Project Update: Investigating Student Understanding of Wavefront Aberrometry

PER Seminar, KSU Dept of Physics
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Outline

- Physics of wavefront aberrometry
  - Basic principles
  - Zernike polynomials
- Most recently completed phase of project
  - Resources
  - Transfer
  - Scaffolding
- Future steps

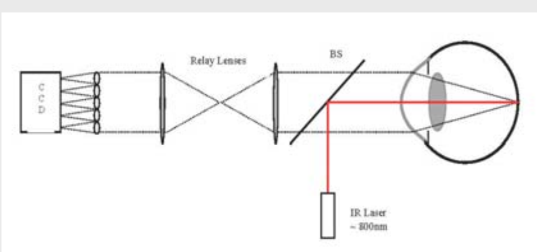
Wavefront Aberrometry

- 4 Types
  - ray tracing
  - Tscherning
  - automatic retinoscopy
  - Hartmann-Shack
    - Used in laser surgery procedures
      - We focus on this one

Focal Shift

- Perfect Lens: refracts all incident beams of light through its focal point and parallel to the optical axis
- Aberrated lens refracts light either in front of or behind the focal point
- The change in position is the focal shift.
- Focal shift is dependent on the local aberrations
- Examine focal shifts at many points – find local aberrations – combine to find total

Wavefront aberrometer



Hartmanogram

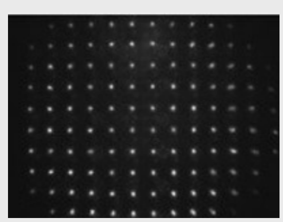
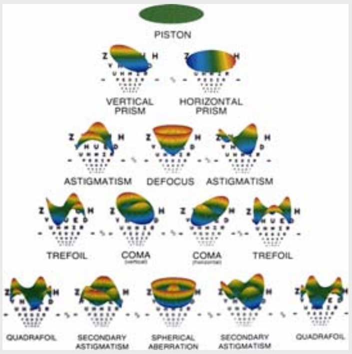


Image from www.optics.ru

- CCD camera reads out information about Hartmanogram
- An eye that was free of all aberrations would have a “perfect” grid pattern

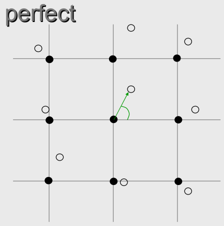
Aberrations



http://research.opt.indiana.edu/Library/VSIA/VSIA-2000_taskforce/TOPS4_3.html

Zernike Polynomials[1]

- Normal people – not so perfect grid
  - Measure differences from perfect
    - radial distance
    - azimuthal angle



- Zernike polynomials:
  - Hypergeometric functions
    - Even and odd
  - Normalization relates to Bessel functions

[1]Born and Wolf (1999)

Zernike Polynomials

$$U_n^m(\rho,\phi) = R_n^m(\rho)\begin{matrix}\sin(m\phi)\\ \cos(m\phi)\end{matrix}$$

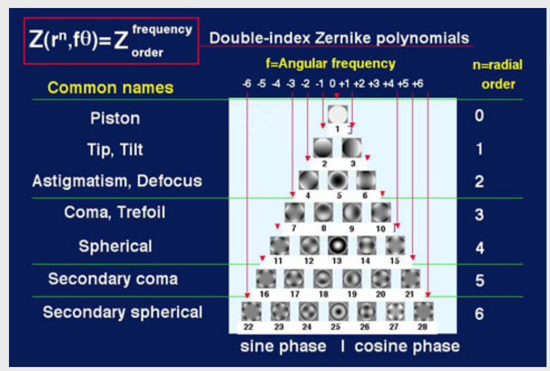
ρ is the radial distance

Φ is the azimuthal angle

$$R_n^m(\rho) = \begin{cases} \displaystyle\sum_{l=0}^{\frac{(n-m)}{2}} \frac{(-1)^l (n-m)!}{l!\left[\frac{1}{2}(n+m)-l\right]!\left[\frac{1}{2}(n-m)-l\right]!}\rho^{n-2l} & \text{For (n-m) even} \\ 0 & \text{For (n-m) odd} \end{cases}$$

$R_0^0(\rho)=1 \quad R_2^0(\rho)=2\rho^2-1 \quad R_3^1(\rho)=3\rho^3-2\rho \quad R_4^0(\rho)=6\rho^4-6\rho^2+1$

$R_1^1(\rho)=\rho \quad R_2^2(\rho)=\rho^2 \quad R_3^3(\rho)=\rho^3 \quad R_4^2(\rho)=4\rho^4-3\rho^2$

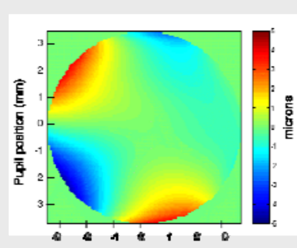


Thibos (1999)

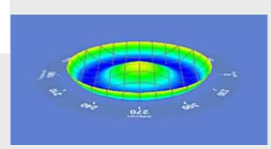
Zernike Expressions

	M	N	Z	expression
Defocus	2	0	Z_2^0	$\sqrt{2}\left(2r^2-1\right)$
Coma	3	1	Z_3^{-1}	$\sqrt{8}\left(3r^3-2r\right)\sin(\theta)$
Astigmatism	2	2	Z_2^{+2}	$\sqrt{6}r^2\cos(2\theta)$

Wavefront Maps



* Weighted sum of Zernike Polynomials



Images from www.allaboutvision.com and http://research.opt.indiana.edu/Library/VSIA/VSIA-2000_taskforce/TOPS4_3.html

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Goals of Phase 2

- How do students understand wavefront aberrometry?
  - What resources do they use?
- What scaffolding might be helpful in activating the appropriate resources?
- Further explore notion of subjective/objective

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Phase 2 – Data Collection

- 2-part Interviews
  - 18 participants completed both
  - EP2 students
- First meeting – eye materials
  - Followed lesson plans by DZ
- Second meeting – aberrometer
  - Same protocol used in prior phases

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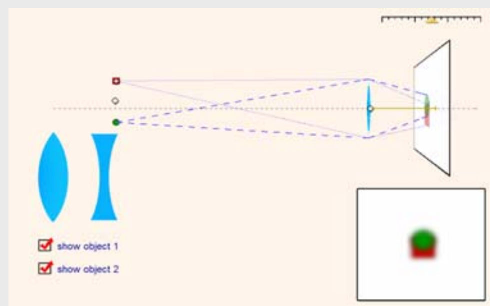
Computer Simulation



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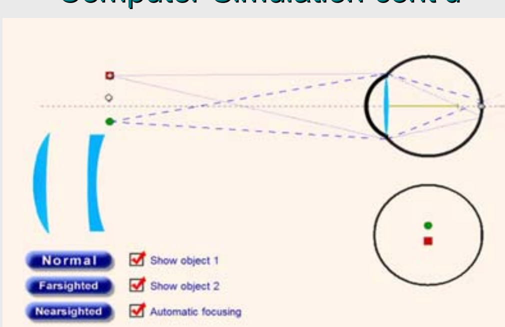
Computer Simulation cont'd



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Modeling Aberrometry

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Results

- Transfer of Learning did occur
  - Spontaneous Transfer (10 of 18)

    "I'm trying to think in terms of what we did on this computer, the images and how close they were together and where the focal points moved."
  - _______ Transfer (6 of 18)

    When asked why they answered a question the way they did, they said "Oh, we discussed this last time."
  - No Transfer (2 of 18)

    "I learned about it in high school, I think."

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Resources

- *The length of the eye determines how far you can see*

"Well it should be opposite [explores using simulation]. So yeah, with the retina as close as it can get [to the lens], I can put the objects farthest away and still see them."

- *Different shapes of eye will make the grid pattern focus at different distances*

"You're looking at changing the distance, as far as the back of the eye … it just goes hand-in-hand with the length of the eye. So if you move it [the retina] back, you're going to have to move this [the screen] either backward or forward, I just don't remember which."

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Resources cont'd

- *Closer objects appear larger*

While exploring with the model, the student noted "Well, the further the object is, the smaller the image seems"

- *The size of the grid determines whether the person can see near or far objects.*

"Well, by looking at it [the grid] they can see what size of image they get, and then say what type of problem the person must have based on the image. Like people who can see far but not close. Like farsightedness and the other."

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Resources cont'd

- *A defect in the lens will only distort the part of the grid that is getting the light from the defect.*
  - Many students predicted that only a portion of the grid would be distorted, corresponding to the part of the lens that was defective.
- *Lenses can only affect the light that enters them*
  - Resource from everyday life?
  - Related to the notion of covering half lens/half image disappears?

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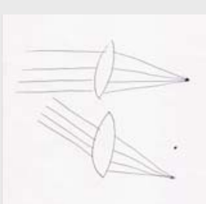
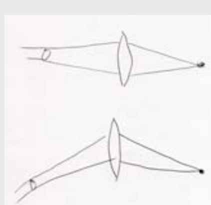
Resources cont'd

- *Light entering a lens differently will focus differently*
  - P-prim: changing input changes output
  - Most basic form of cause-and-effect

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Reflect/Refract

- In previous phases we noticed incorrect usage of these words
- This time: 7 of 18
- Indication is just a vocabulary issue
  - "Light reflects through the lens"
    - Say the word you know

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Subjective/Objective

- Initial Impressions
  - Eye chart
    - Subjective – 9
    - Objective – 5
  - Aberrometer
    - Subjective – 2
    - Objective – 12
  - 4 didn't know definitions
- After given definitions
  - Eye chart
    - Subjective – 6
    - Objective – 1
  - Aberrometer
    - Subjective – 0
    - Objective – 7

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One problem …

- A convex lens makes the light focus closer
- A concave lens makes the light *"focus farther"*
- Inducing a misconception by not treating the diverging lens singly
  - They only see it in a combination with the eye or another convex lens
  - Need to address in all future phases

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Scaffolding

- Prompt to talk about the eye as a part of the system that forms the grid
  - Too obvious to state?
- Think about what happens when light enters lens at any other incidence
  - And resulting effect for grid pattern
- Which defect is long/short eye
- Which lens does what

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Phase 3 – Group Interviews

- April 2008
- GP2 Students
- **Post**-Instruction Interviews
  - Already know lenses/eye
    - Eliminate issue with diverging lens
  - More realistic
  - Only 1 interview session
- Aiming for 10-12 groups, 2-3 students each

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Protocol

- Includes same aberrometry as before
  - Model aberrometer, ask for explanation
- Still ask about subjective/objective
- Start with intro to accommodation and our eye model
- Hartmann-Shack Aberrometer

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Goals of Phase 3

- Further investigate:
  - Resources
  - Scaffolding
    - What works and doesn't
    - Where addition is needed
- Also investigate
  - Group dynamics
  - Transfer from a 'typical' lecture class

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Thank You!

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