ASSESSING VISUAL SEARCH IN CEREBRAL VISUAL IMPAIRMENT USING VIRTUAL REALITY

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MASSACHUSETTS EYE AND EAR
## Ocular versus Cerebral Visual Impairment

### Ocular Visual Impairment (OVI)
- Cause related to eye or optic nerve (pre-geniculate)
  - Ocular Albinism
  - Leber's congenital amaurosis

### Cerebral / Cortical Visual Impairment (CVI)
- Peri-natal developmental brain injury
  - Hypoxic Ischemic Injury (HIE, PVL)
  - Seizure activity
  - Infection
  - Other (e.g., genetic, trauma, etc.)
Ocular versus Cerebral Visual Impairment

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The Case of CVI ... a public health crisis?

CVI affects nearly 2 out of every 1000 live births, and accounts for nearly 20-25% of visually impaired children in developed countries.

(Durnian et al., Eye (Lond). 2010; Kozeis, Hippokratia 2010)

Causes of vision loss in students from schools for the blind in the United States (n=3070)

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>1999</th>
<th>% of total</th>
<th>2012</th>
<th>% of total</th>
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<td>7</td>
<td>106</td>
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<tr>
<td>ROP</td>
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<td>31</td>
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<tr>
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<tr>
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<td>156</td>
<td>1</td>
<td>282</td>
<td>9</td>
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<tr>
<td>total</td>
<td>2553</td>
<td>100</td>
<td>3070</td>
<td>100</td>
</tr>
</tbody>
</table>

N/A, data not showed separately; ROP, retinopathy of prematurity.

Kong et al., Journal of AAPOS 2012 (USA)
A problem of assessment

CVI is suspected by:

- A "normal" eye examination (acuity)
- Potential co-occurring ocular pathologies
- Visual impairment cannot be explained by ocular causes alone
- Presence of unique behavioral dysfunctions (e.g. visuo-spatial and motion processing, complexity/crowding, and attention deficits)

Assessment

- Traditional clinical techniques can fail
- Real-world inspired visual deficits
A problem of assessment

Virtual Reality

Stimulus Control

Functional Vision

Ecological Validity
Usage of virtual reality in clinical fields

• Experimental control
• Real-world behavior
• Task flexibility
• Participant safety
• Robust data collection
• Engaging

Method of assessment beyond traditional clinical techniques

Stroke Rehabilitation

Exposure Therapy

Learning and and Development

https://www.evl.uic.edu/entry.php?id=1624
http://dcoe.mil/sites/default/files/field/image/VR_Mask_2.jpg
http://www.digitalspace.com/projects
Focus group studies

Teachers, Parents, and Clinicians – Identify areas of concern

- Finding a favorite toy in a toy box
- Identifying a person in a crowded hallway

Questionnaire (Likert scale [1 to 7]) to rate experimental factors

<table>
<thead>
<tr>
<th>Virtual Toy Box</th>
<th>Virtual Hallway</th>
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<tbody>
<tr>
<td>Realism</td>
<td>5.7</td>
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<tr>
<td>Feature Importance</td>
<td>6.8</td>
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<tr>
<td>Additional Features</td>
<td>Feature Matched Toy</td>
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</tbody>
</table>

Realism
Feature Importance
Additional Features
Participants

Preliminary data shown with 48 participants

Age ranged from 14 to 28 years of age

- Control mean = 18.9, SD = 2.2 (n = 35)
- OVI mean = 25.0, SD = 1.4 (n = 2)
- CVI mean = 18.4, SD = 3.9 (n = 11)

For OVI group, individuals possessed visual acuity within the low vision range (20/60 to 20/100 Snellen acuity)

For CVI group, individuals possessed a range of visual acuity between normal to low vision (20/20 to 20/100 Snellen acuity)

Controls had normal or corrected to normal visual acuity
Virtual Toy Box

Visual Perception Testing: Object Crowding Research Preview
Methodology

3 runs with 35 trials each
Runs last approximately 3.5 minutes
Brief rest between runs

Adaptive color/theme matched toy
blue truck → blue helicopter
yellow duck → yellow giraffe
orange basketball → orange helmet

Low (1 - 3 toys)  Medium (4 - 6 toys)  High (7 - 9 toys)
Additional Details

Eye Tracking Specifications

- Tobii 4C
- 90 Hz sampling rate
- 7 point calibration protocol
- Head tracking with free movement (no chin rest)

Setup Details

- Participants seated approximately 70 cm from screen
- Screen size is 60 cm wide
- 120 Hz refresh rate for screen

Simulation Details

- Field of view for perspective is 75 degrees
- Maintained 60 Hz frames per second
Data Analysis

1. Centering the Data

2. Visualizing the Data

Colors represent varying levels of density
- Yellow: more time looking in that area
- Blue: less time looking in that area

(No color indicates insufficient point density)
Heat maps

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>OVI</th>
<th>CVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td><img src="image1.png" alt="Control" /></td>
<td><img src="image2.png" alt="OVI" /></td>
<td><img src="image3.png" alt="CVI" /></td>
</tr>
<tr>
<td>High</td>
<td><img src="image4.png" alt="Control" /></td>
<td><img src="image5.png" alt="OVI" /></td>
<td><img src="image6.png" alt="CVI" /></td>
</tr>
</tbody>
</table>
Hypotheses

CVI and OVI performance will be worse than controls
  • Increased error and time

Individuals with CVI will show greater sensitivity towards complexity
Gaze Error and Reaction Time Measures

![Gaze Error Diagram](image)

**Gaze Error**

- **Number of Unique Distractors**
  - Low
  - Medium
  - High

- **Error (Arc Degrees)**
  - Control
  - OVI
  - CVI
Gaze Error and Reaction Time Measures

![Reaction Time (Fixate) graph]

Time (ms)

0 500 1000 1500 2000

Low Medium High

Number of Unique Distractors

Control OVI CVI
Gaze Error and Reaction Time Measures

Group of Individuals (N of 6) with CVI and Acuity ranging from 20/20 to 20/30
Background Clutter and Color Match

**Background Clutter**

- Time (ms)
- Background Presence
- Off vs On
- Control, OVI, CVI

**Color Match Presence**

- Time (ms)
- Color Match Presence
- Disabled vs Enabled
- Control, OVI, CVI
Video Capture

Control

CVI

Low Distractors

75% normal speed
Virtual Hallway

Methodology

3 runs about 3.5 minutes each

- 9 trials per run
- Brief rest between runs

Crowd density classified into levels
- Low (5 people) (A)
- Medium (10 people) (B)
- High (15 people) (C)
  range of +/- 5 people

Hallway clutter (50% of trials) (D)
Heat map colors represent varying levels of density

- Yellow means more time looking in that area
- Blue indicates less time looking in that area
- No color indicates insufficient point density
Heat maps

Control

OVI

CVI

Low

High

Low

High
Gaze Error

Gaze Error

Distractor Density

Error (Arc Degrees)

Low Medium High

Control OVI CVI

CVI - Control

Difference (Arc Degrees)

Low Medium High
Group of Individuals (N of 6) with CVI and Acuity ranging from 20/20 to 20/30
Reaction Time

**Reaction Time (Fixate)**

- Error (Arc Degrees)
- Distractor Density: Low, Medium, High
- Reaction Time (Fixate)

**Missed Targets**

- Miss Rate (Percent)
- Distractor Density: Low, Medium, High

Graphs showing reaction time and missed targets for different distractor densities and conditions (Control, OVI, CVI).
Group of Individuals (N of 6) with CVI and Acuity ranging from 20/20 to 20/30
Environmental Clutter

Gaze Error

Error (Arc Degrees)

Clutter Presence

NoClutter | Clutter
---|---
Control | OVI | CVI

Clutter Off | Clutter On
Demonstration

Control

CVI

Low Distractors

75% normal speed
Additional Manipulations

Gaze Error

Gaze Error in Arc Degrees

Control
Individual with CVI
CVI with Motion
CVI with Yellow Jacket

Distractor Density
LOW MEDIUM HIGH
VISUAL PERCEPTION TESTING: HUMAN CROWDING

WITH HIGH SALIENCE VS WITHOUT EXAMPLES
Behavioral Takeaways

Behavioral responses to static and dynamic visual search tasks

• Gaze error and response times
• Visually impaired groups versus controls
• Effect of complexity on individuals with CVI

Differences between tasks

• Increased sensitivity to complexity in dynamic setting

Disconnect between visual function and functional vision

• ‘High’ acuity does not offset visual spatial processing deficits

Positive benefits of some manipulations

• Saliency (yellow jacket condition)

Neural Correlates?
**Task related neural correlates**

**Electroencephalography (EEG)**
- High temporal resolution (ms)
- Low spatial resolution (cm)
- Timing of brain responses
- Well suited for repeated static trial presentation (virtual toy box)

**Functional Magnetic Resonance Imaging (fMRI)**
- Low temporal resolution (sec)
- High spatial resolution (mm)
- Location of brain responses
- Well suited for continuous dynamic video presentation (virtual hallway)
EEG study – Virtual Toy Box

4 runs with 50 trials per run
Pseudorandom order
Equal low and high

Lowest Complexity

Highest Complexity

Data Recording
EEG Pilot Results

Brain Response

- Control: 300 ms, 325 ms, 350 ms, 375 ms, 400 ms
- CVI: 300 ms, 325 ms, 350 ms, 375 ms, 400 ms

Stimulus Onset: 0 ms

- Control: ~1000 ms
- CVI: ~1500 ms

Locate Target
Disregard irrelevant information

- conserve resources for task relevant information

EEG ERP events: N170 versus P300

- Separate impairments to ignoring of distractors from locating and fixating
- Potential issues of fatigue
fMRI paradigm

Low Number of Distractors

3 runs lasting about 3 minutes each

High Number of Distractors

Pseudorandom order of low and high
fMRI study – Virtual Hallway

Control

CVI

Faces
Places
Objects
Body

p < 10^-6
Conclusions

Virtual Reality as a tool for assessment
  • Stimulus control and ecological validity
  • Engaging for participant
  • Robust eye tracking data

Behavioral differences between CVI and OVI compared to Controls
  • Complexity further impacts CVI performance

Neuroimaging techniques illuminate neural correlates (ongoing)
  • High temporal and spatial resolution with multiple techniques
  • Understanding of underlying neuro-physiology of visual perceptual deficits

Limitations: Additional data for OVI to better characterize trends
Ongoing and future work

Further CVI and OVI data capture

Additional Study Runs

Further Analysis
  • Fixation metrics
  • Smooth Pursuit

Other Potential Scenarios

Potential for training and strategy testing
  • Individualized and adaptive
Thank you

Collaborators

- Emma Bailin
- Corinna Bauer
- Peter Bex
- Timothy Gottlieb
- Lotfi Merabet

Funding Sources

- NIH/National Eye Institute
- Research to Prevent Blindness
- Lions International
- Massachusetts Lions Eye Research Fund
- Knights Templar Eye Foundation

Special Thanks

- Focus Group
- Participants and Families
- Webinar Organizers