The most beautiful campus that ever there was.

- Robert Frost
Children Ages 6-12 Learning Optical Spatial Reasoning during Educational Video Game Play: An ERP study examining the role of cognitive load.

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Optical Spatial Reasoning

Or Naïve Optics

A subcomponent of spatial visualization
Spatial Reasoning & Naïve Optics

- Croucher, Bertamini, and Hecht (2002)
  - physically draw equal angles when asked about a ray of light reflected by a mirror
  - erroneously apply naïve theories or heuristics when encountering images depicting the use of mirrors in the horizontal plane
  - Hypothesis: people rotate mirrors toward a specific vantage point of an observer

![Diagram showing mirror and observer points with statistics]

- Mean distance from mirror edge: -60 mm
- \( r(25) = -9.35, p < .001 \)
- Mean error: 19 mm
- \( r(25) = 2.88, p = .014 \)

Jane walks through the door and across the room, please mark the point at which she can first see the cat in the mirror.
Spatial Reasoning & Naïve Optics

Savardi, Bianchi, and Bertamini (2010)

• individuals’ predictions of both dynamic and static mirror reflections

• people make either perceptual errors that can be corrected through visual feedback, or conceptual errors that cannot
Visuospatial Working Memory
• Macaque monkeys activate the **occipitoparietal pathway** with the dorsal limbic and dorsal frontal cortex (Mishkin et. al., 1983, p. 414)
• VSWM activates the **superior frontal sulcus** (ie., Courtney et. al., 1998)
• Dorsolateral Prefrontal Cortex (DLPFC- **spatial**) & Ventrolateral prefrontal cortex (VLPFC- **objects**) (Nakahachi et al., 2010)
VSWM Tutoring-induced functional brain plasticity in children 7-9 with MD.
Source Iuculano et al., 2016.
Research Questions
Research Questions & Hypotheses

1. Can children increase spatial reasoning abilities through video game play?
   • $H_1 =$ Yes they can.

2. Are there developmental and gender differences in behavioral performance during spatial reasoning video game play?
   - $H_1 =$ Yes there should be with Males outperforming Females; Older children outperforming Younger.
3. What neural correlates of the brain are significantly impacted in spatial reasoning learning?

H₁ = Fronto-Parietal Network

H₂ = Reduced Parietal Amplitude ERPs for Increase in Number of Mirrors

- Research points to less positive values in more mental rotation turns

H₃ = Frontal L/R differences & correlations

- JTF-Coherence Value Calculations
Study Design
Methods

Study Design

• Conditions within the 3 blocks; pretest, practice (with feedback, see figures), and posttest blocks; 1 mirror, 3 mirror, 5 presentations (& 7 posttest)
  • three blocks totaled 152 trials, 46 trials pretest, 48 trials practice block, and 58 trials posttest block
Pretest Mirror Progression
Participants

• Twenty-one (21) children ages 6 to 12; 11 boys and 10 girls
• Average Age 9.2
  • 7 children in the 6-7 Age group
  • 5 children in the 8-9 Age group
  • 9 children in the 10-12 Age group
• All Right-handed
Can children increase spatial reasoning abilities through video game play?
Results

Children *overall* performed better on the practice (F=7.97, p<.001) and the posttest (F=15.33, p<.001) than on the pretest.

Average Number Correct Per Block & Mirror

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<table>
<thead>
<tr>
<th>Mirrors</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>N</td>
</tr>
<tr>
<td>Pre-test</td>
<td>315</td>
<td>.511</td>
<td>.500</td>
<td>284</td>
</tr>
<tr>
<td>Practice</td>
<td>336</td>
<td>.836</td>
<td>.370</td>
<td>336</td>
</tr>
<tr>
<td>Post-test</td>
<td>315</td>
<td>.835</td>
<td>.371</td>
<td>293</td>
</tr>
</tbody>
</table>

Note. * = p < .05, *** = p < .001.
Are there developmental and gender differences in behavioral performance during spatial reasoning video game play?
Behavioral Results- Gender

**Figure 1.** Gender comparison over three blocks
## Behavioral Results - Gender

### Gender (Independent samples t-test)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Male</th>
<th>Female</th>
<th>F</th>
<th>t</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>.549</td>
<td>.520</td>
<td>2.706</td>
<td>-.907</td>
<td>943</td>
</tr>
<tr>
<td>Practice</td>
<td>.765</td>
<td>.706</td>
<td>17.880</td>
<td>-2.124***</td>
<td>1006</td>
</tr>
<tr>
<td>Post-test</td>
<td>.782</td>
<td>.695</td>
<td>48.084</td>
<td>-3.486***</td>
<td>1216</td>
</tr>
</tbody>
</table>

Note. * = p < .05, *** = p < .001.

**Table 2. Three blocks’ means for males and females test (F=48.08, p=.000)**

No significant difference between males and females in the pre-test (F= 2.706, p=.100).
• Both genders performed better.
• Males performed significantly better on Practice and Posttest for select mirrors
Results

Development (ANOVA)

- No significant differences between developmental levels in the pretest (F=.292, p=.589)
- Significant differences in developmental levels during the practice (F=14.72, p<.001) and the posttest (F=13.25; p<.001) blocks.

Table 2 Developmental comparison results

<table>
<thead>
<tr>
<th>Development Age Level</th>
<th>6-7</th>
<th>8-9</th>
<th>10-12</th>
<th>F</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>N 7 M .540</td>
<td>SD .50</td>
<td>N 5 M .556</td>
<td>SD .50</td>
<td>9 M .521</td>
</tr>
<tr>
<td>Practice</td>
<td>N 7 M .662</td>
<td>SD .47</td>
<td>N 5 M .758</td>
<td>SD .42</td>
<td>9 M .785</td>
</tr>
<tr>
<td>Post-test</td>
<td>N 7 M .650</td>
<td>SD .48</td>
<td>N 5 M .828</td>
<td>SD .38</td>
<td>9 M .762</td>
</tr>
</tbody>
</table>

Note. * = p < .05, *** = p < .001.
Results

**Figure 2. Developmental comparison over three blocks**

![Graph showing developmental differences over three blocks: pre, prac, and post. The graph compares developmental differences across three age groups: 6 to 7, 8 to 9, and 10 to 12. Significant differences are indicated by asterisks.](image-url)
Behavioral Results-Reaction Time

ANOVA (Developmental Level)

• Significant differences were found in all three Blocks: Pretest F(1,942)=37.44, p<.001, Practice F(1,1005)=12.24, p<.001, Posttest F(2, 1215)=5.98, p=.003.

• Posthoc results for Development (Scheffe)
  • Significant differences between in Pre: 6-7 and 8-9, and 10-12
  • Significant differences between in Prac: 6-7 and 8-9, and 10-12
  • Significant differences between in Post: 8-9 and 10-12**
    **10-12 year-olds much faster 1,000ms
Behavioral Results-Reaction Time

Paired sample T-tests Pre-Prac-Post

- Significant difference Pre-Prac
  \[ t(944)=11.438, p<.001 \]
- Significant difference Practice-Post
  \[ t(1007)=-11.11, p<.001 \]
- Significant difference Pre-Post
  \[ t(944)=3.01, P<.005 \]
  - Pre Mean RT = 4,700ms
  - Practice Mean RT = 2,174ms
  - Post Mean RT = 4,012ms
    - Correlation between Pre-Post \( r=.09, p=.005 \)
Behavioral Results - Reaction Time

- Male overall had faster reaction times on all three blocks.
- Female reaction time decreased as the game progressed.
What neural correlates of the brain are significantly impacted in spatial reasoning learning?

How do children learn this concept?
Phase 1
ERPs & Topo Maps

Overall; Pre-Test, Posttest; F3, F4, PostParietal
F3 N200 ERP Statistical Differences

• Interaction between Block, Gender, and Developmental Level
  • F (4, 30)= 4.817, p<.005 η² = .39, Power=.92

• Interaction between Block, Mirror, and Gender
  • F (4, 60)= 3.466, p<.05 η² = .19, Power=.83

• Interaction between Block, Mirror, Gender, and Developmental Level
  • F (8,60)= 2.437, p<.05 η² = .25, Power=.86
Developmental Performance

No significant differences Pretest ($F=.292, \ p=.589$)

Significant differences during the Practice ($F=14.72, \ p<.001$)
Posttest ($F=13.25; \ p<.001$)
<table>
<thead>
<tr>
<th></th>
<th>1 Mirror</th>
<th>3 Mirror</th>
<th>5 Mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
</tr>
<tr>
<td>6-7</td>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td>8,9</td>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
<td><img src="image9" alt="Graph" /></td>
</tr>
<tr>
<td>10-12</td>
<td><img src="image10" alt="Graph" /></td>
<td><img src="image11" alt="Graph" /></td>
<td><img src="image12" alt="Graph" /></td>
</tr>
</tbody>
</table>
ERPs Compared to Performance

- **Left Superior Frontal Sulcus**
  - Developmental Differences 6/7 to 8-12
  - Male/Female Differences N2 & Slow Wave

Liang et al 2006
Phase 2
ERPs & Topo Maps

Correct vs. Incorrect;
Pre-Test, Posttest; F3, F4,
Posterior Parietal
<table>
<thead>
<tr>
<th>Correct</th>
<th>Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td><img src="image1.png" alt="Graph" /></td>
</tr>
<tr>
<td>Posttest</td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
</tbody>
</table>
Pretest 3 Mirrors

![Graphs showing data points and trends for Pre3CorF3, Pre3IncorF3, Pre3CorF4, Pre3IncorF4, and Pre3CorPP, Pre3IncorPP.](attachment:graphs.png)
<table>
<thead>
<tr>
<th></th>
<th>Correct</th>
<th>Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pretest</strong></td>
<td><img src="image1" alt="Pretest Correct" /></td>
<td><img src="image2" alt="Pretest Incorrect" /></td>
</tr>
<tr>
<td><strong>Posttest</strong></td>
<td><img src="image3" alt="Posttest Correct" /></td>
<td><img src="image4" alt="Posttest Incorrect" /></td>
</tr>
</tbody>
</table>
Phase 3
Joint Time Frequency
Pretest
5 Mirrors
Posttest
1 Mirror

- Correct, Post
- Incorrect, Post

Frequency (Hz) vs. Time (ms) graphs for Correct and Incorrect trials, showing temporal frequency patterns.
Discussion

• JTF demonstrate reduction in brain activation in fronto-parietal network after learning (Soltanlou et al., 2018)

• Alpha differences in Pre and Post 1 & 5 Mirror conditions at Superior Frontal Sulcus during Incorrect.
  1. Attending to a visuospatial reasoning task at SFG
  2. Alpha is not suppressed in the incorrect trials. Participants had difficult with cognitive control, or engagement in the task.
  3. Alpha Decrease is associated with Retrieval Strategies (Pfurtscheller, 2001)
  4. In order to correctly engage in spatial reasoning, Frontal Sulcus would need to work to suppress alpha.

• Three mirror Gamma bursts in Prefrontal Cortex
• VSWM task
Conclusions

• Children Ages 6-12 can learn spatial reasoning through videogames
  • 6-7 year-olds have difficulties with individual differences
  • Developmental, Gender, & Individual Differences in development in Spatial Concept Learning
• The more difficult the spatial reasoning task, the higher the cognitive load in the Parietal Area (Overall ERPs).
• Prefrontal Cortex important for VSWM for Attention & Reasoning
  • Superior Frontal Sulcus is crucial for Spatial Reasoning Concept Learning- VSWM Retrieval for children
Future Work

• Replicate & Combine for Power.
• Eye-Tracking
• Novel Transfer Tasks
• Virtual vs Real World
Thank you.

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P300

P3 most active in parietal lobe during mental rotation (Wijers et. al., 1989; Heil et. al., 2002, Milivojevic, et. al., 2009)

✓ Amplitude modulation as a correlate of mental rotation
  o Heath et.al., (2015) did not find increase in amplitude
    ✓ Qualitatively different task of reaching