Mobile VR for vision testing and treatment

U Rochester CVS / RIT – VR Symposium – June 1, 2018

Benjamin T. Backus
Vivid Vision Inc, San Francisco, USA
SUNY College of Optometry, New York, USA
Disclosures

• I work for Vivid Vision Inc, which sells the VR tests and treatments described in this talk.
• I receive royalties from a patent covering use of eye tracking to test and treat dysfunctions of binocular vision
  • Owned by the Research Foundation of SUNY
  •Licensed by Vivid Vision - Patent grant US8602555B2

ben@seevividly.com
Today

1. Binocular vision: testing and treatment
2. 3D target tracking confirms VR different from off-head displays
3. Visual field testing in VR – rationale and preliminary findings
1. Binocular vision: testing and treatment
5 binocular vision problems we might try to treat

- Suppression
- Amblyopia (lazy eye)
- Convergence insufficiency
- Strabismus (eye turn)
Strabismus

Like amblyopia, strabismus is a problem in the central nervous system.

But the current treatment is eye muscle surgery, which does not directly treat the cause of the problem.

- Each eye has full motility on its own.

http://www.childrenseyefoundation.org/Programs/Adult-Strabismus.aspx
What goes wrong with BV?

Ohzawa & Freeman
J Neurosci 1988

Figure 10. Hypothetical receptive fields of cortical cells. A, An example of a normal, simple-cell receptive field, where elongated discrete ON and OFF regions are positioned regularly side by side. B, A spatially disorganized positioning of ON and OFF areas, which causes abnormalities in orientation and spatial frequency tuning properties.
Why virtual reality?

• Independent control of left and right eye luminance and contrast
• Adjust images for ocular misalignment
  • Sensory training before and after eye muscle surgery
• Games are more engaging than old style exercises
  • Improves compliance
  • Attention and arousal may improve the efficiency of perceptual learning
5 binocular vision problems we might try to treat

- Suppression
- Amblyopia (lazy eye)
- Convergence insufficiency
- Strabismus (eye turn)
- Lack of stereoscopic depth perception
The problem

• ~10% of the population is *stereo deficient*
  • Stereoblind
  • Unable to see small disparities as depth

• **Common causes of stereodeficiency**
  • 3-4% of population has strabismus (crossed/uncrossed eyes)
  • 3-4% has amblyopia (50% overlap with strabismus)
  • Convergence insufficiency
  • Optical deficits causing “form deprivation”
  • Developmental anomalies such as albinism
Binocular vision is complex

• What has to go right to see stereo depth
  • Eyes look in the same direction (no large *strabismus*)
  • Neither eye completely *suppressed*
  • Good optical images in both eyes
    • No occlusion from cataract
    • No *anisometropia* such as unilateral hyperopia = far-sighted in one eye
  • These things must happen during the first two years of life for stereo vision to *develop normally*
But stereo deficiency can be treated even in adults

- ...if the neural hardware is in place
  - How often is this true? Answer: Unknown.

- Recovery of stereo depth perception even in adults is now firmly established
  - Levi and colleagues (UC Berkeley)
  - Hess, Thompson & colleagues (McGill, Waterloo)
  - Backus & colleagues (SUNY Optometry)
For example

Data from Law & Backus, 2018
Approach: Target specific subsystems

- Control of vergence eye posture
  - Will be better with eye tracking (thanks Gabriel Diaz)
- Regulation of interocular suppression
- Extraction of binocular disparity despite residual binocular misalignment
- Utilization of disparity to
  - estimate depth
  - adjust convergence
- Combination of stereo with monocular depth cues
The explosion of new VR HMDs give us a **cheap** and **available** hardware platform for accurately controlling the image being sent to each eye. VV (Rift, Vive, mobile) is in 120 clinics world-wide.
Amblyopia treatment of adults with dichoptic training using the virtual reality oculus rift head mounted display: preliminary results

Peter Žiak, Anders Holm, Juraj Halička, Peter Mojžis and David P Piñero

Abstract

Background: The gold standard treatments in amblyopia are penalizing therapies, such as patching or blurring vision with atropine that are aimed at forcing the use of the amblyopic eye. However, in the last years, new therapies are being developed and validated, such as dichoptic visual training, aimed at stimulating the amblyopic eye and eliminating the interocular supression.

Purpose: To evaluate the effect of dichoptic visual training using a virtual reality head mounted display in a sample of anisometropic amblyopic adults and to evaluate the potential usefulness of this option of treatment.
Data From Pilot Study

% OF PATIENTS

STEREO ACUITY (IN ARCSECONDS)

- Before training:
  - Unmeasurable: 47.1%
  - 400 to 200": 35.3%
  - 201 to 100": 11.8%
  - 101 to 50": 17.6%
  - Below 50": 17.6%

- After training:
  - Unmeasurable: 11.8%
  - 400 to 200": 35.3%
  - 201 to 100": 11.8%
  - 101 to 50": 17.6%
  - Below 50": 17.6%
Clinical use of the Vivid Vision system to treat disorders of binocular vision

Benjamin T. Backus, PhD  
Tuan Tran, OD  
James Blaha

Abstract

New head-mounted displays and virtual reality software make it possible for the first time to deliver customized, dichoptic visual stimulation at reasonable cost to patients with binocular vision disorders. These disorders include stereo-depth deficiency, amblyopia, convergence insufficiency, and strabismus. Vivid Vision, Inc. has pioneered this new treatment approach and has the leading commercial product, used in more than 100 optometry and ophthalmology clinics worldwide. The Vivid Vision System use games that are fun to play in order to improve adherence. Children typically respond better to binocular vision treatments than do adults, and recent studies in adults suggest that treatments using Vivid Vision are effective; however, large clinical trials with better controls are needed to quantify effectiveness across this heterogeneous patient population.
Come to the demo during Poster Session
2. VR vs off-head displays: 3D Target tracking
“Is stereo depth perception fast or slow?”

• If stereo is slow, it’s not useful.
  • People who lose stereodepth perception miss it, and people who get it for the first time (e.g. “Stereo Sue” Barry) describe it as a transformative experience.
  • But if it’s not useful, there’s no real benefit for treating it.

• The stereo system has a long integration time: Oscillations in depth were not tracked faster than 10-12 Hz
  • Richards (1972)
  • Norcia & Tyler (1984);
  • Kane, Guan & Banks (2014)

• But does this mean that stereo is too slow to be useful?
• No. For example...
  • Mary Hayhoe lab findings during motor activities (walking, object avoidance)
  • David Knill lab findings during fast reaching movements
  • Caziot & Backus, 2015 PLOS ONE
Stereo *can* be very fast

Caziot & Backus, 2015 PLOS One

- Task: 2 AFC with feedback: Which side is close? Or dark?
- *Deadline* procedure with 250, 300, 350, or 400 ms for response (in blocked trials)
Individual speed-accuracy tradeoffs
Application of a new paradigm: *continuous tracking for psychophysics*

- For eye tracking
  - Mulligan, Stevenson & Cormack (*Human Vision and Electronic Imaging XVIII*, 2013)

- For hand tracking
Continuous tracking

1 cm in lab space = 1 cm in virtual space

Continuous tracking

Continuous tracking

- Frontoparallel tracking: fast and precise
- Depth from stereo: slow and less precise
- Why so much slower?

Let’s try this in VR

• Virtual reality might overcome flatness cues from a flat display.
• But the instructions might also matter.
  • Manipulation: explicit instruction to attend in depth
    • 2 trials “Track the target” – no special depth instructions
    • 2 trials “Focus on Z”
    • 2 trials “Just track the target again, no special focus on Z”
Task & stimulus

• Task: track the target with the tracker
Task & stimulus

• Task: track the target with the tracker
• Stimulus
  • Oculus Rift
  • 90 Hz display, tracker position
  • Gaussian 3D random walk
• Depth tracking was necessary to do this task in Z
  • Occlusion cues were removed by using a single color, no shading
  • Size cues were removed by keeping target angular size = 1 deg
Effect of instructions on Z-tracking in VR

- Small effect of instruction on Z-tracking for some observers
- S2 has albinism
  - Nystagmus & poor stereo
Comparison for X, Y, and Z (mean of N=6)

• X-tracking was faster and more precise than Z—or Y
• Y and Z were similar
  • Poor Y and Z tracking: motor sluggishness for arm vs wrist movement
What is the effect of instruction to attend to depth when tracking in a flat-panel display?

- New data (UT)
- As before, Y looks similar to X, not Z
- Even with instruction, Z-tracking was poor
- Agrees with demonstrations of greater weight for disparity during depth perception if you don’t see the flat display (e.g. Banks Lab)
Conclusions

• Continuous tracking works well for visual psychophysics
  • High fun:data ratio
  • Well suited to clinical applications
• We replicated Bonnen et al. (2015), in VR
  • Z-axis tracking was better in VR
  • Tracking in Z was still a bit slower than X and Y in most people
    • But not all of them
• Tracking in depth shows fast, accurate use of binocular disparity in VR: *more so than in off-head displays.*
3. Visual field testing in mobile VR
Perimeters / Campimeters

Carter rotating-arc perimeter (1873)

Tübinger perimeter (1955)

Humphrey Visual Field Analyzer (contemporary)
Mobile visual field testing

For screening

  - 5746 Americans age 40 or older were sampled
  - Est. incidence is 2.1% = 2.9 M Americans age 40 or older
  - 50% were unaware they had glaucoma = 1% of older Americans

For monitoring the progression of disease

- Measuring rate, and detecting change in rate, is important
  - When to treat a patient more aggressively?
  - Is a new therapy effective for rescuing vision?
  - Measurement of progression is currently limited by
    - Test frequency (3x/year, if lucky): Personnel cost, equipment cost, patient comfort, inconvenience of multiple trips to the clinic
    - Test reliability: Clinically significant progression of 1-2 dB per year in “mean deviation” can’t be measured because current tests (such as HVFA) have a test-retest error of 1-2 dB in many patients.
    - Some patients (20%?) can’t be measured at all
Vivid Vision Perimetry

• VVP adapts *oculokinetic perimetry* to VR
• Changing fixations are a natural part of the test
• VR let’s the patient make head movements

Bertil Damato, MD, PhD
UCSF Ophthalmology
Advantages of VR

• Can be implemented on new consumer-grade head-mounted displays (HMD)
  • Inexpensive: Pico Goblin, Oculus Go all-in-ones cost < US $300, weight < 500 g
  • Binocular testing (see Matsumoto et al. 2016, PLOS One description of “imo” VF tester)
Binocular fixation, monocular targets

Displayed:

Perceived:

Advantages of VR

• Can be implemented on new consumer-grade head-mounted displays (HMD)
  • Inexpensive: Pico Goblin, Oculus Go all-in-ones cost < US $300, weight < 500 g
  • Binocular testing (see Matsumoto et al. 2016, PLOS One description of “imo” VF tester)
  • Comfortable – sit in your favorite chair at home
  • Take the test when you are feeling awake and alert
• Computer control of stimuli
• Gamification to make test-taking more tolerable
• Using Unity for cross-platform support
• Free head movement -> Better fixation of the target
  • Fixation stability and compensation studies by Rucci & colleagues
VVP test trial structure

1. Fixation task
   • Use a task that encourages foveation of the fixation mark

2. Target presentation
   • VVP currently uses suprathreshold dark-on-light 0.43 deg targets

3. Response: report target location
   • Head-orienting task to report target location, if seen
1. Fixation task

Move the *head-pointer* onto the *fixation target*.

- The head-pointer is always visible at the center of the display.
- The fixation target, when visible, has a location in the world.
- Task: “Move the head-pointer onto the fixation target.”

*Head-pointer*
2. Target presentation
2. Target presentation
3. Response
Next trial

US Patent grant US9706910B1, Patents pending
Next trial

US Patent grant US9706910B1, Patents pending
VVP Demo
December 2016

Layout: radial target array (can be 24-2, 10-2, etc)
Vivid Vision Perimeter™
An automated head-mounted visual field test

Produced by:
James Blaha, CEO, Vivid Vision, Inc.
Benjamin T. Backus, PhD, CSO, Vivid Vision, Inc.
Bertil Damato, MD, PhD, Professor, UCSF
Michael Deiner, PhD, UCSF
Manish Gupta, CTO, Vivid Vision, Inc.
### UCSF Pilot Study (Damato et al.)

**Conditions:** Glaucoma  
**OS:** Pericentral Ring Scotoma  
**OD:** Pericentral Ring Scotoma  
**Dilated:** YES  
**Subject:** 76 yo Cauc. male  
**Tech Exper:** Daily Smartphone, Rarely games, Never VR  

<table>
<thead>
<tr>
<th>Survey</th>
<th>HVF</th>
<th>VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discomfort?</td>
<td>moderate</td>
<td>none</td>
</tr>
<tr>
<td>Fatigue?</td>
<td>large amt.</td>
<td>none</td>
</tr>
<tr>
<td>Dissatisfied? (falls asleep, disorder)</td>
<td>loved it!</td>
<td></td>
</tr>
</tbody>
</table>
**Conditions:** Glaucoma  
**OS:** Pericentral Ring Scotoma  
**OD:** Pericentral Ring Scotoma  
**Dilated:** YES  
**Subject:** 76 yo Cauc. male  
**Tech Exner:** Daily Smartphone. Rarely exercises. Never VR

<table>
<thead>
<tr>
<th>Survey</th>
<th>HVF</th>
<th>VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discomfort?</td>
<td>moderate</td>
<td>none</td>
</tr>
<tr>
<td>Fatigue?</td>
<td>large amt.</td>
<td>none</td>
</tr>
<tr>
<td>Dissatisfied? (falls asleep, disorder)</td>
<td>loved it!</td>
<td></td>
</tr>
</tbody>
</table>
HVF 30-2

Conditions: Glaucoma
OS: Pericentral Ring Scotoma
OD: Pericentral Ring Scotoma
Dilated: YES
Subject: 76 yo Cauc. male
Tech Exper: Daily Smartphone, Rarely games, Never VR

Test grid: 30-2 / 10-2
Test duration: 7m41s / 8m19s
Discomfort?: moderate none
Fatigue?: large amt. none
Dissatisfied?: falls asleep, disorder loved it!
HVF 30-2

Conditions: Glaucoma
OS: Pericentral Ring Scotoma
OD: Pericentral Ring Scotoma
Dilated: YES
Subject: 76 yo Cau. male
Tech Exper: Daily Smartphone, Rarely games, Never VR

Test grid: 30-2 / 10-2
Test duration: 7m41s / 8m19s

Survey: | HVF | VR
---|---|---
Discomfort? | moderate | none
Fatigue? | large amt. | none
Dissatisfied? | (falls asleep, disorder) | loved it!
Conditions: Glaucoma
OS: Pericentral Ring Scotoma
OD: Pericentral Ring Scotoma
Dilated: YES
Subject: 76 yo Cauc. male
Tech Exper: Daily Smartphone, Rarely games, Never VR

Test grid: 30-2 / 10-2
Test duration: 7m41s / 8m19s
Survey:
| Discomfort? | moderate | none |
| Fatigue?    | large amt. | none |
| Dissatisfied? | falls asleep, disorder | loved it!

HVF 30-2

HVF 10-2
Conditions: Glaucoma
OS: Pericentral Ring Scotoma
OD: Pericentral Ring Scotoma
Dilated: YES
Subject: 76 yo Cauc. male
Tech Exper: Daily Smartphone, Rarely games, Never VR

Test grid: 30-2 / 10-2
Test duration: 7m41s / 8m19s
Survey: HVF VR
Discomfort? moderate none
Fatigue? large amt. none
Dissatisfied? (falls asleep, disorder) loved it!

HVF 30-2

HVF 10-2
HVF 30-2

Conditions: Glaucoma
OS: Pericentral Ring Scotoma
OD: Pericentral Ring Scotoma
Dilated: YES
Subject: 76 yo Cauc. male
Tech Exper: Daily Smartphone, Rarely games, Never VR

Test grid: 30-2 / 10-2
Test duration: 7m41s / 8m19s
Survey:

Discomfort? moderate none
Fatigue? large amt. none
Dissatisfied? [falls asleep, disorder] loved it!

HVF 10-2

Central 10-2 Threshold Test
Three important points

1. **Make the test comfortable**
   - Vision is inherently high-bandwidth – 1.2M ganglion cells participate per eye
   - Shorter tests *necessarily* sacrifice sampling spatial resolution
   - If the test is fun, it need not be short

2. **Do a natural task that requires high resolution vision at fixation**
   - Allow free head movements

3. **Exploit the “labeled-line” nature of seeing**
   - You don’t see *that* a target occurred without seeing *where* it occurred
   - Don’t throw away this information by using a yes/no button-press response!
   - Instead, use reported location to prevent *patient false alarms* from looking like *hits*. An octant (45-deg sector) seems to work well.
Demonstration of high-resolution blind spot mapping without eye tracking

Normally sighted, well-trained observer
March 2018
**Test parameters**

- Backgr luminance = white (~200 cd/m$^2$)
- Target luminance = 0.5 x white
- Target duration = 300 ms
- Lattice spacing = 0.7 deg
- Target spot size = 0.3 deg diameter
- Test detection radius = 3 deg
- Total test time 15 min, 45 sec
- Array center = (15.0, -2.0) deg
- Array radius = 5 deg
- Number of locations = 245
- Pink = standard blind spot test location
Test parameters

- Backgr luminance = white (~200 cd/m²)
- Target luminance = 0.5 x white
- Target duration = 300 ms
- Lattice spacing = 0.7 deg
- Target spot size = 0.3 deg diameter
- Test detection radius = 3 deg
- Total test time 15 min, 45 sec
- Array center = (15.0, -2.0) deg
- Array radius = 5 deg
- Number of locations = 245
- Pink = standard blind spot test location
- Seen
- Missed, then seen
- Missed twice
- Expected BS center

OS

OD
Fundus images from UCSF using Zeiss OCT fundus imager, inverted up-down
0.3 deg spacing
0.3 deg spot diameter
Lt gray spots 80% white
Background white

Angioscotomata

Standard blind spot test location was the same in both tests. Placed with no free parameters.
Visual field conclusions

- Consumer-grade HMDs are good enough for at-home perimetry
- Patient comfort may soon be more important than short test time
  - If cost of personnel and equipment is low
- Psychophysically sensible testing procedures should be introduced *now*, along with the new hardware
  - Use a natural, high-acuity task at fixation
  - Using directional responses instead of go/no-go button presses allows patient false positives to be distinguished from hits
Research collaborators

Dennis Levi  
UC Berkeley Optometry

Martin Banks  
UC Berkeley Optometry

Daphné Bavelier  
U Geneva Cognitive Science

Bertil Damato  
UCSF Ophthalmology

Michael Deiner  
UCSF Ophthalmology

Mitchell Dul  
SUNY Optometry

Larry Cormack  
UT Austin

Kate Bonnen  
UT Austin
Vivid Vision Team

James Blaha
CEO, Founder

Manish Gupta
CTO, Founder

Ben Backus
Chief Science Officer

Tuan Tran
Chief Optometrist

Brian Dornbos
Director of Optometry

Sunao Miyoshi
VP Asia

Monica Fehrs
Vision Therapist

Amina Weed
VR Specialist FCOVT

John Drake
Designer

Alan Purdy
Software Engineer

J Braunstein
Customer Success

Ken Nicholls
Customer Support

Eric Medine
Art Director