Neural correlates of similarity- and rule-based generalization

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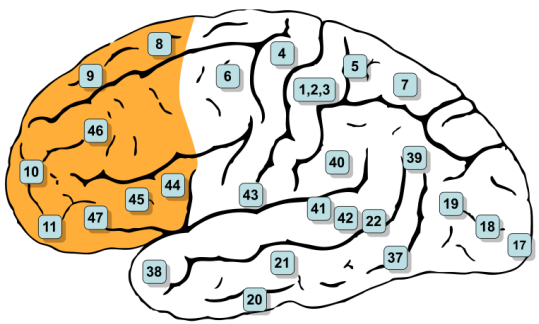
"A bachelor is an unmarried man"

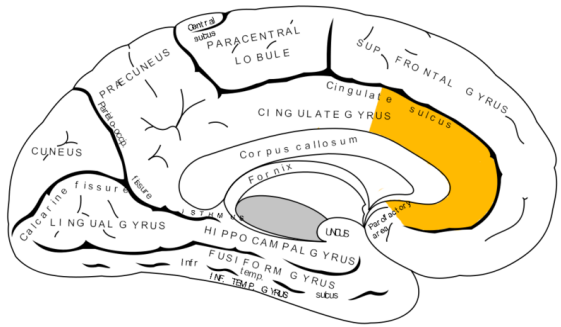
The pope is a bachelor.

Bachelor examples

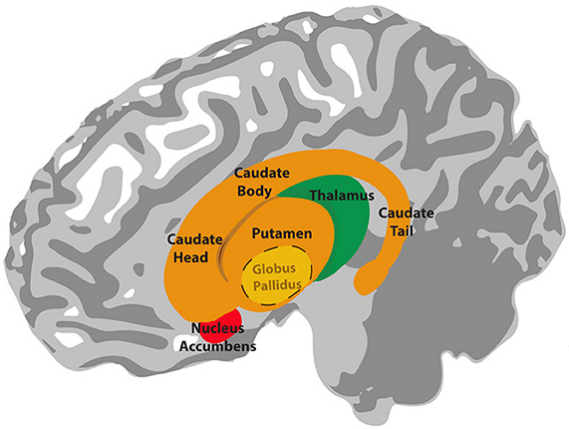
The pope may be a poor example of a bachelor.

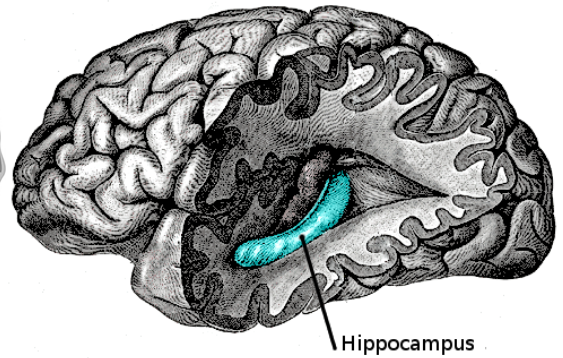
Rule-based system (COVIS)





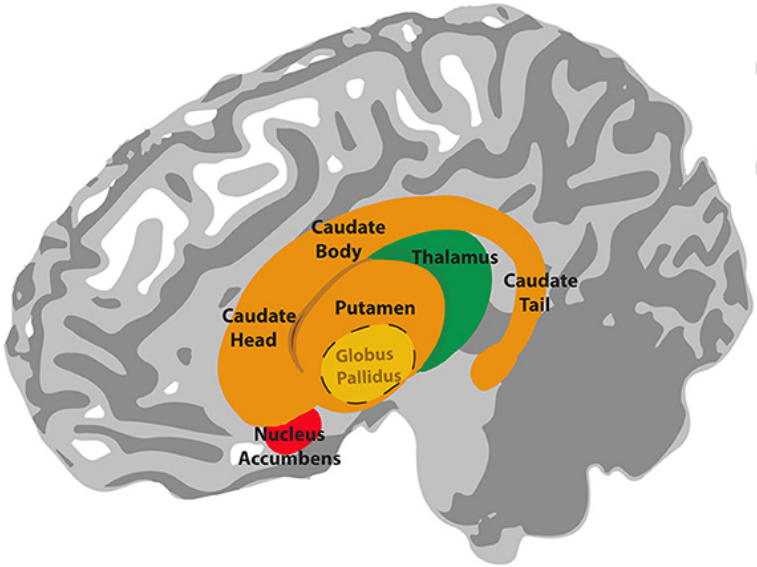
Prefrontal cortex, anterior cingulate

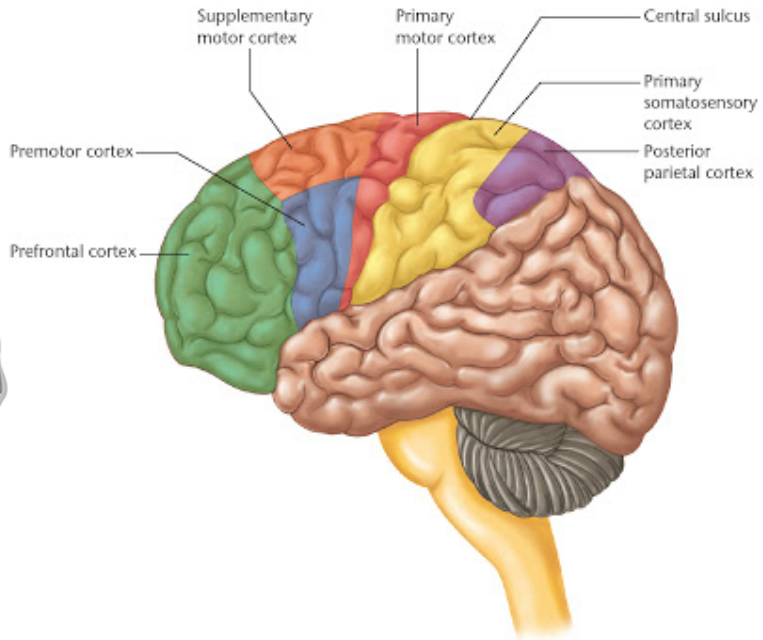




Caudate head, hippocampus.

Procedural system (COVIS)





Putamen, supplementary motor area.

Previous neuroimaging studies

1. Patalano, A.L., Smith, E.E., et al. (2001). *Cognitive, Affective & Behavioral Neuroscience*.
2. Grossman, M., Smith, E.E., Keonig, P. et al. (2002). *NeuroImage*.
3. Tracy, J.I. et al. (2003). *Brain & Cognition*.
4. Keonig, P., Smith, E.E. ... & Grossman, M. (2005). *NeuroImage*.
5. Nomura, E.M. et al. (2007). *Cerebral Cortex*.

Pizza-quarter procedure (Rips, 1989)

Object that is round, 2 inches in diameter. Pizza or quarter?

Criterial-attribute procedure

- Introduced by
  - Kemler Nelson, D.G. (1984). *Journal of Verbal Learning and Verbal Behaviour*.
- Used in the following fMRI studies:
  - Tracy, J.I. et al. (2003). *Brain & Cognition*.
  - Keonig, P., Smith, E.E. ... & Grossman, M. (2005). *NeuroImage*.
- Critiqued by:
  - Wills, A.J., Inkster, A.B. & Milton, F. (2015).*Cognitive Psychology*.
- Critique consistent with following fMRI study:
  - Milton, F., Wills, A.J. & Hodgson, T.L. (2009). *NeuroImage*.

RB / II procedure (Nomura et al., 2007)

- Inspired by Greg Ashby's work, e.g.
  - Ashby, F.G. & Maddox, W.T. (2011). *Annals of the New York Academy of Sciences*
- ...which has been extensively critiqued e.g.
  - Edmunds, C.E.R. et al. (2015). *QJEP*.
  - Newell, B.R. et al. (2013). *Psychological Science*.
- ...and Nomura's conclusion turns out to be largely wrong:
  - Carpenter, K. et al. (2016, submitted). *Human Brain Mapping*.

Allergy prediction: Example trial

Mr X consumes a meal containing

Apples and Bananas

C= No Reaction M= Reaction

Allergy prediction: Example trial

Incorrect Mr X had a Reaction

Shanks-Darby procedure

Training			Test		
A+	B+	AB-	A?	B?	AB?
C-	D-	CD+	C?	D?	CD?
E+	F+	EF-	E?	F?	EF?
G-	H-	GH+	G?	H?	GH?
I+	J+		I?	J?	**IJ?**
		KL-	**K?**	**L?**	KL?
M-	N-		M?	N?	**MN?**
		OP+	**O?**	**P?**	OP?

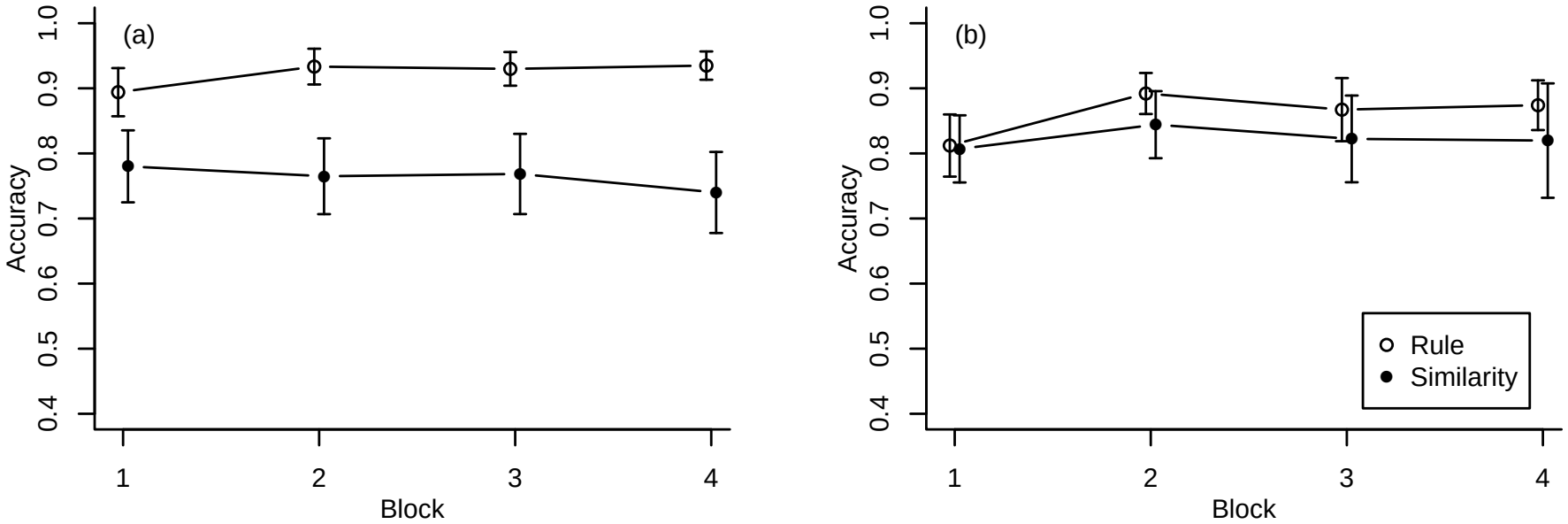
Similarity-based inference - IJ makes Mr.X sick, MN is fine.
Rule-based inference - IJ is fine, MN is sick.

Selected Shanks-Darby results

- Effect of concurrent load
  - Wills, A.J., Graham, S., Koh, Z., McLaren, I.P.L., & Rolland, M.D. (2011). Effects of concurrent load on feature- and rule-based generalization in human contingency learning. *Journal of Experimental Psychology: Animal Behavior Processes, 37,* 308-316.
- Working memory capacity
  - Wills, A.J., Barrasin, T.J., & McLaren, I.P.L. (2011). Working memory capacity and generalization in predictive learning. In L. Carlson, C. Holscher, & T. Shipley (Eds.). *Proceedings of the 33rd Annual Conference of the Cognitive Science Society* (pp. 3205-3210). Austin, TX: Cognitive Science Society
- Rats, pigeons, and adult humans
  - Maes, E., De Filippo, G., Inkster, A., Lea, S.E.G., De Houwer, J., D'Hooge, R., Beckers, T., & Wills, A.J. (2015). Feature- versus rule-based generalization in rats, pigeons and humans. *Animal Cognition, 18,* 1267–1284.

Exeter MR centre

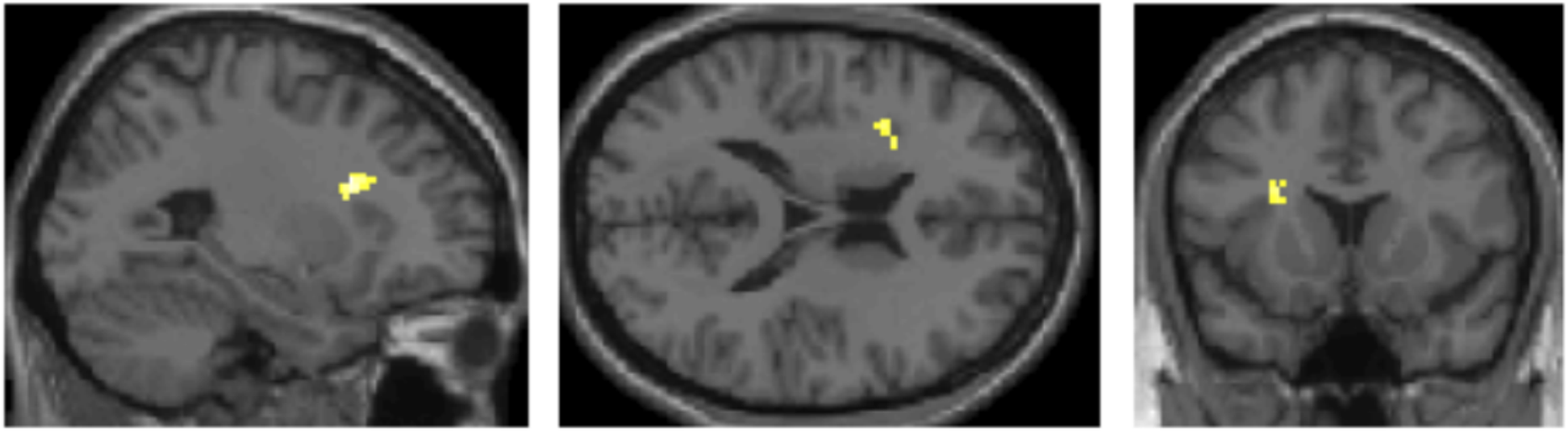
Results: Behavioural



Filled circles = rule-consistent. Open circles = similarity-consistent

Error bars are difference-adjusted 95% confidence intervals for the between-subjects effect.

Results: Imaging (Rule - Similarity)



x = -26; y = 14; z = 16

$p < .001$ uncorrected, combined with 24-contiguous-voxel cluster threshold, resulting in an overall corrected threshold of $p < .05$, according to AlphaSim in the REST toolbox (Song et al., 2011).

Results (more detail)

			Talairach Coordinates			
Region	*Cluster size*	*BA*	*x*	*y*	*z*	*z-score*
Similarity - Rule-based						
Left occipital lobes	149	18	-20	-67	-10	4.24
Left cerebellum		-	-20	-67	-12	4.04
Left lateral globus pallidus	58	-	-20	0	-7	4.13
Left amygdala		-	-24	-3	-18	3.67
Right parietal lobes	90	40	56	-39	31	4.11
Right inferior parietal lobes		40	50	-39	41	3.58
Left inferior frontal gyrus	57	47	-50	19	-4	4.01
Left inferior parietal lobes	28	40	-34	-38	52	3.48
Left precuneus		7	-26	-44	48	3.48
Rule-based - Similarity						
Left middle frontal gyrus	58	9	-26	17	21	4.23
Left insula		13	-32	11	16	3.60

Note. BA = brodmann's area. All activations significant at p<.001. Indented rows