Virtual Training: Learning Transfer of Assembly Tasks

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Introduction

- Training costs in industry can be high
- Retention of learning is important

This study examines

- Learning transfer between training in the virtual environment and performing in the real environment
Learning Transfer

- **Transfer of practice**: Thorndike and Woodworth (1901)
- Relies on task similarity and domain knowledge and a person’s ability to perceive the similarity: Gick and Holyoak (1987)
- Transfer occurs when similar affordances and constraints are present in two dissimilar environments: Greenco et al. (1993)
Skill Acquisition and Learning

Fitts three-stage skill acquisition

1) cognitive stage: learner identifies how something works
2) associative stage: learner corrects errors in cognitive stage
3) autonomous stage: learner gradually improves

Learning Curve

- Rapid improvement in assembly over time
- Learning hits a "plateau" or stabilization point
Learning Transfer in VR

- Virtual training: pilots, military, medical, sports, routing and mapping
- Assembly
  - Real world training was more effective than virtual training (Hamblin, 2005)
  - Haptics feedback was necessary for more efficient learning transfer (Adams et al., 1999)
  - No significant difference in performance between virtually trained and physically trained, (Hall and Horwitz, 2001)
- Gerbaud et al. created a rich software platform GVT for teaching procedural tasks (2008)
This Study ....

Expand on the previous study to:

- Control for training time – compare assembly performance
- Examine how color influences assembly performance
- Examine retention of learning
Burr Puzzle Assembly

- Use 6 piece burr puzzle assembly
- Required specific assembly sequence with only one path
- Puzzle doesn’t require domain knowledge for assembly
Fishtank VR with Haptics and Glove
Software

- SPARTA (Scriptable Platform for Advanced Research in Teaching and Assembly)
  - VR Juggler
  - VR JuggLua
  - Voxmap Pointshell (VPS)
Original Study

1. Entrance Survey & Spatial Ability Test

2. Equipment Training Video

3. Control: Training with Colored Physical Blocks

4. Experimental: Training with Colored Virtual Blocks

5. Exit Survey

6. Testing with uncolored block and without instructions
The puzzle is made of these six pieces:

Solution

Step 1

Step 2

Step 3

Step 4

Step 5

Step 6
### Study Variables

#### Independent Variables

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Classification</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training Condition</td>
<td>Between</td>
<td>Physical, Virtual</td>
</tr>
<tr>
<td>Color Order</td>
<td>Between</td>
<td>Color First, Wood First</td>
</tr>
<tr>
<td>Test Order</td>
<td>Within</td>
<td>Initial Test, Retention Test</td>
</tr>
</tbody>
</table>
Participants and Conditions

- 63 participants (22 female, 41 male)

<table>
<thead>
<tr>
<th></th>
<th>Color First Testing</th>
<th>Wood First Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical Training</strong></td>
<td>Female: 4, Male: 13</td>
<td>Female: 6, Male: 10</td>
</tr>
<tr>
<td><strong>Virtual Training</strong></td>
<td>Female: 6, Male: 10</td>
<td>Female: 6, Male: 8</td>
</tr>
</tbody>
</table>
# Gender Differences

<table>
<thead>
<tr>
<th></th>
<th>Male Mean (Std. Dev.)</th>
<th>Female Mean (Std. Dev.)</th>
<th>(df, t)</th>
<th>(p)</th>
<th>Overall Mean (Std. Dev.)</th>
<th>Measurement Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Engineering Courses Taken</td>
<td>2.80 (0.90)</td>
<td>2.95 (1.50)</td>
<td>(t(61) = -0.09)</td>
<td>0.92</td>
<td>2.85 (6.22)</td>
<td>Range: 0-30</td>
</tr>
<tr>
<td>Computer Technical Expertise</td>
<td>3.45 (0.10)</td>
<td>3.23 (0.09)</td>
<td>(t(60) = -1.39)</td>
<td>0.16</td>
<td>3.37 (0.60)</td>
<td>Likert (1=low to 5=expert)</td>
</tr>
<tr>
<td>Video Game Playing</td>
<td>3.18 (0.18)</td>
<td>1.86 (0.20)</td>
<td>(t(60) = -4.43)</td>
<td>&lt;.001</td>
<td>2.70 (1.27)</td>
<td>Likert (1=never to 5=play daily)</td>
</tr>
<tr>
<td>Mental Rotation Score</td>
<td>12.98 (0.92)</td>
<td>10.77 (1.34)</td>
<td>(t(61) = -1.38)</td>
<td>0.17</td>
<td>12.21 (6.09)</td>
<td>Score Range: 0-20 (low-high)</td>
</tr>
</tbody>
</table>
Findings

- Initial test: Physical training outperformed virtual training
- Retention test: The virtually trained participants who trained with color first actually improved their assembly times considerably, while all other groups took longer than their initial test times
Results

- A significant three-way interaction exists between the three independent variables on the dependent variable of time.

\[ t(28) = 2.26, \ p = 0.03 \]
Two-way Interactions (Training Environments)

- Physically trained
  - Testing session and color order not significant
- Virtually trained
  - Testing session and color order is significant
Recall Strategy (self reported)

- Physically trained: primarily shape
- Virtually trained: primarily color
Learning Curve

Average Training Time (seconds)

Assembled Puzzle Number

Training
- Physical
- Virtual
<table>
<thead>
<tr>
<th>Strategies Employed</th>
<th>Physical Training</th>
<th>Virtual Training</th>
<th>Test</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison to Target After Training (Vandenberg and Kuse #5)</td>
<td>number of</td>
<td>number of</td>
<td>$\chi^2$ (2, N=63) = 7.29</td>
<td>$p = 0.02$</td>
</tr>
<tr>
<td>I always compared the options to the target figure.</td>
<td>16</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once I found the matching puzzle piece, I compared the rest of the options to the match.</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I did a bit of both.</td>
<td>11</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem Solving Approach After Training (Vandenberg and Kuse #6)</td>
<td>number of</td>
<td>number of</td>
<td>$\chi^2$ (2, N=63) = 13.30</td>
<td>$p = 0.001$</td>
</tr>
<tr>
<td>I developed a specific approach to solve the problems.</td>
<td>23</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I tried various approaches to solve the problems.</td>
<td>4</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I did a bit of both.</td>
<td>6</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Observations – Virtual Training

- Higher cognitive load (software and hardware)
- Lack of gravity
  - Didn’t require two hands
  - Pieces didn’t have to fit together perfectly
Conclusion

- Training in virtual environment
  - Outperformed by physical training in initial tests
  - In retention, there were mixed results
Recommendations

- While virtual training is outperformed by physical training on initial tests, appropriate use of color cues in virtual training can make it equally effective to physical training on performance testing after time has passed.

- The learning curves produced by physical and virtual training can differ, requiring different numbers of training iterations for each mode to avoid overlearning and premature skill degradation.
When designing training, it is important to consider not only the training time, but the anticipated time spent in Fitts’ cognitive stage within that overall time.
Future Work

- Add snap-to-fit for virtual assembly
- Improve part grouping in virtual assembly
- Design a task that requires two hands in both environments
- Test after several longer periods to explore learning retention
Acknowledgements

Patrick Carlson  Anicia Peters  Stephen B. Gilbert  Andy Luse

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