Introduction
Feedback is critical to learning. We examine how feedback timing affects two separate learning systems.

Two separate learning systems
Explicit, Hypothesis-testing system
- frontally mediated
- verbalizable rules
Implicit, Procedural learning system
- striatally mediated
- no verbalizable rules

Rule-Based (RB) Information-Integration (II)

Changes in feedback timing should have a greater effect on the procedural system. Hypothesis-testing system can maintain verbalizable rules.

Procedural-learning
Timing is critical
Stimulus-response relationships developed in the caudate.
Feedback timing must be optimized
- Glutamate – primes calcium
- Dopamine - reinforces synapse
Best learning takes place when calcium and dopamine levels are both high.

Hypothesis: Temporal window exists for best procedural learning.
Feedback too late
- Synapse inactive; cannot be reinforced
Feedback too early
- Synapse not primed for feedback

Experiment 1
Examined RB and II learning with different feedback delay intervals
- 0ms, 500ms and 1000ms delays
Feedback Delay should affect II but not RB learning

Accuracy with Different Feedback Delay Intervals

<table>
<thead>
<tr>
<th>Feedback Delay</th>
<th>RB Proportion Correct</th>
<th>II Proportion Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>0ms</td>
<td>0.80</td>
<td>0.75</td>
</tr>
<tr>
<td>500ms</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>1000ms</td>
<td>0.65</td>
<td>0.65</td>
</tr>
</tbody>
</table>

II learning best with 500ms Feedback Delay
No effect on RB learning

Experiment 2
Responses may be best reinforced by unexpected rewards.
- 500ms delay interval may just create unexpectancy
Varied feedback delay intervals around 500ms for II task
Low Variance – Mean=500ms, SD=75ms
High Variance – Mean=500ms, SD=150ms
More variance in feedback delay may heighten dopaminergic reward signal and improve learning.

Overall Accuracy Based on Variance of Feedback Delay

<table>
<thead>
<tr>
<th>Variance of Feedback Delay</th>
<th>Proportion Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Variance</td>
<td>0.90</td>
</tr>
<tr>
<td>High Variance</td>
<td>0.85</td>
</tr>
<tr>
<td>No Variance (Exp. 1)</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Performance best with low variance around the optimal 500ms feedback delay interval time

Experiment 3
How does the system know that a response has been made?
We separated visual and sensorimotor response feedback.
- Manipulated stimulus offset and feedback delay.

Accuracy with Different Offset and Feedback Delay Intervals

<table>
<thead>
<tr>
<th>Feedback Delay</th>
<th>Proportion Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>250ms offset delay + 250ms feedback delay</td>
<td>0.75</td>
</tr>
<tr>
<td>250ms offset delay + 500ms feedback delay</td>
<td>0.65</td>
</tr>
<tr>
<td>0ms offset delay + 500ms feedback delay</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Performance only significantly different between 250-250ms and 0-500ms conditions.
Combination of visual and sensorimotor response feedback is needed for best learning.

Conclusions
- Procedural system learns best with 500ms feedback delays.
- Response feedback timing is also critical.
- Supports models of synaptic plasticity in the striatum.

References

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