Kirkpatrick and Douglas

Application-based Evaluation of Haptic Interfaces


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**Experiment: 3D Shape recognition**

Research Dimensions

- **Tasks**
  - Property Recognition
- Haptic properties
  - Tactile (3D Shapes)
- Individual differences
  - none
- Sense combinations
  - Haptics only, Haptics + Graphics
- Haptic Device Types
  - PHANToM

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**Research Questions**

- How well do people recognize 3D shapes haptically?
  - Recognition of Koenderink Shapes
  - Measured by Task time
  - Compare performance with real physical objects:
    - Kappers, Koenderink, Lichtenegger (1994)
- Does having a graphic cursor aid in recognition?
Critical points on Koenderink’s Shape scale

- **Cup**: $S = -1.0$
- **Ridge**: $S = 0.5$
- **Saddle**: $S = 0.0$
- **Groove**: $S = -0.5$
- **Top**: $S = 1.0$

Stimuli: Koenderink surfaces

- Monge-form equation for surface patches
  \[ z(x, y) = \frac{k_1 x^2 + k_2 y^2}{2} \quad k_1, k_2 \]
- Koenderink Shape and Curvedness scales
  \[
  S = -\frac{2}{\pi} \arctan \left( \frac{k_1 + k_2}{k_1 - k_2} \right) \\
  C = \sqrt{\frac{k_1^2 + k_2^2}{2}}
  \]

Experimental design

- 2 x 2 within-subjects design
  - Interaction technique: Cursor present or absent (counterbalanced)
  - Shape size: small or large
  - Training followed by testing
- 5 shapes x 2 sizes x 3 rotations = 30 trials / modality, 60 trials total
Shape recognition: Method

• 12 different unpaid graduate students from the Computer Science Department

Results: Controlled factors

Interaction Line Plot for log(time)
Error Bars: 95% Confidence Interval

Legend
Actual Results
Hypothesized Results

Median time = 23 s

Shape recognition results

ANOVA Table for log(time)

<table>
<thead>
<tr>
<th>Effect</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
<th>Effect size</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>11</td>
<td>5.213</td>
<td>.474</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mode</td>
<td>1</td>
<td>.006</td>
<td>.006</td>
<td>7</td>
<td>.145</td>
<td>1%</td>
<td>(-14%, 16%)</td>
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<td>Size*Subject</td>
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<td>1.622</td>
<td>.057</td>
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<td>.210</td>
<td>6.986</td>
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<td>(2%, 22%)</td>
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<td>.331</td>
<td>.030</td>
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<tr>
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<td>2.790</td>
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<tr>
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<td>.155</td>
<td>.014</td>
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</tbody>
</table>

Interaction Line Plot for log(time)
Error Bars: 95% Confidence Interval
Results in context: Physical shape recognition

<table>
<thead>
<tr>
<th>Effector Condition</th>
<th>Time (s)</th>
<th>Ratio to gloved hand</th>
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</thead>
<tbody>
<tr>
<td>1 finger, unflexed</td>
<td>47</td>
<td>2.8</td>
</tr>
<tr>
<td>5 Fingers, unflexed</td>
<td>26</td>
<td>1.5</td>
</tr>
<tr>
<td>Point force device</td>
<td>23</td>
<td>1.4</td>
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<tr>
<td>Full hand, flexible</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Both hands, flexible</td>
<td>—</td>
<td>5.29</td>
</tr>
</tbody>
</table>


Summary: Shape recognition

- Absence of cursor effect
  - In this case, graphics did not help!
  - Fundamental limitations on temporal integration?
- This simple task is difficult
  - 2/14 Ps could not do it all
  - Learning to use a point force device?
- Koenderink Shape recognition protocol is a useful benchmark for testing haptic devices

Overall Observations

- Limitations of Point Force Devices
  - Temporal integration problems
  - Recognition is 3 times faster with human hands
- Haptics plus graphics? Not always a benefit
  - Visible cursor did not help recognition
- Graphics plus haptics? Not always a benefit
  - Shape recognition seems primarily visual