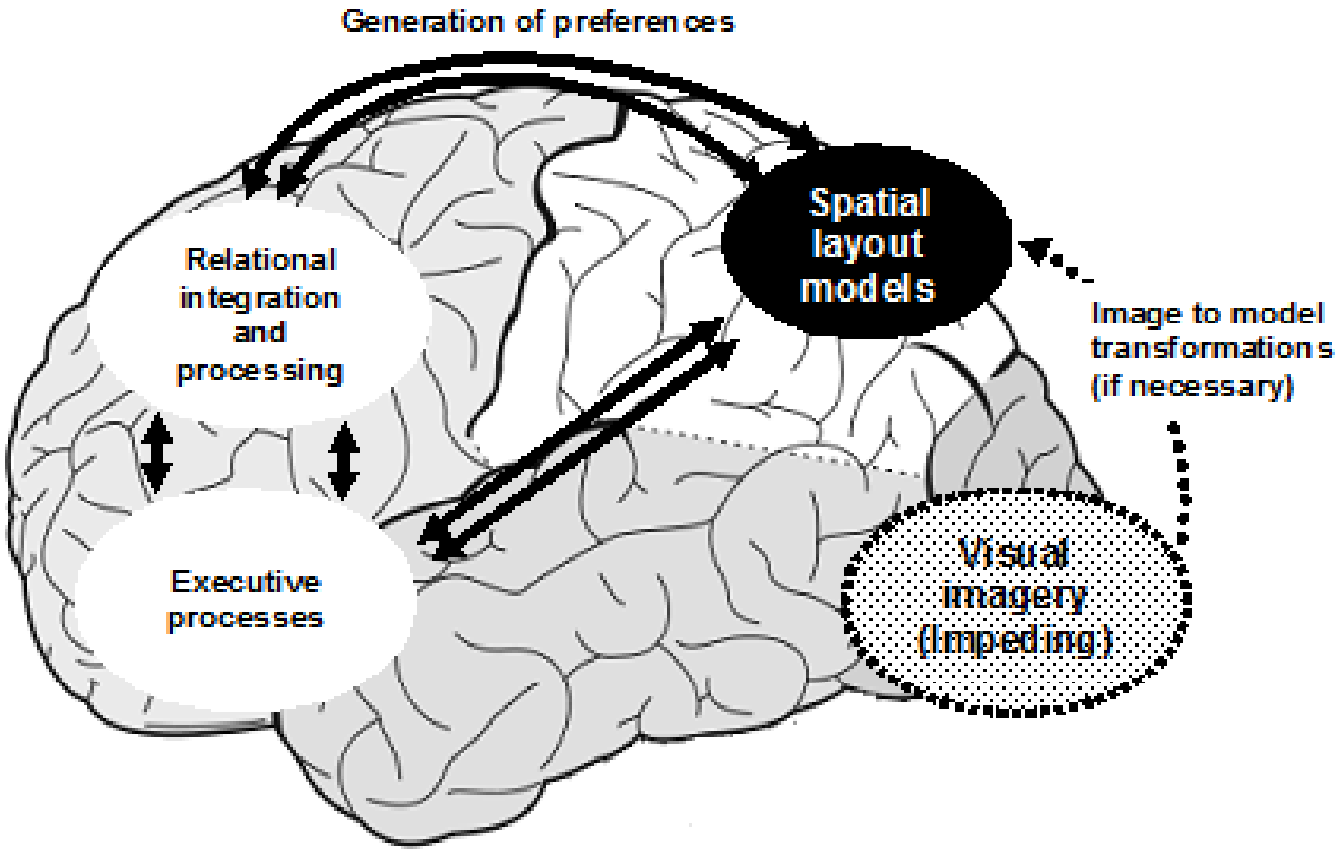
The hammer is to the right of the pliers.
The screwdriver is to the left of the hammer
The wrench is in front of the screwdriver.
The saw is in front of the hammer.

There are two possible models:



# Knauff, M. (to appear). *Space to Reason*. Cambridge, MA: MIT Press.





# Take-home-message

- previous studies have often shown activation of visual association cortices which points to the role of “visual mental imagery” in reasoning
- the theory explains why visual brain areas are indeed involved in premise processing and the construction of an initial static representation of the initial model
- but that more abstract spatial representations held in parietal cortices are crucial for the actual reasoning processes
- **Thus: visual images can impede reasoning**

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# Space to Reason

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For every complex problem, there is an answer that is short, simple, and wrong.

*H.L. Mencken (1880 - 1956)*