Feedback Matters: Effects of Feedback Properties on Category-Learning

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Real World Rule-Based Classification

Which frogs are poisonous?
Real World Rule-Based Classification

Rule: Bright coloring – probably poisonous.
Real World Information-Integration

Which of these chest x-rays show tumors?
Real World Information-Integration

No verbalizable rule can be used for optimal performance.
Category Learning

• How can we help people diagnose tumors and avoid picking up poisonous frogs?
  – By studying perceptual category learning

• What training procedures optimize category learning?
  – Feedback properties are ones we can easily manipulate in the laboratory
• Procedural and Hypothesis-Testing Systems of Category-Learning
• Feedback Properties
  – Stimulus-Feedback Co-Occurrence
  – Feedback Delay Intervals
• Experiment
• Discussion, Implications etc.
Competition between Verbal and Implicit Systems (COVIS)

Different neural circuits mediate learning of different category structures

Explicit, *Hypothesis-testing* system mediates learning of “rule-based” (RB) category structures.


(Maddox and Ashby, 2004; Ashby et al., 1998)
### Rule-Based (RB) vs. Information-Integration (II)

<table>
<thead>
<tr>
<th><strong>Rule-Based</strong></th>
<th><strong>Information-Integration</strong></th>
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<tr>
<td>• Hypothesis-testing</td>
<td>• Procedural</td>
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<tr>
<td>• Verbalizable rule can be used.</td>
<td>• Cannot be solved by a verbalizable rule.</td>
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<td>• Requires working memory resources to learn the category structure.</td>
<td>• Not working memory intensive.</td>
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<tr>
<td>• Frontally-mediated</td>
<td>• Striatally mediated</td>
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Typical Category Learning Task
Correct
No, that was in A
No, that was in B
Correct
Correct
Correct
No, that’s not a tumor
Rule-Based Task

Except with many exemplars per category
Information-Integration Task

Except with many exemplars per category
Two Proposed Systems
Explicit (Hypothesis-Testing) System

• Logical reasoning system

• Uses working memory and executive attention

• Prefrontal cortex, anterior cingulate, head of the caudate nucleus, thalamo-cortical loops implicated.
A Model of the Explicit System
Implicit (Procedural Learning) System

• Uses a form of procedural learning

• Not as dependent upon frontal cortical structures (Knowlton, et al, 1996)

• Highly dependent upon posterior caudate nucleus (Gaffan & Eacott, 1995; Packard & McGaugh, 1992; Poldrack, et al, 1999)
A Model of the Implicit System
Cortico-striatal (medium spiny cell) synapse

Adapted from Schultz (1998)
Competition between systems

- Hypothesis-testing system competes with Procedural system for control of the response.
- Hypothesis-testing system initially controls the response:
  - Participants first try explicit rules
- Control is gradually passed to the Procedural system in II tasks.
Competition

Hypothesis-testing System

Procedural System

Competition for Control of Response

Initial bias toward Hypothesis-testing system

RESPONSE
Competition

• Reliance on the Hypothesis-testing system may delay transfer of control to Procedural system.

• Increased rule use will hurt performance on II tasks.

• Feedback properties may affect the passing of control from the Hypothesis-testing to the Procedural System
Experimental Manipulations

• Examine two feedback properties to determine their effect on category-learning
  – Stimulus-feedback co-occurrence
    • Should help Hypothesis-testing system
      – Less WM demands with stimulus present
      – Stimulus there to evaluate after feedback
    • Delays the transfer of control to the Procedural System
  – Feedback delay
    • Should affect the Procedural system
    • Feedback needs to come at an optimal time for the system to learn
Stimulus Present vs. Absent

**Present**
- Stimulus Appears
- Feedback Delay
- 3500ms feedback time
- Response
- Feedback

**Absent**
- Stimulus Appears
- Feedback Delay
- 3500ms feedback time
- Response
- Feedback
Competition

Hypothesis-testing System

Procedural System

Competition for Control of Response

RESPONSE
Competition

Stimulus Present

-Delays transfer of control to Procedural System

Hypothesis-testing System

Feedback

Procedural System

Competition for Control of Response

RESPONSE

Better RB

Worse II
Competition

Hypothesis-testing System

Procedural System

Feedback

Stimulus Absent
- Speeds transfer of control to Procedural System

Competition for Control of Response

RESPONSE

Worse RB
Better II
Other Research

• Maddox, Love, Glass, & Filoteo (2008) - full or minimal feedback on 4-choice RB and II tasks
  – Full feedback helped Hypothesis-testing system
  – Better RB worse II

• Working Memory manipulations
  – Increase WM = Enhance Hypothesis-testing system

• Regulatory Fit, Social Pressure, Stereotype Threat
  – Fit enhances Hypothesis-testing system

e.g. Zeithamova & Maddox, 2006; Decaro et al., 2008; Grimm et al., 2008; Maddox et al., 2006; Markman et al., 2006; Worthy et al., in press
Feedback Delay

Long Feedback Delay
- Hurts performance on II tasks
- Has no effect on RB tasks
  (e.g. Maddox, Ashby & Bohil 2003; Maddox & Ing, 2005)
Increased Feedback Delay can hurt the Procedural system

Competition

RESPONSE

Hypothesis-testing System

Procedural System

Competition for Control of Response
Experiment

• 2 X 2 X 3 design
  - 2 (Category Types) X 2 (Stimulus Presence) X 3 (Feedback Delay intervals)
• 5 80-trial blocks
Predictions

- Stimulus Present conditions should do better
- Feedback Delay should have no effect

- Stimulus Absent conditions should do better
- Performance worse with longer feedback delay
Stimulus Present
0ms Delay
Correct
Stimulus Absent
0ms Delay
Correct
Stimulus Present
500ms Delay
Correct
Stimulus Absent
500ms Delay
No, that was a B
Stimulus Present
1000ms Delay
No, that was in A
Stimulus Absent
1000ms Delay
Results - Overall Accuracy

Stimulus Present conditions better for RB

Best Performance for Stimulus Absent with 500ms Delay
-Not the predicted monotonic decrease with delay interval
Decision Bound Modeling

- Decision bound models assume stimuli are classified based on which side of the decision bound they fall on.
- Several models are fit to the data.
- Best-fitting model gives information about which strategy each participant probably used to classify the stimuli.
Decision Bound Modeling

Best Fit by Frequency Model

Best fit by Orientation Model

Best Fit by Optimal General Linear Classifier Model

Best Fit By Random Response Model
Model Fitting Procedure

• Fit each subject’s data on a block-by-block basis
• Used AIC to determine best fitting model for that block
  Penalizes for free parameters
• Examined the proportion of data sets best fit by each model over the final three blocks of the task
RB model fits

- More RB participants in Stimulus Present conditions fit best by unidimensional rule model along the spatial frequency dimension
More participants in the Stimulus Absent 500ms condition fit best by II models compared to all other conditions.
Discussion

- No surprise – RB performance better with stimulus-feedback co-occurrence.

- II performance better when stimulus was not present during feedback.
  - Optimal performance with 500ms feedback delay
Why is 500ms optimal?

• 0ms Delay
  – Memory trace for stimulus may not have decayed.
  – Need a small temporal delay between response and feedback

• 1000ms Delay
  – Stimulus-response association that gets reinforced by DA following reward may have decayed.
  – Reason we predicted decline in performance over longer feedback delay intervals.
Implications

• Suggests there may be optimal feedback conditions to train the procedural system
  – Training on implicit tasks (e.g. radiology)
  – Therapy for diseases affecting the striatum (e.g. Parkinsons) could be improved.
  – Improve sports and fine motor skills training (can we design an optimal golf-training system that gives feedback at the optimal time?)
Implications

• Need to better understand the neuro-biological underpinnings of the procedural system.
  – Does the cortico-striatal synapse require a small temporal gap for the DA reward response to strengthen it?
  – Is 100ms feedback delay enough?

• Experimental Design
  – Feedback properties are not trivial
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II accuracy

-By the final block the Stimulus Absent condition is nearly 20% more accurate