Word-Object Learning via Visual Exploration in Space (WOLVES): A Process Model of Cross-Situational Word Learning

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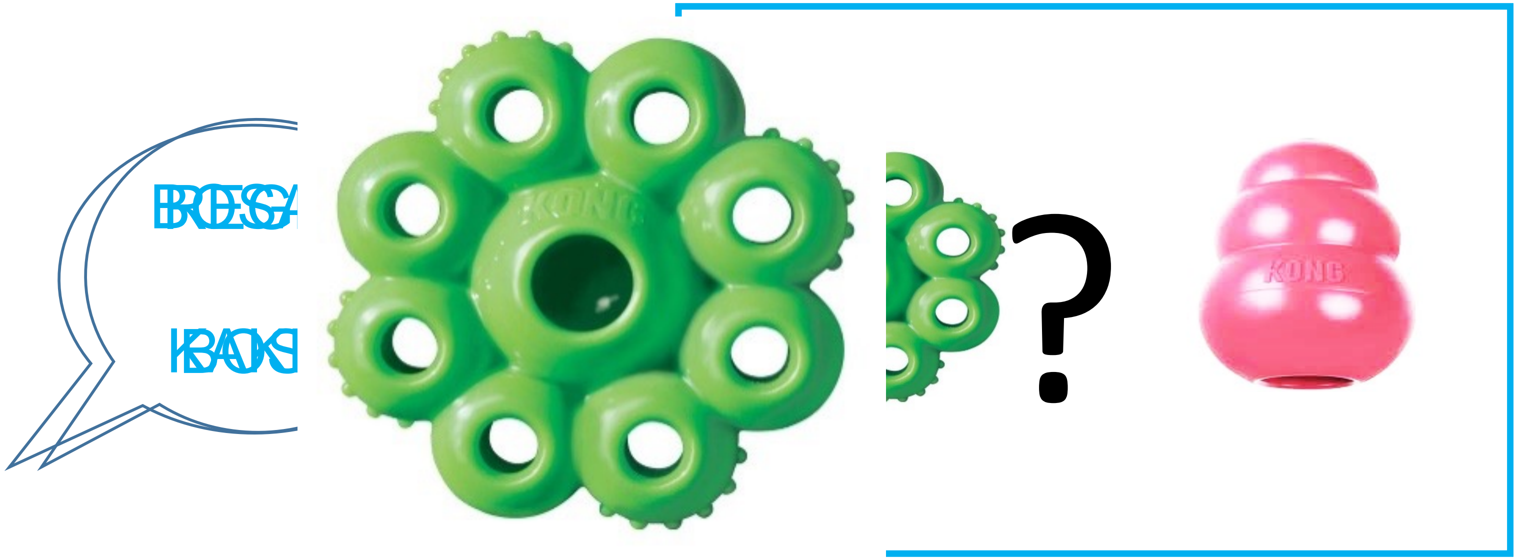
Cross-Situational Word Learning

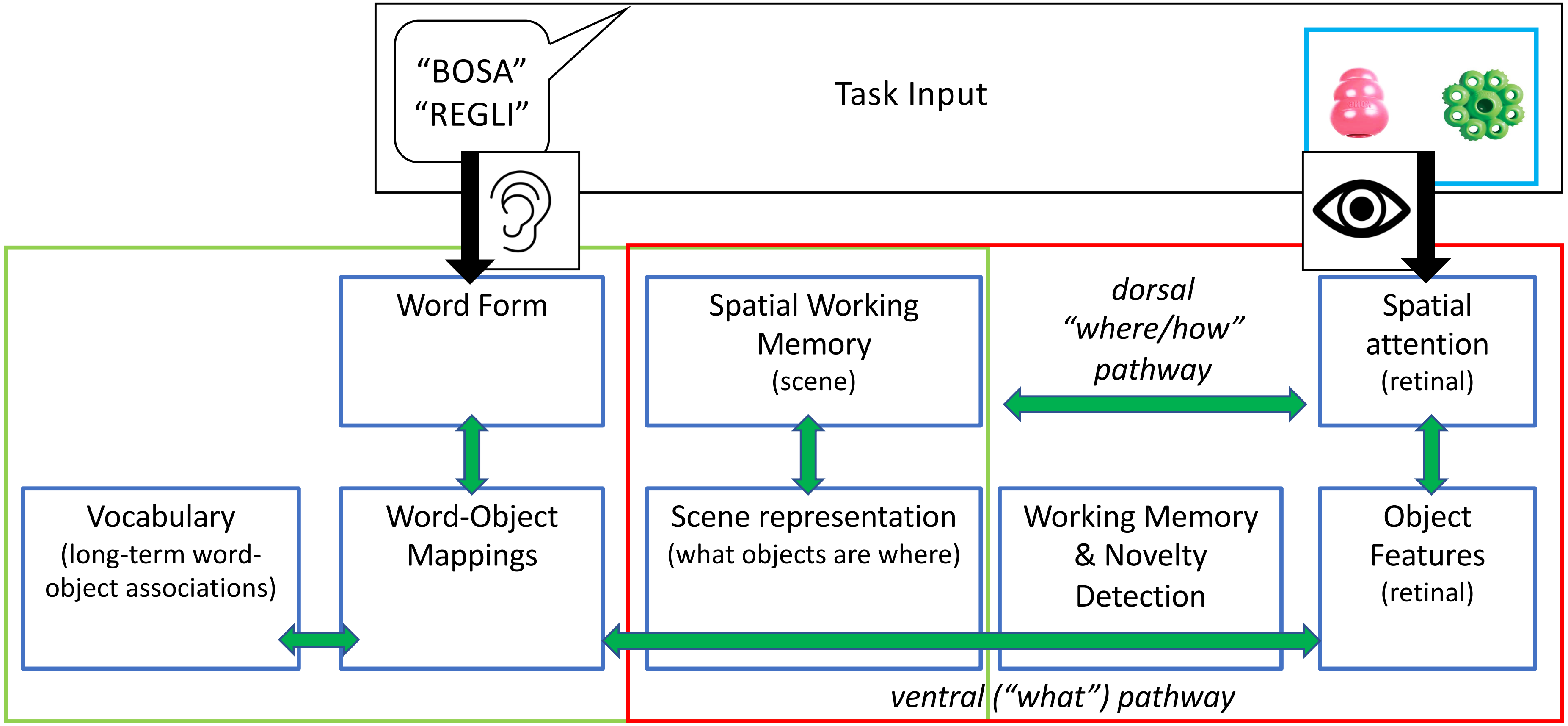


- 12-14 month old children can learn 4 words (Smith & Yu, 2008, Yu & Smith, 2011). Older kids and adults can learn up to 9-16 words.
- Individual differences: ‘strong’ vs ‘weak’ learners.
- Moment-by-moment variation in looking matters.
- There is evidence of multiple learning processes (e.g., habituation).
- Changes over the timescale of development

Today's talk

- WOLVES
  - Overview of model & demonstrate that it is a good model.
- Timescale of the task
  - Simulations that highlight role of attention and learning processes.
- Timescale of development
  - Present the first developmental account of CSWL highlighting the role of memory processes.
- Future Directions
  - How we want to use the model to understand individual differences.

WOLVES



Word-Object Learning

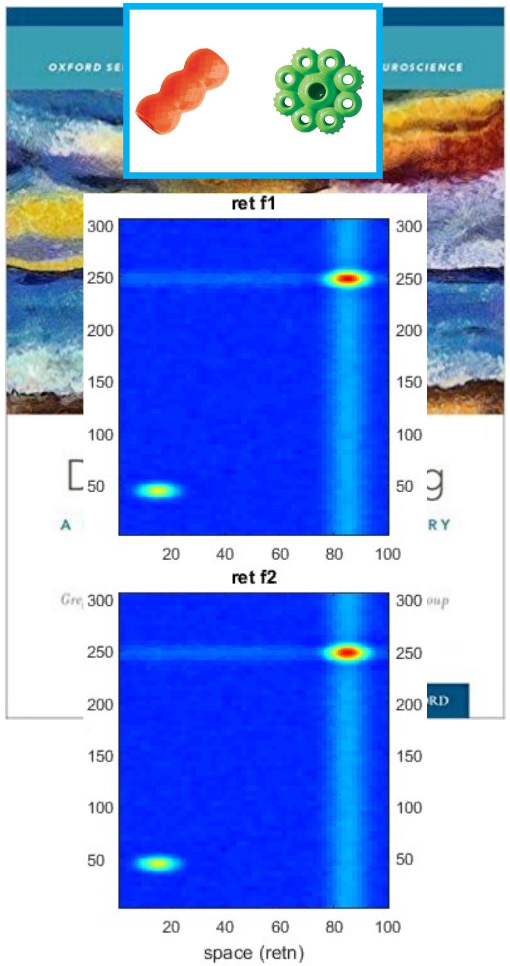
Samuelson, Smith, Perry & Spencer (2011);
Samuelson, Jenkins & Spencer (2013)

Visual Exploration in Space

Johnson, Spencer & Schöner (2009);
Perone & Spencer (2013b)

WOLVES: Overview

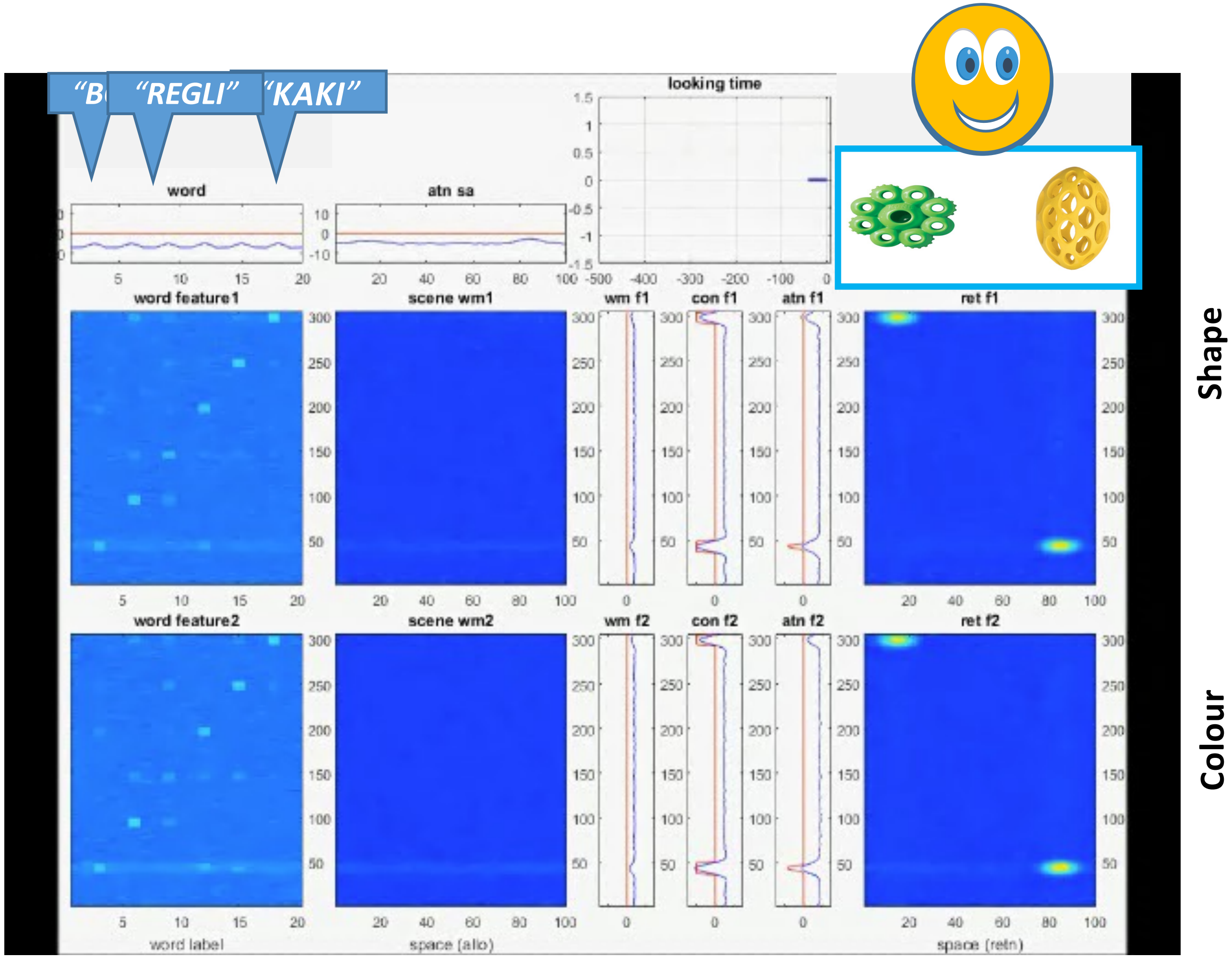
- Uses the concepts of Dynamic Field Theory – a theoretical framework for understanding how neural population dynamics give rise to behavior, learning, and development
- Real-time integration of information creates neural attractor states called ‘peaks’ that reflect localized decisions about the world
    - ✦ The green round object is on the right



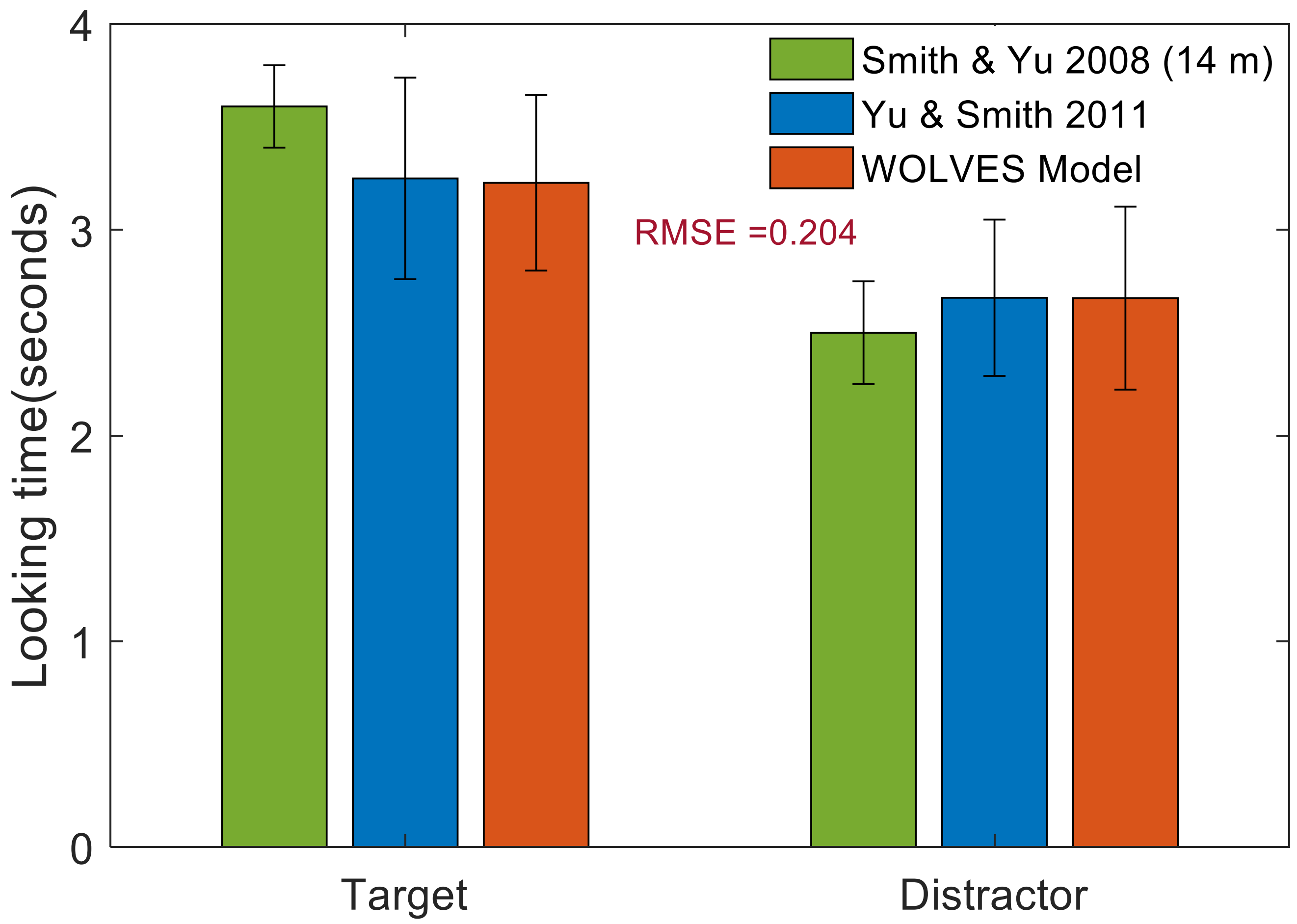
- ✦ These decisions are remembered in memory traces that can bias decision-making over learning
    - ✦ Like local connection weights in a neural network model

WOLVES in action

- Cycles of novelty detection and consolidation in working memory.
- Associative learning that is non-linear.
- Evolving memory traces
- Top-down memory driven attention.



Smith & Yu (2008) , Yu & Smith (2011)

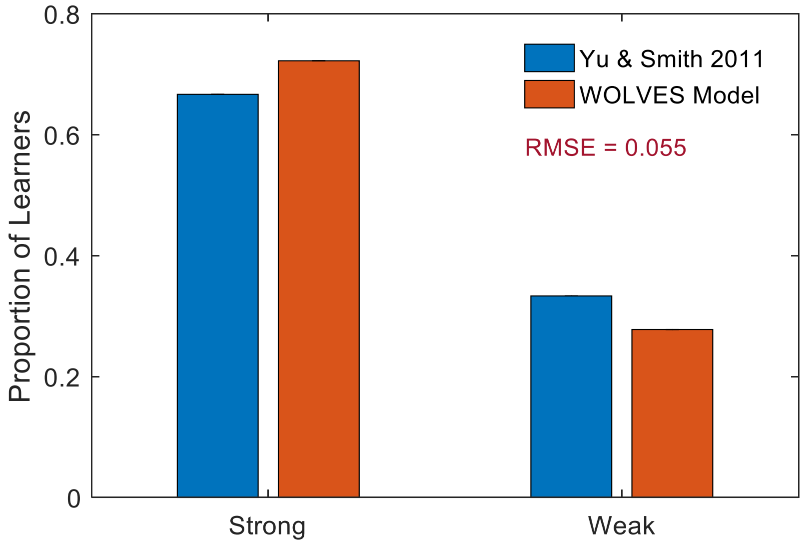


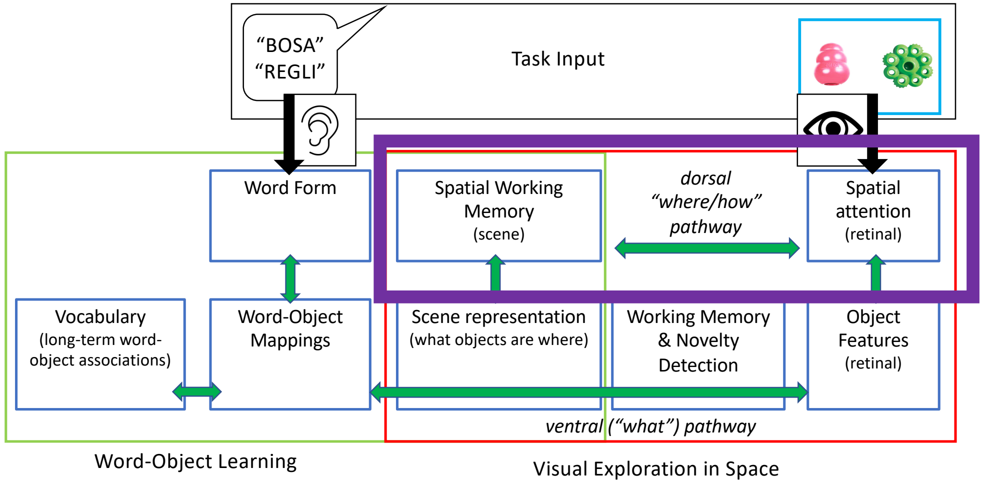
Smith & Yu (2008) , Yu & Smith (2011)

Measure	S & Y (2008)	Y & S (2011)		WOLVES	RMSE	MAPE
Test Trials						
Mean looking per 8s trial	6.10	5.92		6.26	.26	4.22
Pref. looking ratio	.60	.54		.54	.04	6.10
Mean words learned (of 6)	4.0	3.5		4.0	.35	7.14
Prop. Strong/weak learners	NA	.67		.74	.07	10.45
Mean looking to target per trial	3.6	3.25		3.36	.19	5.03
Mean looking to distractor per trial	2.5	2.67		2.89	.32	11.92
Training Trials		S	W			
Mean looking per 4s trial	3.04	2.96	3.07	3.01	.02	.71
Mean fixations per trial	NA	2.75	3.82	2.89	.22	6.98
Mean fixation duration	NA	1.69	1.21	1.31	.22	14.38

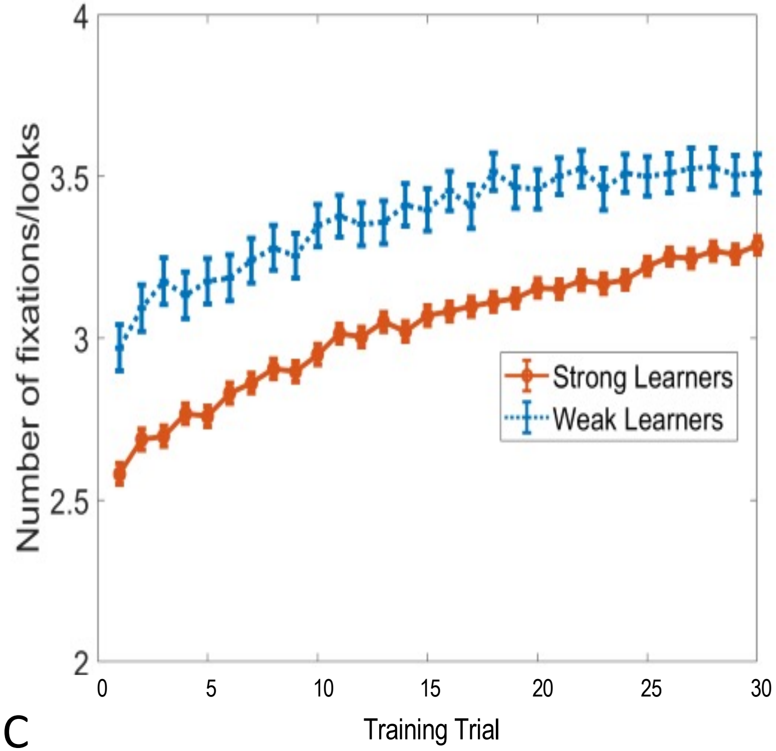
RMSE = Root Mean Squared Error, MAPE = Mean Absolute Percentage Error

The Role of Spatial Attention





- Spatial attention parameter
- Sort by strong/weak learners.
- Weak learners have more, shorter, fixations.



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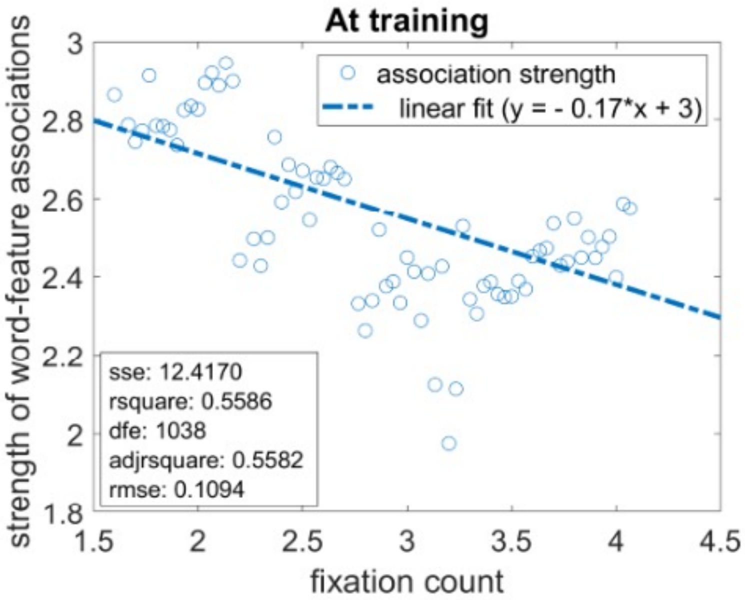
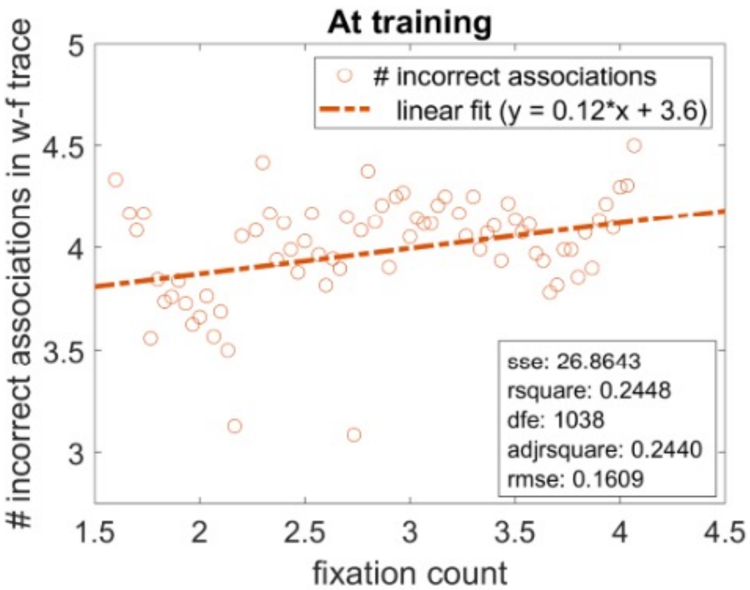
The Role of Spatial Attention





- As fixations go up, association strength goes down.
- As fixations go up, incorrect associations go up.

We created the difference between strong and weak learners via manipulation of a particular parameter.

This mechanistically relates variations in spatial attention to learning outcomes.

Model Validation; coverage & comparison

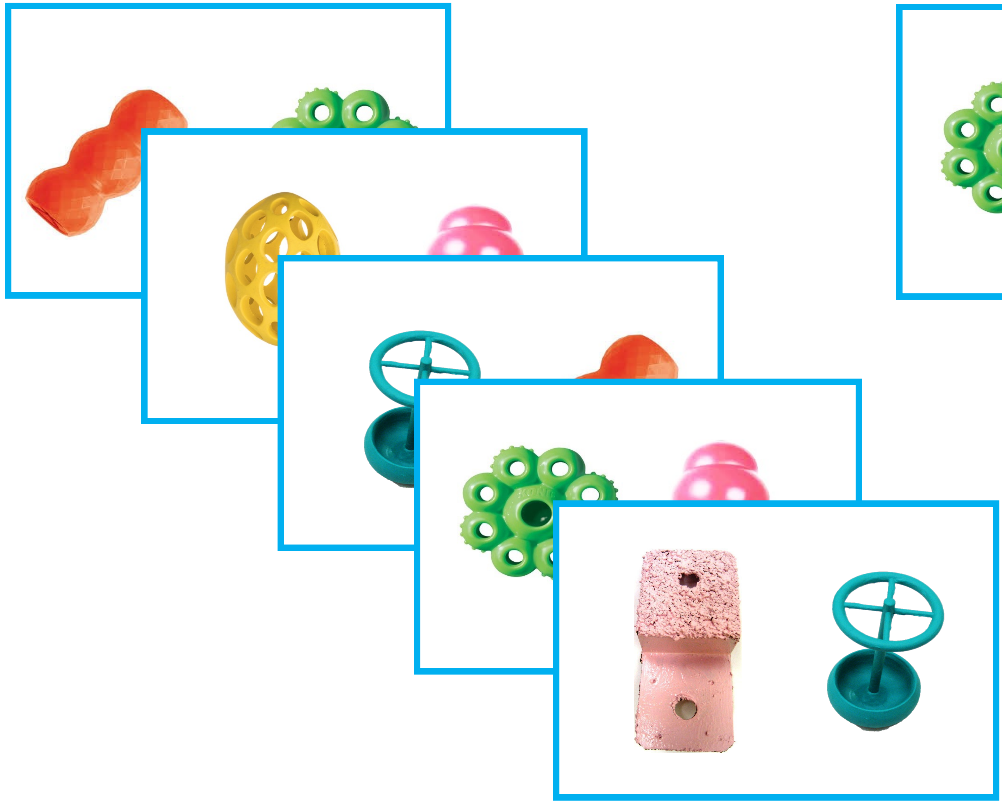
- 5 CSWL studies with adults
  - Trueswell et al. (2013), Yu & Smith (2007), Yu, Zhong & Fricker (2012), Yurovsky et al. (2012), Kachergis et al. (2012)
- 7 CSWL studies with infants, toddlers & children
  - Smith & Yu (2008), Yu & Smith (2011), Smith & Yu (2013), Vlach & Johnson (2013), Vlach & DeBrock (2019), Vlach & DeBrock (2017), Suanda et al. (2014)

Measure	Data Points	WOLVES		Kachergis et al.+		Pursuit*	
		RMSE	MAPE	RMSE	MAPE	RMSE	MAPE
Grand Mean Specific tasks	69	.05	13.51	.08	19.95	.20	42.13
Standard Deviations	69	.04	15.79	.07	21.99	.13	25.52
Grand Mean	132	.10	15.80	unable to capture			
Overall AIC		-239.67		-295.78		-193.32	

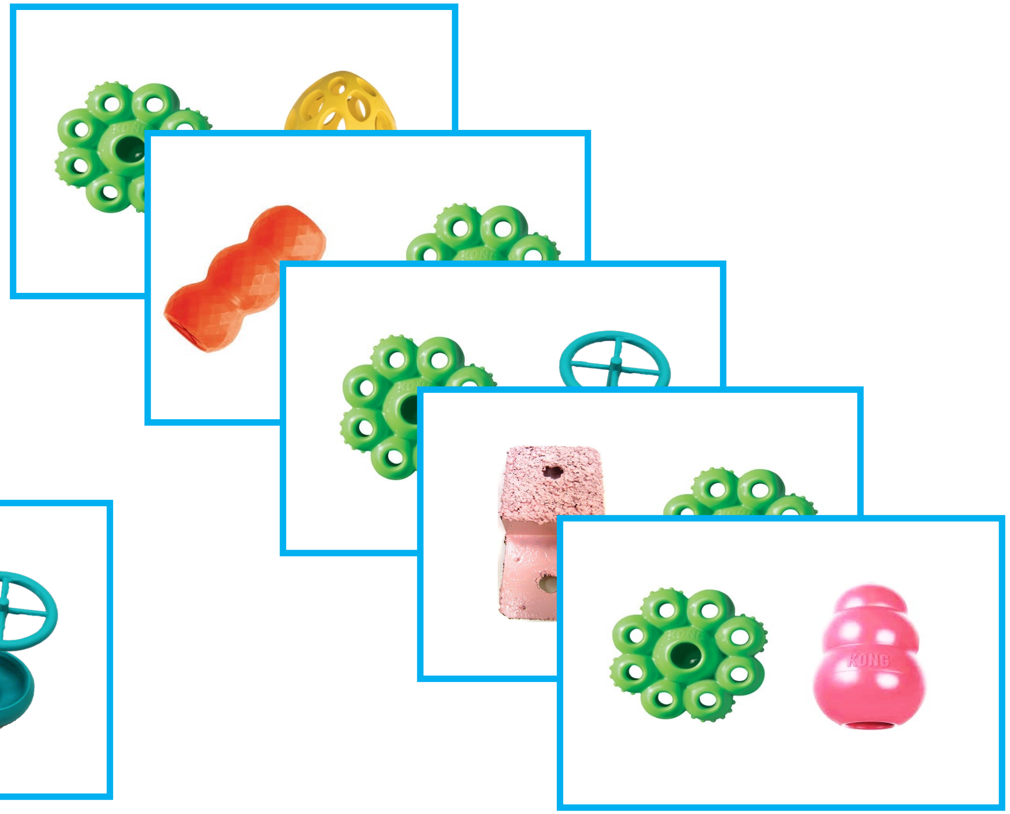
+Kachergigs et al. (2012, 2013, 2017); *Stevens et al. (2017)

Timescale of the task

Smith & Yu (2008)



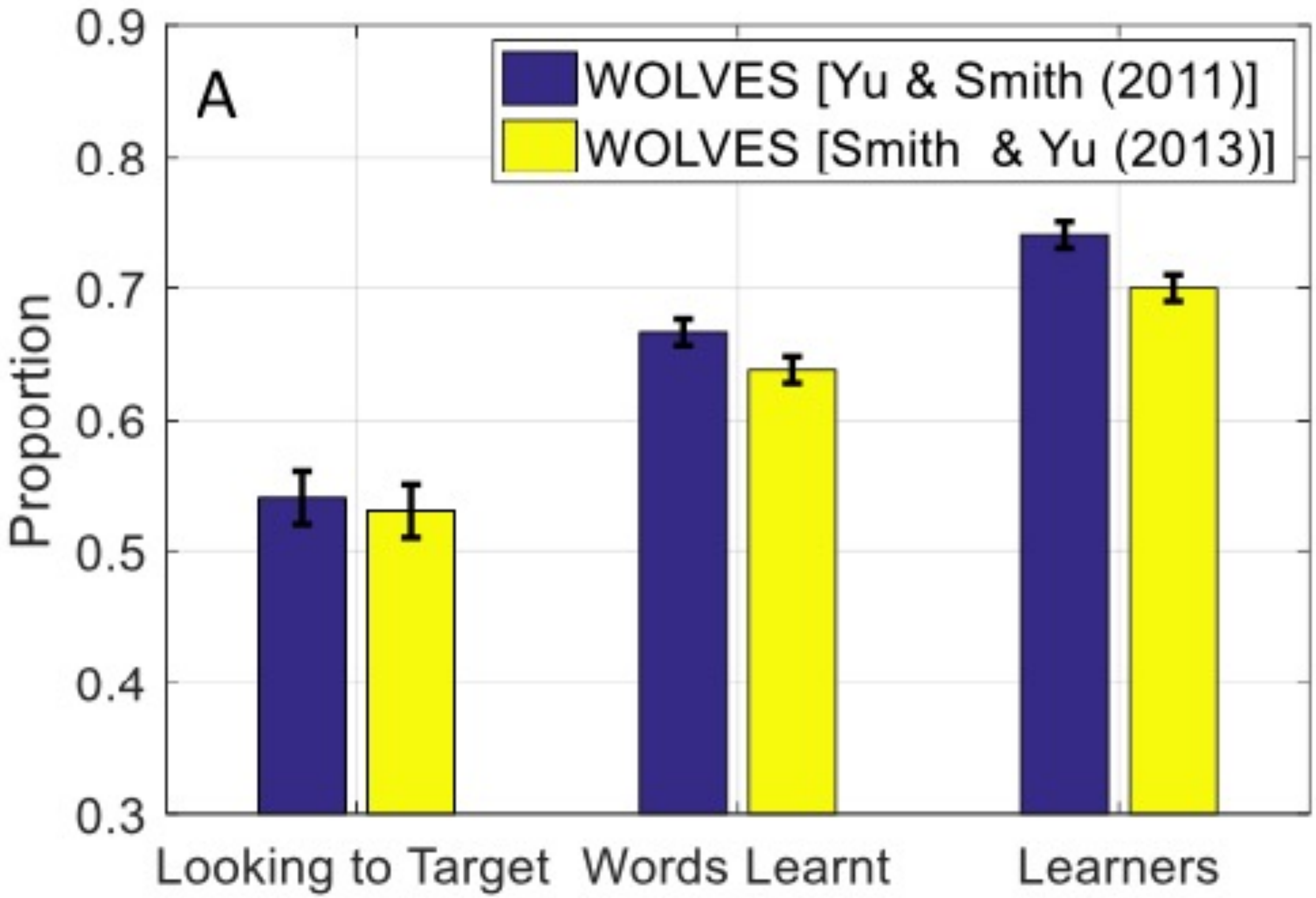
Smith & Yu (2013): Novelty Trap



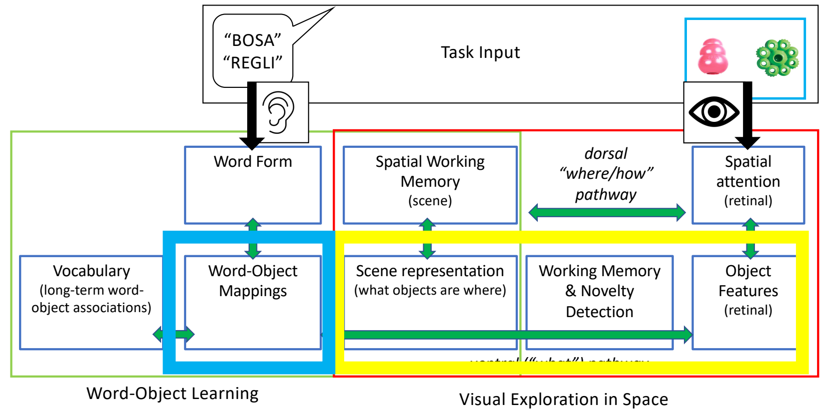
No overall difference in looks to target v. distractor at test

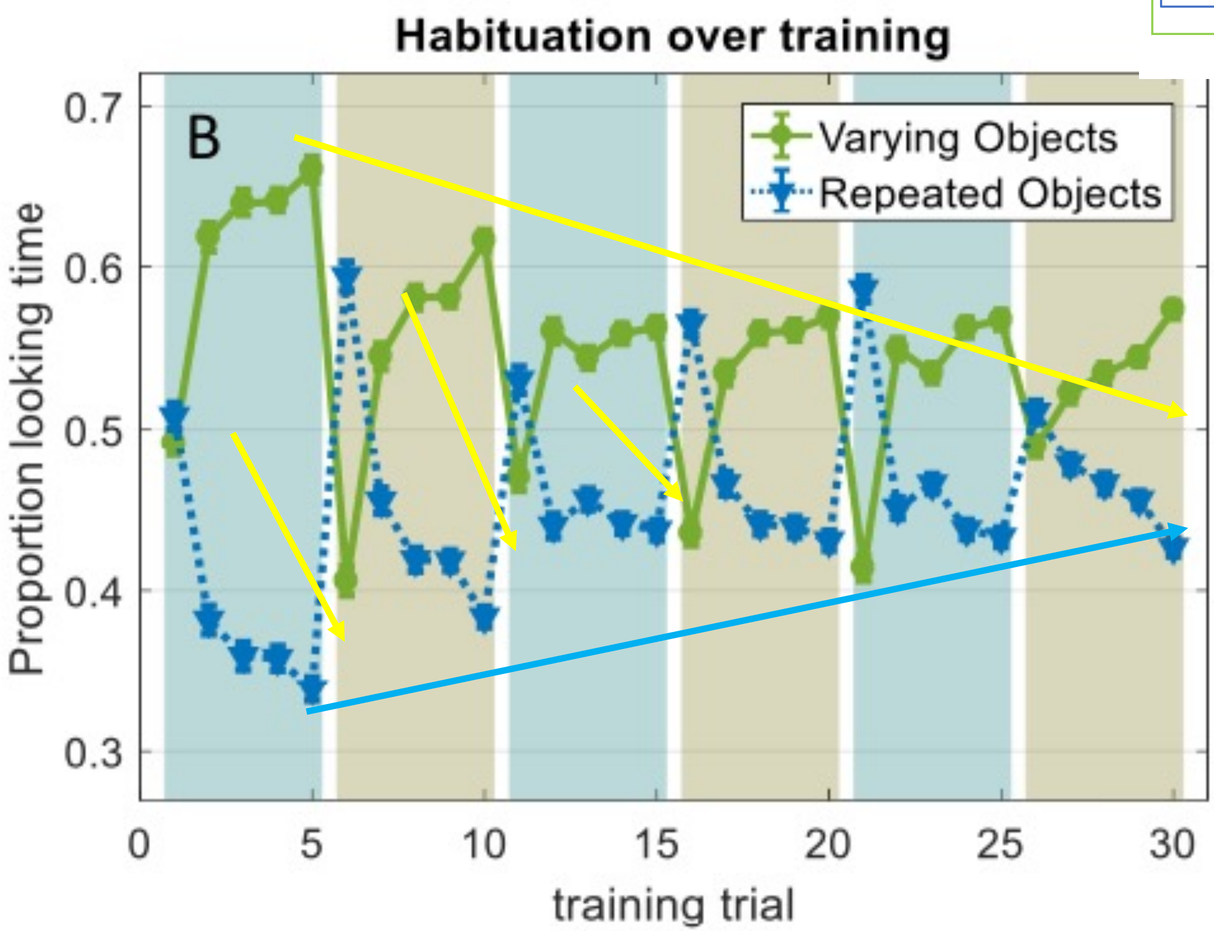
Fewer “learners”

Timescale of the task



Timescale of the task





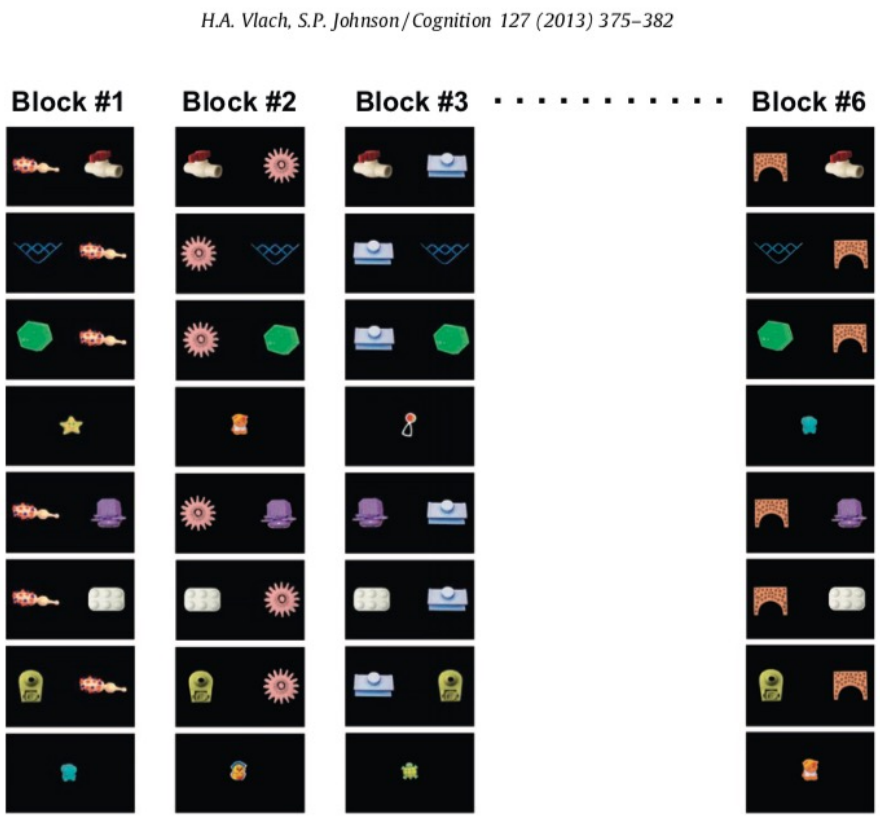
- Novelty detection & consolidation in working memory
- Top-down attention driven by growing associations

Two types of learning on timescale of the task:

- learning / habituating to visual features
- learning word + object mappings

Timescale of Development

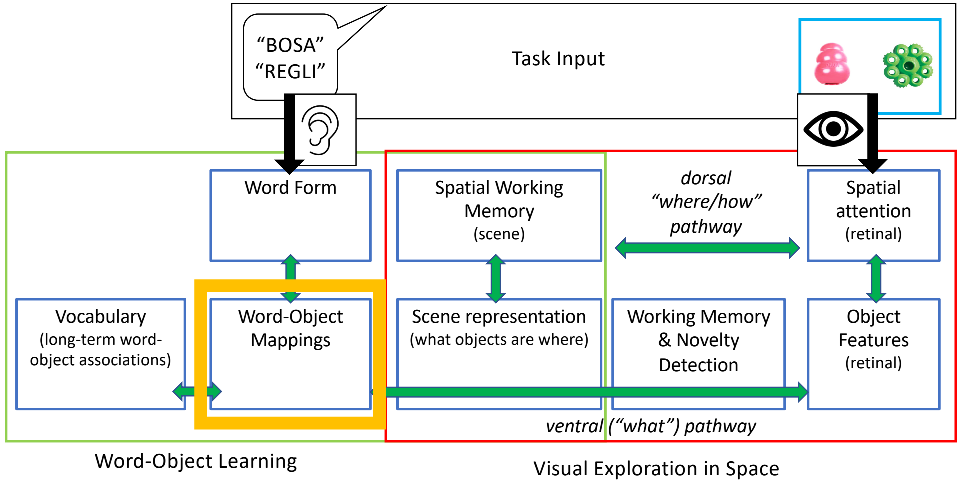
- Vlach & Johnson (2013), Vlach & DeBrock (2017, 2019)

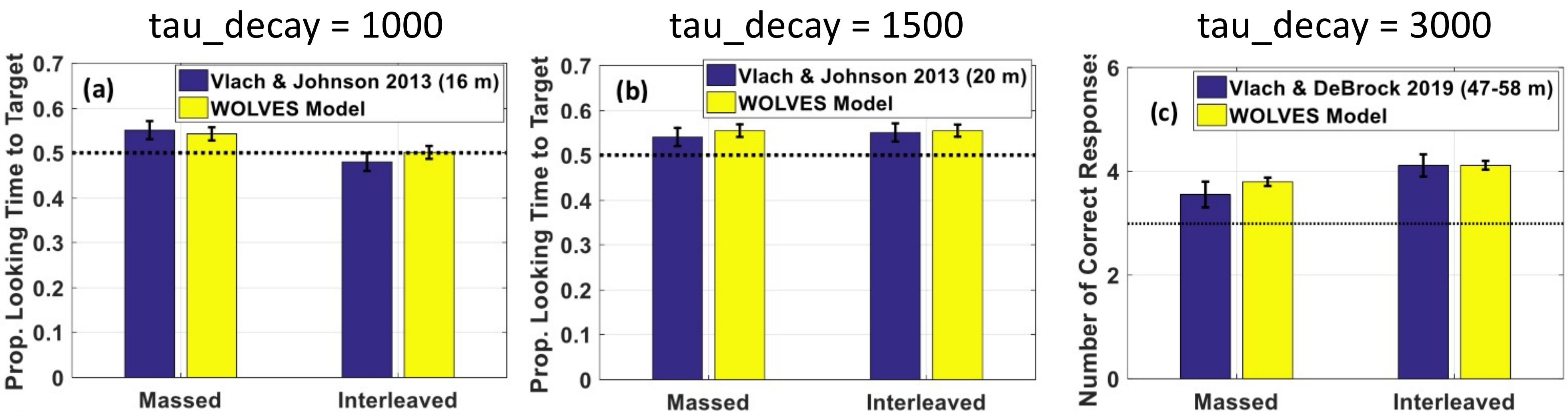


- 16 mo learn words from massed but not interleaved presentation.
- 20 mo learn equally with massed or interleaved.
- Older children learn better with interleaved presentation.

Timescale of Development

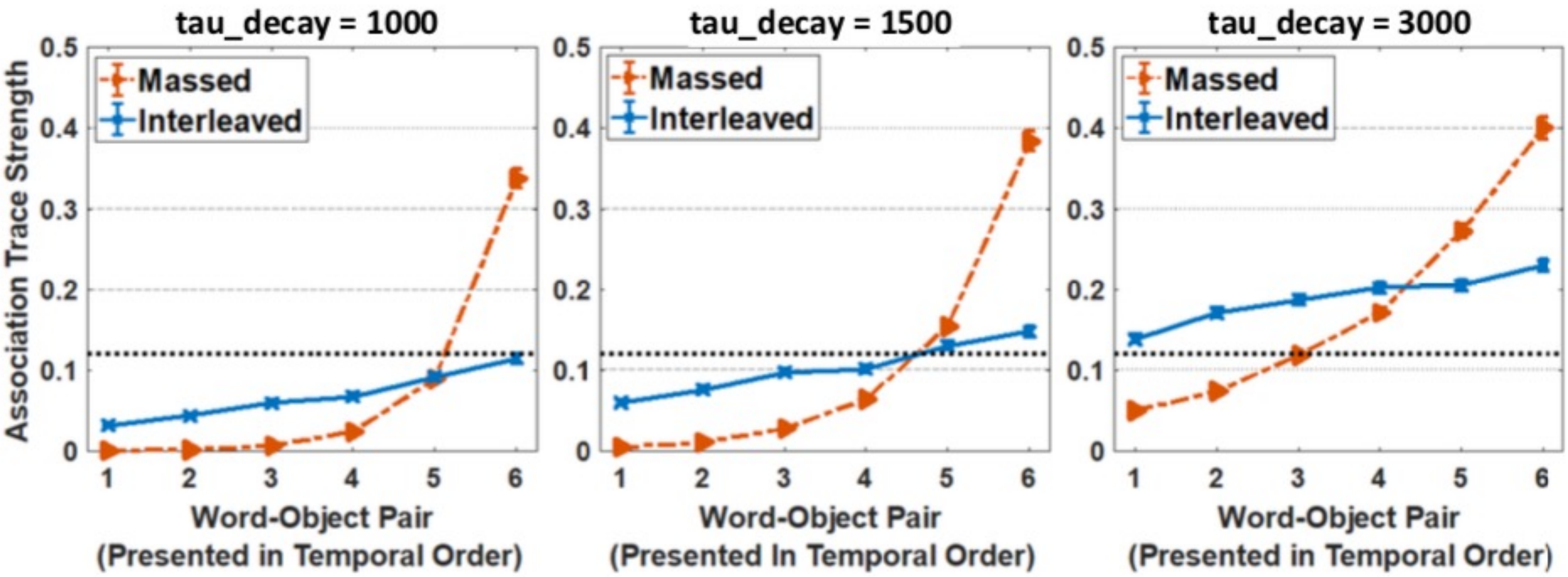
- Memory: Tau_Decay defines how fast a memory trace deteriorates.





- Unified developmental account of CSWL

Timescale of Development



We captured 60 datapoints from 12 months to 5 years with a change to just one parameter.

WOLVES is a powerful *developmental* model

This is because it has rich real-time and learning dynamics.

But is development really that simple?

Implications: Individual Differences

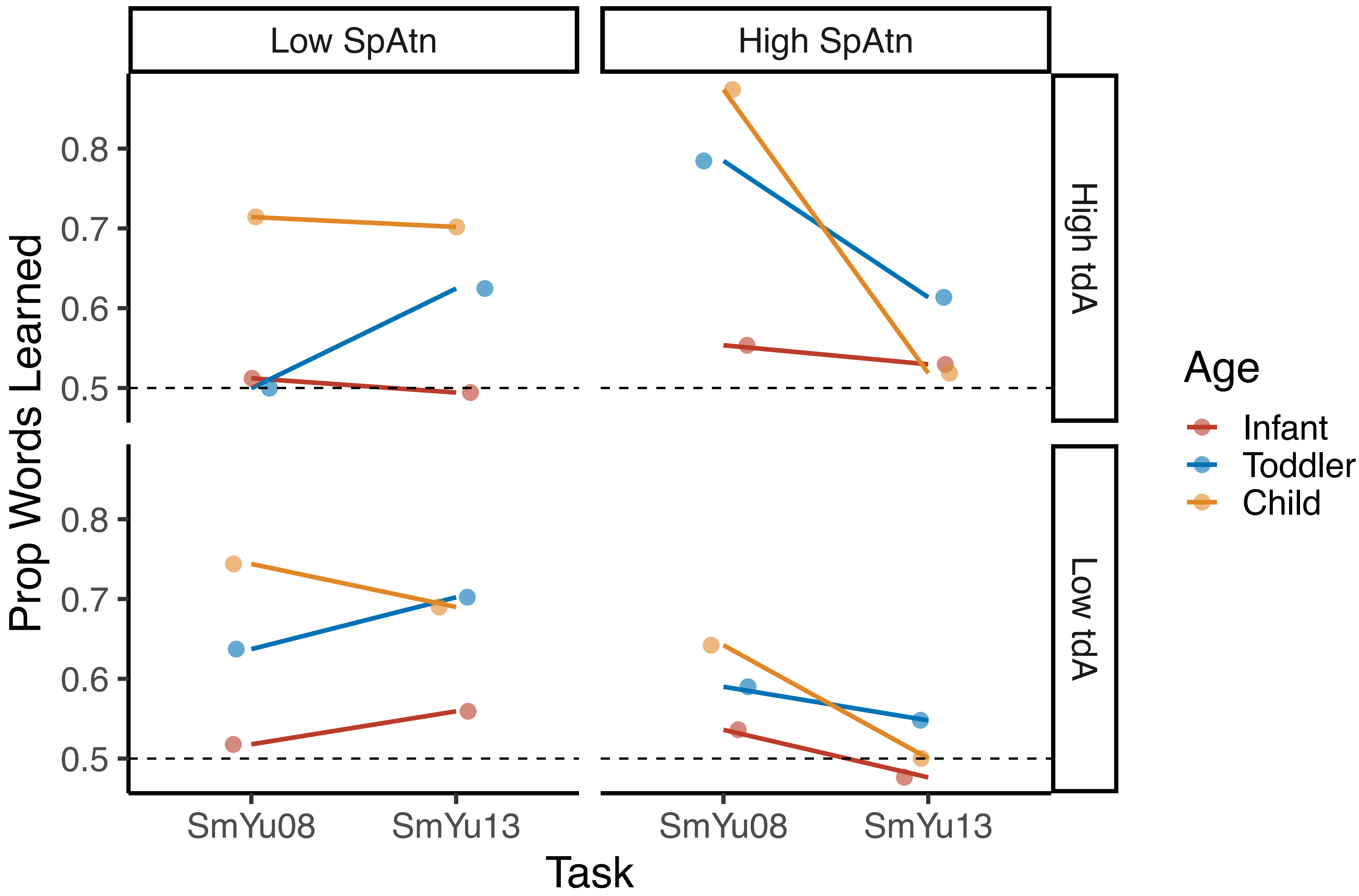
Three critical parameters:

- Spatial Attention
- Top-Down Attention
- Memory Decay

Manipulate of parameters to look at changes in performance.

- High and Low values of Top-Down & Spatial Attention
- Three values of memory decay to simulate infant, toddler and child performance.
- Tested in Smith & Yu (2008) and Smith & Yu (2013)
- 20 individuals per parameter combination and age group

Implications: Predictions



Conclusions

- WOLVES
  - Formal neural-process account of CSLW based on autonomous real-time visual exploration and gradual associative learning.
  - Captures a large range of data and beats other models in direct comparison.
  - Mechanistically related the strength of spatial attention to learning outcomes.
- Timescale of the task
  - Two types of learning: habituation to visual features and word-object mappings.
- Timescale of development
  - Presented the first developmental account of CSWL based on changes in memory strength.
- Future Directions
  - How we can use the model to make predictions, understand relations between tasks and understand individual differences.

Thank you

Members of Developmental Dynamics Lab, University of Easy Anglia

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