Acquisition and Retention of Basic Components of Skill

Robert W. Proctor
Purdue University

Research Associates: Motonori Yamaguchi; Jim Miles; Yanmin Zhang; Yun Kyoung Shin

Research Objective: Study basic tasks that isolate the perceptual, cognitive, & motor components of skill, & examine factors that influence acquisition & retention of these components.

MURI Annual Meeting: August 2009
Research Topics

I. Factors affecting transfer of learning
   - Relation to the quantitative framework
   - Power law of learning
   - Rate of learning
   - Context similarity
   - Decay and interference

II. Performance with mixed mappings and tasks
   - Joint project with CMU

III. Performance of concurrent tasks (not covered today)
   - Psychological refractory period
   - Ideomotor compatibility and bypassing of bottleneck
   - Explicit vs. implicit payoff manipulations
I. Factors affecting transfer of learning

General Method:

- In the transfer task, responses are typically faster when stimulus and response locations correspond than when they do not (the Simon effect).
- Transfer of learning is implied if the Simon effect is reduced after practice with a spatially incompatible mapping.
I. Factors affecting transfer of learning

Architectural model of Simon task:

Stimulus (location + color)

Spatial feature (task-irrelevant)
  Left  Right

Chromatic feature (task-relevant)
  Red  Green

Response
  Left  Right

Stimulus (location + color)
I. Factors affecting transfer of learning

Architectural model of Simon task:

Stimulus (location + color)

Spatial feature (task-irrelevant)

Chromatic feature (task-relevant)

Task-defined associations

Response
I. Factors affecting transfer of learning

Architectural model of Simon task:

Stimulus (location + color)
- Left
- Right

Spatial feature (task-irrelevant)
- Left
- Right

Chromatic feature (task-relevant)
- Red
- Green

Response

Long-term associations

Stimulus
(location + color)
I. Factors affecting transfer of learning

*Corresponding trial*

- **Stimulus** (location + color)
- **Response**
  - **Left**
  - **Right**
  - **Red**
  - **Green**
I. Factors affecting transfer of learning

*Non-corresponding trial*

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Stimulus (location + color)
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Response
```

```
Left  Right
```

```
Red  Green
```

I. Factors affecting transfer of learning

**Effect of practice**

![Diagram showing the relationship between stimulus, response, and new associations. The stimulus includes location and color, leading to response options for left and right, with new associations creating additional response options for red and green.](image-url)
I. Factors affecting transfer of learning

**Effect of practice**

- **Stimulus** (location + color)
- **Response**
- **Left**
- **Right**

**Transfer of learning**

“How do the new associations behave?”

→ General quantitative framework
I. Factors affecting transfer of learning

General quantitative framework:

\[ a_N = \sum_{i=1}^{N} \beta_i t_i^{-\lambda} e^{\alpha S_i} \]

- \( a_N \): Activation of trained skill or knowledge at the \( N \)th trial
- \( \beta \): Learning rate
- \( t \): Interval between the \( i \)th and \( N \)th practice trial
- \( \lambda \): Decay rate
- \( \alpha \): Generalizability constant
- \( S_i \): Contextual similarity between the \( i \)th and \( N \)th practice trial
I. Factors affecting transfer of learning

\[ a_N = \sum_{i=1}^{N} \beta_i t_i^{-\lambda} e^{\alpha S_i} \]

Efficiency of training is determined by:

- Number of trials \((N)\)
- Learning rate \((\beta)\)
- Contextual similarity \((S)\)
- Time passage \((t & \lambda)\)
I. Factors affecting transfer of learning

Effect of practice: *Formation of new associations*
I. Factors affecting transfer of learning

Effect of practice: *Formation of new associations*

Proctor, Yamaguchi, Zhang, & Vu (2009)

![Diagram showing the relationship between practice and transfer with a bar graph illustrating the Simon effect before and after practice.](Diagram)
I. Factors affecting transfer of learning

Effect of trial number: *Strengthening the new associations*

**Practice**
*(0 ~ 600 trials)*

**Transfer**

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I. Factors affecting transfer of learning

Effect of trial number: *Strengthening the new associations*

**Practice**
(0 ~ 600 trials)

**Transfer**

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Proctor, Yamaguchi, Zhang, & Vu (2009)
I. Factors affecting transfer of learning

Effect of learning rate: *Ease of learning*

<table>
<thead>
<tr>
<th>Practice (84 trials)</th>
<th>Physical Location</th>
<th>Arrow Direction</th>
<th>Spatial Word</th>
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<tbody>
<tr>
<td></td>
<td><img src="image" alt="Circle" /></td>
<td><img src="image" alt="Left Arrow" /></td>
<td><img src="image" alt="LEFT" /></td>
</tr>
<tr>
<td>Transfer</td>
<td><img src="image" alt="Green and Red Circle" /></td>
<td><img src="image" alt="Double Arrow" /></td>
<td><img src="image" alt="LEFT LEFT" /></td>
</tr>
</tbody>
</table>
I. Factors affecting transfer of learning

Effect of learning rate: *Ease of learning*

Proctor, Yamaguchi, Zhang, & Vu (2009)
I. Factors affecting transfer of learning

Effect of contextual similarity: *Specificity of learning*

| Metric model (Shepard, 1987) | Contrast model (Tversky, 1977) |
I. Factors affecting transfer of learning

Effect of contextual similarity: *Specificity of learning*

**Metric model (Shepard, 1987)**

\[ S(C_p, C_t) = -d(C_p, C_t) = \ln p(C_p, C_t) \]

* *d*: psychological distance

* *p*: probability of generalization

**Contrast model (Tversky, 1977)**
I. Factors affecting transfer of learning

Effect of contextual similarity: *Specificity of learning*

**Metric model (Shepard, 1987)**

\[ S(C_p, C_t) = -d(C_p, C_t) \]
\[ = \ln p(C_p, C_t) \]

* \( d \): psychological distance
  \( p \): probability of generalization

**Contrast model (Tversky, 1977)**

\[ S(C_p, C_t) = f(C_p \cap C_t) \]
\[ = \sum_{x \in C_p, y \in C_t} M(x, y) \]
I. Factors affecting transfer of learning

Effect of contextual similarity: *Specificity of learning*

<table>
<thead>
<tr>
<th>Practice (84 trials)</th>
<th>Joystick</th>
<th>Keyboard</th>
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<tbody>
<tr>
<td></td>
<td><img src="image" alt="Joystick Practice" /></td>
<td><img src="image" alt="Keyboard Practice" /></td>
</tr>
<tr>
<td>Transfer</td>
<td><img src="image" alt="Joystick Transfer" /></td>
<td><img src="image" alt="Keyboard Transfer" /></td>
</tr>
</tbody>
</table>
I. Factors affecting transfer of learning

Effect of contextual similarity: *Specificity of learning*

Yamaguchi & Proctor (2009)
I. Factors affecting transfer of learning

Effect of contextual similarity: *Specificity of learning*

**Other factors affecting contextual similarity**

i) Stimulus modality: visual vs. auditory
   
   (Vu, Proctor, & Urcuioli, 2003; Proctor, Yamaguchi, & Vu, 2007)

ii) Stimulus mode: visual-spatial vs. semantic-spatial
   
   (Proctor, Yamaguchi, Zhang, & Vu, 2009)

iii) Spatial dimension: vertical vs. horizontal
   
   (Vu, 2006; Proctor, Yamaguchi, & Vu, 2007)
I. Factors affecting transfer of learning

Effect of time passage: *Decay of learned associations?*
I. Factors affecting transfer of learning

Effect of time passage: *Decay of learned associations*?

![Diagram showing the effect of time passage on transfer of learning](chart)

Vu, Proctor, & Urcuioli (2003)
I. Factors affecting transfer of learning

Effect of intervening task: *Decay vs. interference*

<table>
<thead>
<tr>
<th>Word Only</th>
<th>1st Practice</th>
<th>2nd Practice</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>No 1st Block</td>
<td>LEFT</td>
<td>LEFT</td>
<td>LEFT</td>
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</table>

<table>
<thead>
<tr>
<th>Arrow to Word</th>
<th>1st Practice</th>
<th>2nd Practice</th>
<th>Transfer</th>
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</thead>
<tbody>
<tr>
<td>LEFT</td>
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<th>Word to Arrow</th>
<th>1st Practice</th>
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<td>LEFT</td>
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I. Factors affecting transfer of learning

Effect of intervening task: *Decay vs. interference*

Unpublished data (research in progress)
I. Factors affecting transfer of learning

Summary:

1. Effect of trial numbers:
   - Magnitude of transfer follows the power law

2. Effect of learning rate:
   - Transfer of learning depends on learning rate

3. Effect of contextual similarity:
   - Transfer of learning depends on feature overlap
I. Factors affecting transfer of learning

Summary (cont.):

4. Effect of decay:
   - Learned associations did not decay (at least for a week)

5. Effect of interference:
   - Intervening task interfered with the prior learning
   - Interference depends on similarity between the intervening task and the prior task?
     * Some component for interference of learning is necessary in the quantitative function.
II. Performance in mixed mappings and tasks

• Joint project with CMU

• Objective: Construction of ACT-R model of human performance and learning in a mixed task

• ACT-R: Modeling platform for human performance

• Instance-based learning theory (IBLT):
  – From algorithm-based to memory-based performance
  – Automatization of performance = retrieval of prior instance similar to the current situation

• CMU constructed ACT-R/IBLT model for the mixed location-relevant and location-irrelevant task
II. Performance in mixed mappings and tasks

- Mixed location-irrelevant task with two location-irrelevant tasks, with compatible and incompatible mappings:

  ![Diagram showing mixed mappings and tasks](image)

  **Location-irrelevant (Simon task)**
  
  ![Diagram of Simon task]

  **Location-relevant (SRC task)**
  
  ![Diagram of SRC task]

  *Horizontal line – compatible mapping*
  *Vertical line – incompatible mapping*
II. Performance in mixed mappings and tasks

• Experiment 1: Basic experiment

• Experiment 2: Differential payoffs for the compatible- and incompatible-mapping trials

• Experiment 3: Different proportions of the SRC and Simon tasks
II. Performance in mixed mappings and tasks

Experiment 1:

- Experimental variables:
  a) Block: 1 - 4
  b) Task: location-irrelevant (Simon), location-relevant (SRC)
  c) S-R compatibility: compatible, incompatible
  d) Task sequence: task-repeat, task-switch
  e) Compatibility sequence: comp-repeat, comp-switch

- Main findings:
  i. Responses become faster over blocks \( \rightarrow \) IBLT model
  ii. Responses are faster for Simon than for SRC \( \rightarrow \) ACT-R architecture
  iii. Responses are faster for task-repeat than for task-switch (task-switch cost) \( \rightarrow \) ACT-R architecture
  iv. Responses are faster for comp-repeat than for comp-switch (comp-switching cost) \( \rightarrow \) ACT-R architecture
  v. Learning effect is larger for SRC than for Simon
  vi. Compatibility effect is larger for comp-repeat than for comp-switch
  vii. Task-switch cost is larger for Simon than for SRC
  viii. Comp-switch cost is larger for SRC than for Simon
II. Performance in mixed mappings and tasks

Experiment 2:
Manipulated payoffs;
- For half the participants, payoff was larger for the compatible-mapping trials than the incompatible-mapping trials (C-favor group)
- For the other half, payoff was larger for the incompatible-mapping trials than the compatible-mapping trials (I-favor group)

• Replicated the results of Experiment 1.

• In addition:
  – Dissociation between the SRC and Simon effects
    ✓ The Simon effect was positive, but the SRC effect was negative.
  – In the first block, the overall compatibility effect (the average of the SRC and Simon effects) was positive for the C-favor group but negative for the I-favor group
    ✓ The difference became smaller in latter blocks and disappeared in the last block.
END
I. Factors affecting transfer of learning

Additional conditions

Location to Word

1st Practice

2nd Practice

Transfer

Word to Location

LEFT

LEFT
I. Factors affecting transfer of learning

Effect of intervening task: *Decay vs. interference*

Unpublished data (research in progress)
II. Performance in mixed mappings and tasks

• The ACT-R/IBLT model accounted for several aspects of the data of Experiment 1.

• The model also provided a good fit to the human data of Experiments 2 and 3.