



So Many Options:

The Roles of Neural Inhibition and Abstract Representations in Selection



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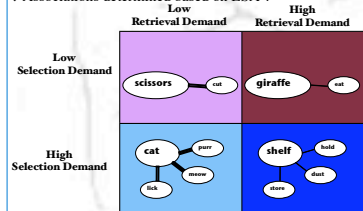
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Abstract

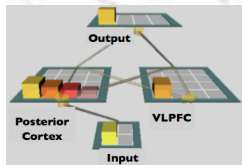
How do we select words to express a thought? We investigated the roles of neural inhibition and abstract category representations during simple language-production tasks. First, we simulated a **verb-generation task** in a neural network model. The model, like people, takes longer to select a verb in response to nouns associated with multiple competing verbs. **Neural inhibition** (simulated via k-Winners-Take-All inhibition in a prefrontal layer) appears critical for resolving such competition. Consistent with this framework, we found reduced selection costs in adult participants administered midazolam (a GABA agonist) and increased selection costs in adult participants high in trait anxiety (associated with poor GABAergic function). **Abstract prefrontal representations** may also aid selection by providing top-down support that constrains the search space of options. Consistent with this framework, we found children's selection in a **verbal fluency task** is tied to individual differences in, and experimental manipulation of, abstract representations.

Verb Generation Task

- Task: for each noun, say the first verb that comes to mind.
- Independently manipulated selection demand (competition) and retrieval demand (association strength) (25 nouns/condition).
- Associations determined based on LSA¹.

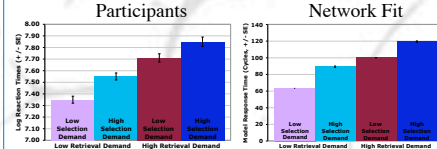


Verb Generation Model



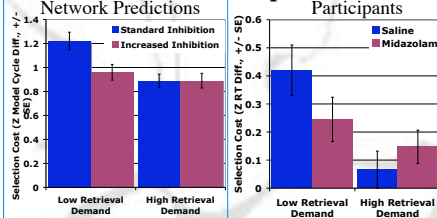
- Input layer (noun stimuli):
 - Low selection demand: project to one posterior cortex layer unit (verb response).
 - High selection demand conditions: project to six posterior cortex layer units (verb responses).
 - Weights based on LSA association strength.
- Posterior cortex layer (verb responses):
 - Projects to VLPFC and output layers.
 - High selection demand condition units have lateral connections to each other (weights set to LSA association strengths).
- VLPFC layer:
 - Projects to posterior cortex and output layers.
 - Recurrent projections (boost weak activations).
 - Strong kWTA competitive inhibition (selection).
- Output layer: cycles to settle (activate one response) recorded.
- All units use point-neuron activation function in Emergent².

Selection & Retrieval Demands Influence RT



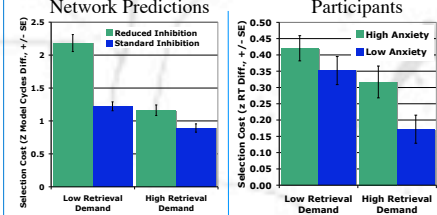
- Independent effects of selection demand ($F(1,82)=215, p<.001$) and retrieval demand ($F(1,82)=388, p<.001$).
- Significant interaction between selection demand and retrieval demand: effect of selection demand most apparent when retrieval demands are low ($F(1,82)=12.1, p=.001$).

Increased Inhibition Improves Selection



- When retrieval demands are low: Increased competitive inhibition in the VLPFC layer improves selection.
- When retrieval demands are high: Midazolam improves selection ($F(1,19)=5.67, p=.028$).
- When retrieval demands are high: Increasing inhibition reduces spreading activation that aids retrieval, canceling out the benefit to selection.
- Test with midazolam (GABA agonist).
- Double-blind placebo-controlled study: midazolam and saline in two counterbalanced sessions.
- When retrieval demands are low: Midazolam improves selection ($F(1,19)=5.67, p=.028$).
- When retrieval demands are high: No effect on retrieval ($F(1,19)=1.71, p=.2$).

Decreased Inhibition Impairs Selection



- Reduced competitive inhibition in the VLPFC layer impairs selection, but not retrieval.
- High anxiety participants high in anxious apprehension (worry, linked to reduced GABAergic function)³.
- Anxiety factor score calculated from 4 standardized anxious apprehension questionnaires.
- High anxious apprehension participants have impaired selection ($F(1,57)=6.32, p=.015$) but not retrieval ($F(1,57)=.72, p=.4$).
- No interaction with retrieval demands ($F(1,57)=.71, p=.4$).

Verbal Fluency Task

- Task: say as many category items as possible in 1 min. (e.g. animals).
- Good performance requires endogenous switching between subcategories (e.g. from farm animals to zoo animals).⁴
- Switching between subcategories requires selecting what to switch to.

- Depends on prefrontal cognitive control⁵ and undergoes protracted period of development (through adolescence).⁶

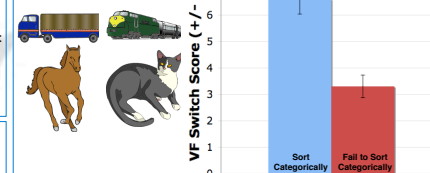
- Current study:
 - Participants: 5 years (+/- 2 months).
 - Children complete animal and food categories.
 - Code number of switches (weighted by cluster size).

Good Performance Example	Poor Performance Example
Word	Time
Time	Word
Word	Word
Elephant	Elephant
0.01	0.01
Zebra	Jaguar
0.04	0.02
Elephant	Jaguar (repeat)
0.05	0.11
Hippo	Lion
0.07	0.29
Rhino	Tiger
0.10	0.30
Giraffe	Elephant (repeat)
0.11	0.46
Tiger	
0.22	
Turtle	
0.30	
Fish	
0.39	
Cat	
0.42	
Dog	
0.44	
Lizard	
0.46	
Snake	
0.58	

Abstract Category Representations Predict Switching

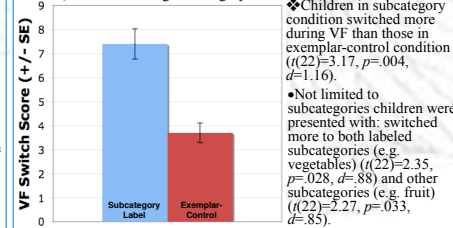
- Abstract representations assessed with picture-sorting task:
 - Children asked to "Make piles of all the pictures that go together."
 - Sort pictures categorically—sort category members together and separate from other categories (e.g. vehicles separate from animals).
 - Children who demonstrate abstract, categorical representations switch more during verbal fluency ($t(25)=3.09, p=.005, d=1.04$).

Picture Examples



Abstract Category Representations Aid Switching

- Promote the use of subcategory representations:
 - Subcategory condition: Experimenter provided initial subcategory labels during instructions (e.g. "vegetables" when producing foods).
 - Exemplar-control condition: Experimenter provided exemplars (e.g. "onion") without labeling subcategory.



- Children in subcategory condition switched more during VF than those in exemplar-control condition ($t(22)=3.17, p=.004, d=1.16$).
- Not limited to subcategories children were presented with: switched more to both labeled subcategories (e.g. vegetables) ($t(22)=2.35, p=.028, d=.88$) and other subcategories (e.g. fruit) ($t(22)=2.27, p=.033, d=.85$).

Mechanisms of Selection

Competitive Inhibition

- Neural network model suggests that competitive inhibitory dynamics in prefrontal networks are critical for selection.
- As predicted by model, midazolam (GABA agonist) improves selection when retrieval demands are low.
 - Suggests GABA agonists may be beneficial in treating cognitive, in addition to affective, symptoms of anxiety disorders.
- As predicted by model, participants high in anxious apprehension (linked to reduced GABAergic function) show impaired selection but not retrieval.
 - Consistent with clinical evidence for decision-making⁷ problems and intolerance of uncertainty⁸ in anxiety disorders.
- Supports key role for GABAergic function in selection.

Abstract Representations

- Children's verbal fluency also linked to abstract, categorical representations in both individual difference analyses and experimental manipulation.
 - Suggests role of abstract representations in reducing selection demands to aid switching.
- Choosing what to switch to endogenously requires selection between competing alternatives (e.g. many animals in VF).
- Abstract, categorical representations may constrain the search space, reducing selection demands (e.g. to a small set of subcategories rather than all exemplars in VF).
 - Selection demands (quantified as LSA entropy⁹) substantially lower between and within subcategories (e.g. zoo animals, farm animals) than between all exemplars in category (e.g. all animals).

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