Neural correlates of similarity- and rule-based generalization

Andy J. Wills[1] Fraser Milton[2]

[1]Plymouth University, UK

[2]University of Exeter, UK

2016-01-08

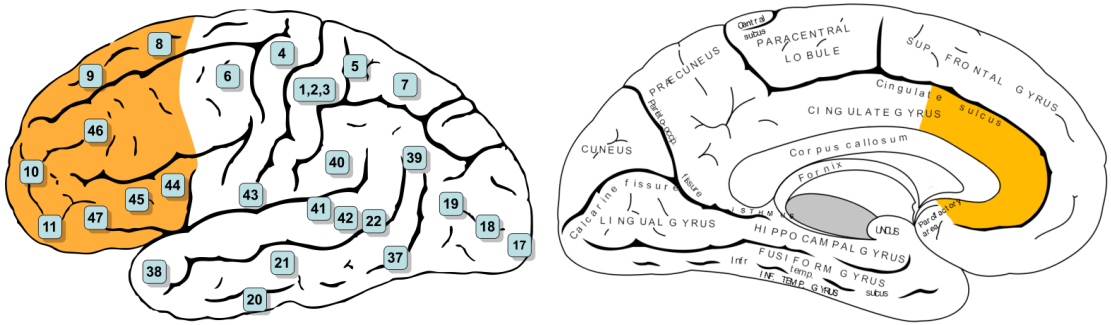
"A bachelor is an unmarried man"

The pope is a bachelor.

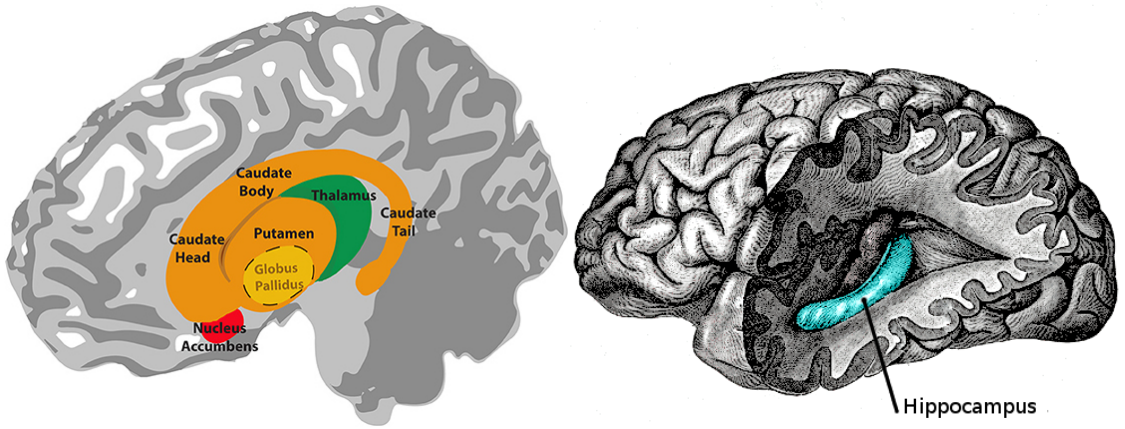
Bachelor examples

The pope may be a poor example of a bachelor.

Rule-based system (COVIS)

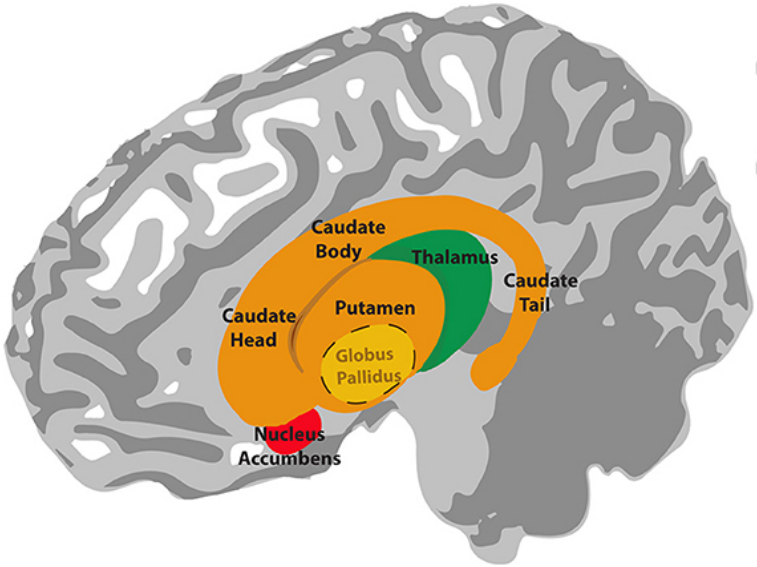


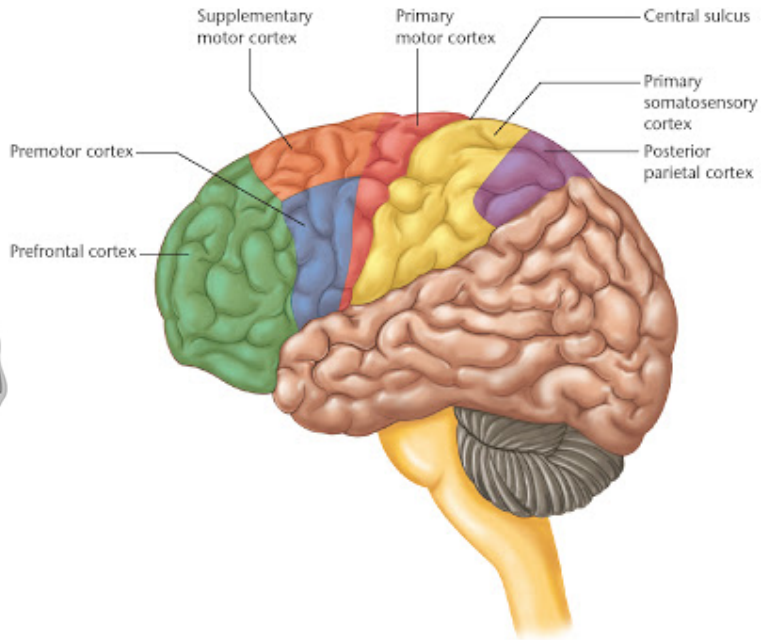
Prefrontal cortex, anterior cingulate



Caudate head, hippocampus.

Procedural system (COVIS)





Putamen, supplementary motor area.

Ed Smith (1940–2012) and colleagues

- Patalano, A.L., **Smith, E.E.**, Jonides, J. & Koeppe, R.A. (2001). PET evidence for multiple strategies of categorization. *Cognitive, Affective & Behavioral Neuroscience, 1*,360–370.
- **Grossman, M., Smith, E.E., Keonig, P.**, Glosser, G., **DeVita, C., Moore, P.** & McMillan, C. (2002). The neural basis for categorization in semantic memory. *NeuroImage, 17,* 1429–1561.
- **Keonig, P., Smith, E.E., DeVita, C., Moore, P.**, McMillan, C., Gee, J. & **Grossman, M**. (2005). The neural basis for novel semantic categorization. *NeuroImage, 24,* 369–383.

Pizza-quarter procedure (Rips, 1989)

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

Criterial-attribute procedure

Deborah Kemler Nelson

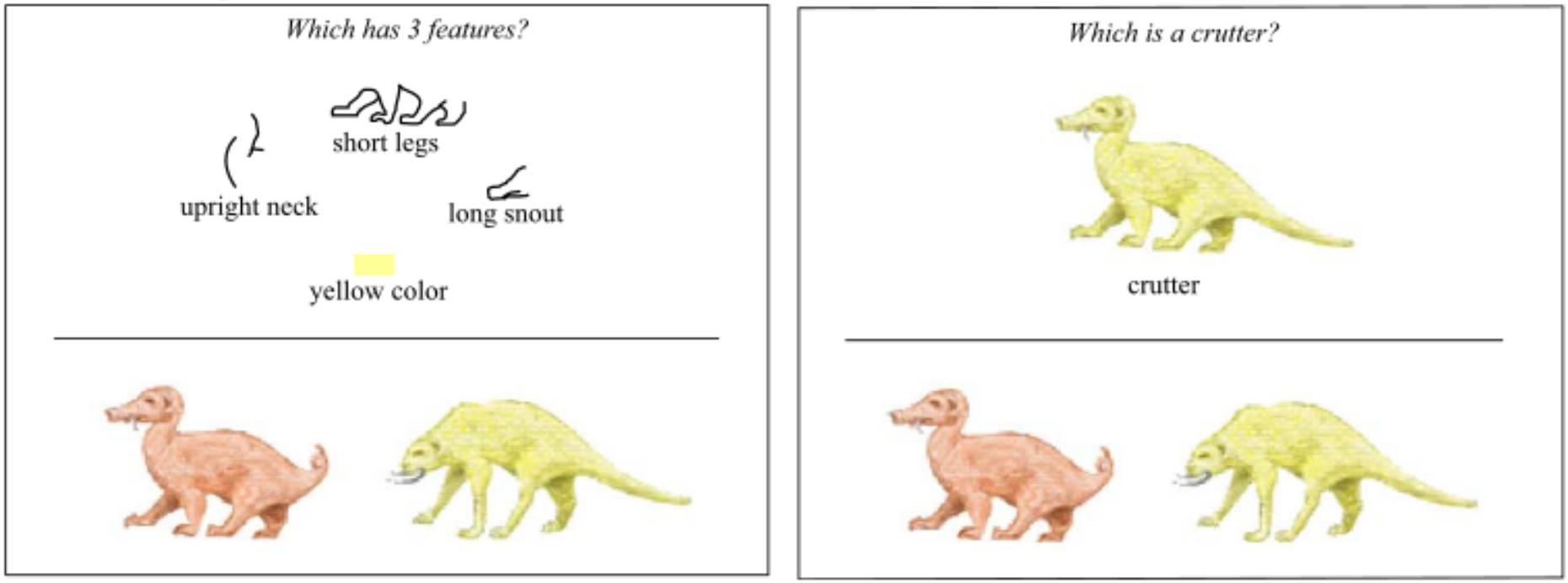
- Kemler Nelson, D.G. (1984). The effect of intention on what concepts are acquired. *Journal of Verbal Learning and Verbal Behaviour, 23,* 734–759.
- Wills, A.J., Inkster, A.B. & Milton, F. (2015). Combination or Differentiation? Two theories of processing order in classification. *Cognitive Psychology, 80,* 1–33.

Tracy et al. (2003)

- "Similarity-based" category structure
  - Category 1: `LIRU,GERU,GITU,GIRA`
  - Category 2: `GETA,LITA,LERA,LETU`
- "Rule-based" category structure
  - Category 1: `BUNO, KYNO, KUNA, BYNA`
  - Category 2: `KYPA, BUPA, BYPO, KUPO`

Tracy, J.I., Mohamed, F., Faro, S., Pinus, A., Tiver, R., Harvan, J., Bloomer, C., Pyros, A. & Madi, S. (2003). Differential brain responses when applying criterion attribute versus family resemblance rule learning. *Brain and Cognition, 51,* 276–286.

Koenig et al., (2005)



Rule procedure (left), and Similarity procedure (right)

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?

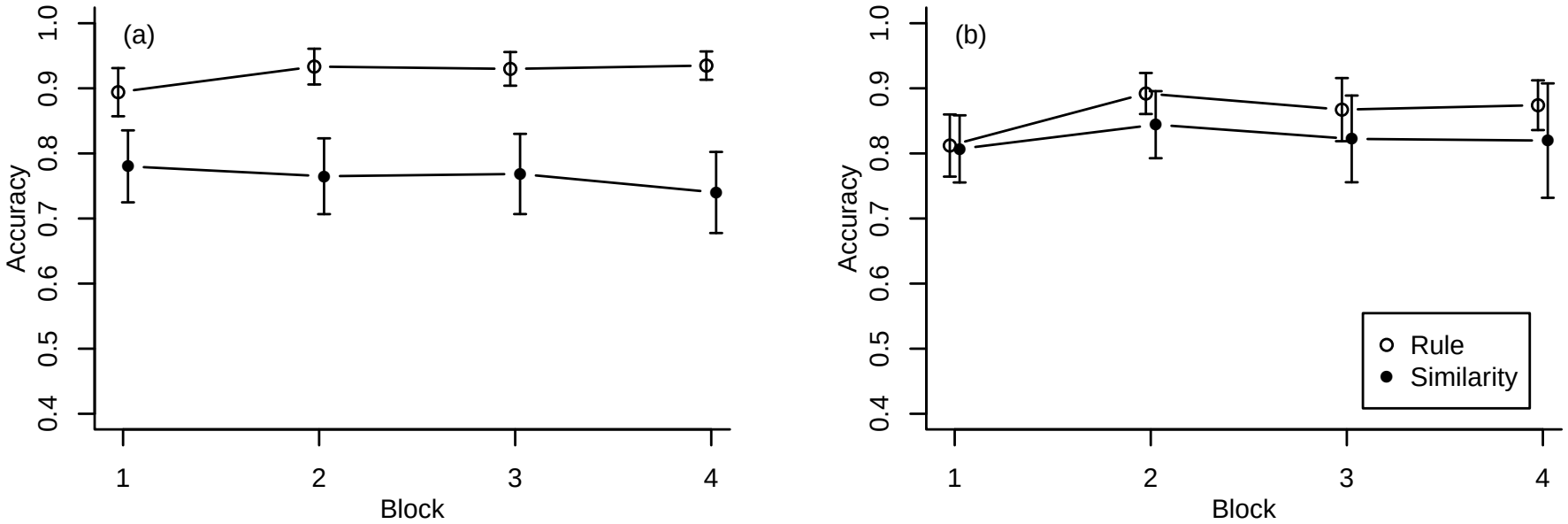
Similarity-based inference - IJ makes Mr.X sick, MN is fine.
Rule-based inference - IJ is fine, MN is sick.

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

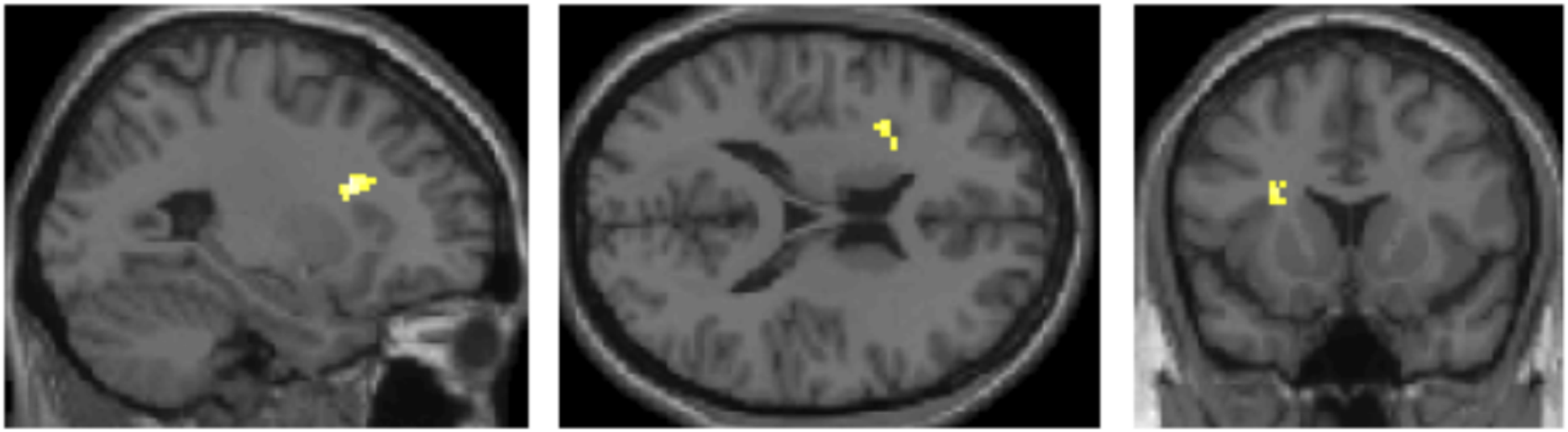
Results: Behavioural



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).

All you need is rules, rules ... rules are all you need

Chris Mitchell (Plymouth University)

Mitchell, C.J., De Houwer, J. & Lovibond, P.F. (2009). The propositional nature of human associative learning. *Behavioral and Brain Sciences, 32*, 183–246.