The Development of Vision
Rain Bosworth, Ph.D.

What can infants see?

<table>
<thead>
<tr>
<th>Newborn</th>
<th>1 month</th>
<th>2-3 months</th>
<th>6 months</th>
<th>12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vision is the least developed of the senses.</td>
<td>can focus on objects or faces 8-12 inches away.</td>
<td>Occasional involuntary fixation on a single object.</td>
<td>Perception of detail, color, depth and distance have improved markedly.</td>
<td>All aspects of vision close to that of adults. Working on visual-motor control.</td>
</tr>
<tr>
<td>can track single large objects from birth... mediated by subcortical structures</td>
<td>Much better at making saccades and smooth pursuit</td>
<td>Extremely attentive to faces.</td>
<td>Refining of vision continues to 4-10 years of age, depending on visual function.</td>
<td></td>
</tr>
</tbody>
</table>
**Why study visual development?**

1) Curiosity about what infants can see.

2) Nature vs. Nurture - *Is experience necessary for visual development?*

3) Define critical periods and plasticity

4) How neural substrates mediate perception

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**Why study visual development?**

*Clinical applications:*

1) Early onset eye disorders: *cataracts, refractive error, strabismus, ptosis*
   - If not treated, cause *Amblyopia*

   - Must know what “normal” visual development is!

Dense central cataract: 📸

Strabismus: 📸
Why study visual development?
-Clinical applications:
2) Earlier detection of disorders:

For example, possible abnormal visual function in Autism – social deficits not obvious until after 1 year of age, but visual deficits could be present earlier.

... This was suggested for dyslexia too – visual motion deficits may precede reading by several years.

... Possibly true for other developmental disorders as well.

Outline of Today’s Lecture:
I. Brief overview of neural development

II. Visual Psychophysics – How do we study vision in infants?

III. Infant Vision (Ages 1 - 6 months):
   1) “spatial” vision
   2) reasons for immaturity
   3) luminance, color, and motion
I. Neural Overview:

Primary Visual Cortex (V1) located in Occipital Lobe

![Diagram showing the neural connections and brain lobes](image)
I. Neural Overview:

- Ipsilateral (same side) connections
- Contralateral connections
Rough schematic of visual brain areas, each has layers, and a specific visual function:

- **Areas of Extrastriate Cortex**
  - Layers of the Primary Visual Cortex
- **Thalamus (LGN)**
- **Retina** (back interior surface of eyeball)

### Brain development:

**Exuberance of cortical synapses:**

- **At birth**
- **3 months**
- **15 months**

Cortical Neurons and Synapses
Brain development: Exuberance followed by pruning of cortical synapses.

Still very much a mystery what the consequences are of exuberance and pruning upon visual perception.

II. Visual Psychophysics – HOW do we measure visual perception in infants?

Modified from Bates, Thal & Janowsky (1992)
II. Visual Psychophysics – HOW do we measure visual perception in infants?

• Babies can’t respond verbally
• We can’t confirm that even older children follow directions

Methods used to assess visual sensitivity in infants:

1) Directional Eye Movements – use optokinetic eye movements to measure sensitivity
2) Preferential Looking – use eye gaze and head turning to measure sensitivity
3) Habituation – measure decline in looking time for familiar stimulus and a novel stimulus
4) Visual Evoked Potentials (VEP) - passive viewing, measures cortical scalp electrical activity
Methods used to assess visual sensitivity in infants:

2) Preferential Looking – use eye gaze and head turning to measure sensitivity

We will focus on this one.

With an emphasis on how we measure “contrast sensitivity”

First, explanation of the stimuli used…..

Grating Stimulus

Gratings are defined in modulation of contrast of luminance (dark vs. light) …

Sine wave (or sinusoidal) gratings

Commonly used in vision studies

QUESTION: Why is it so important to use such a simple image? Why not present infants with richer images?
Grating Stimulus

Gratings are defined in modulation of contrast of *luminance* (dark vs. light) …

Sine wave (or sinusoidal) gratings

*Commonly used in vision studies*
- easily manipulated, described, and quantified
- we know exactly what infants are seeing
- visual neurons have firing “preferences” that can be consistently modulated with gratings

**QUESTION:** Why is it so important to use such a simple image? Why not present infants with richer images?

Grating Stimulus

Gratings are defined in modulation of contrast of *luminance* (dark vs. light) …

Sine wave (or sinusoidal) gratings

**QUESTION:** What does this pattern look like if the amplitude of the peaks and troughs were lower?
Grating Stimulus

Gratings are defined in modulation of contrast of luminance (dark vs. light) …

Sine wave (or sinusoidal) gratings

QUESTION: What does this pattern look like if the amplitude of the peaks and troughs were lower?

Grating Stimulus

Contrast defines how visible the stimulus is. Sensitivity is measured at different contrasts. Threshold is the point at which contrast can no longer be seen.

Contrasts:

<table>
<thead>
<tr>
<th>100%</th>
<th>40%</th>
<th>15%</th>
<th>5%</th>
<th>2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy:</td>
<td>100%</td>
<td>92%</td>
<td>78%</td>
<td>Can’t see:</td>
</tr>
<tr>
<td>100% correct</td>
<td>92% correct</td>
<td>78% correct</td>
<td>50% correct</td>
<td>(5/10)</td>
</tr>
</tbody>
</table>
And NOW, how do we measure visual sensitivity in infants, using grating stimuli at different contrasts?

Forced-Choice Preferential Looking Technique
Task: On each trial, which side does the grating appear?

Did the baby look on the Left OR Right Side?

Example Contrast Threshold from one three-month old infant

Threshold = 6.5% contrast

Sensitivity = 1/thr * 10 = 1/0.065 = 15.4
**Grating Stimulus**

*Spatial Frequency* – metric used to quantify size of grating stripes

- Size is defined in terms of *retinal* image size, not real-world object size. This way we can translate to different viewing distances.

- At arm’s viewing distance, 1 cm object size is approx = 1 degree of visual angle

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**Grating Stimulus**

*Spatial Frequency* - cycles per deg or “cpd”

<table>
<thead>
<tr>
<th>2 cpd</th>
<th>4 cpd</th>
<th>9 cpd</th>
<th>18 cpd</th>
<th>32 cpd</th>
</tr>
</thead>
</table>

**Resolution Acuity** – the smallest size pattern we can resolve. Images with finer detail are harder to resolve
What is a *Contrast Sensitivity Function*?

** Example contrast sensitivity function: **

- One contrast sensitivity *value* is plotted for EACH spatial frequency...
Contrast Sensitivity

Example contrast sensitivity function:

Contrast Sensitivity

Spatial Frequency (cycles/deg)

1 month
3 months

Adults

Contrast Sensitivity

Spatial Frequency (cycles/deg)

1 month
3 months

Adults

3 months
1 month

"Acuity" = the finest (smallest) grating pattern that can be resolved

Low Sensitivity in Infants

Low Resolution in Infants
So what limits infant vision? Why is infant vision so poor?

What limits infant vision?

Eye development:
The eye ball size and shape still increases with age, which improves vision and the ability to accommodate.
What limits infant vision?

Eye development:
One significant reason why vision is so poor in infants is due to photoreceptor morphology and density.

Photoreceptors in the Eye
A) Immature Morphology – short and fat cones

Do not capture light well. Thus, have low sensitivity to light

Hendrickson & Yuodelis, 1984
Infant Photoreceptors in the Eye
B) Infants have lower *Density of photoreceptors*

Spacing of photoreceptors on the retina:

- **Adult**
  ![Adult Photoreceptors]
- **Infant**
  ![Infant Photoreceptors]

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**THE EYE**

- **Photoreceptors**
- **Pupil**
- **Retina**

"Grating" Pattern
Infant Photoreceptors in the Eye
B) Infants have lower *Density of photoreceptors*

Thus, infants do not “resolve” stimuli well, due to subpar sampling.

Example spatial contrast sensitivity function, *from infants*:

- **Low Sensitivity** in Infants
  - Immature Morphology of Photoreceptors

- **Low Resolution** in Infants
  - Reduced density of photoreceptors
Summary: What limits infant vision?

- Optical factors (shape and size of eye and pupil)
- Retinal factors (morphology and density of photoreceptors)
- Cortical factors (pruning and myelination of cortical connections)

Digression: Disease and CSF’s

CSF is a good representation of the visual system and can show differential effects of various disease states…
*Probably true for different developmental disorders too.*

![Graph showing log contrast sensitivity vs. log spatial frequency for different conditions including normal adults, 1 month old infants, mild refractive error, visual deprivation (cats), multiple sclerosis, cataracts, severe refractive errors, and glaucoma.](image)
Development of Sensitivity for **Chromatic** Stimuli

Are there specific immaturities in COLOR vision, beyond those in contrast sensitivity?

**Grating Stimulus**

They can be defined in terms of *chromaticity* instead…

Sine wave gratings

Red bars and green bars have the same *Luminance* but different chromaticity

QUESTION: What does this pattern look like if a subject can not perceive red and green colors?
Infants possess equally low sensitivity for BOTH luminance and chromatic stimuli. Thus, no “special” color deficit, at least for red-green discriminations.
Development of Sensitivity to \textit{Motion} Stimuli

Are there specific immaturities in MOTION perception, beyond those in contrast sensitivity?

\textbf{Speed Contrast Sensitivity Function}

\begin{itemize}
  \item \textbf{SLOW}
  \item \textbf{FAST}
\end{itemize}

Obtain Contrast Sensitivity at different moving speeds
Contrast Sensitivity

The shape of motion sensitivity function is adultlike by 3 months... they just need more contrast.

Summary: What can infants see?

By 2-3 months of age
- Very good: Sensitivity to faces, flicker, orientation, and gross motion
- Pretty good: Contrast, spatial frequency, accommodation, eye control, color, small motion discriminations
- Still developing: some colors (blue-yellow?), global motion segregation and integration, 3D vision, fine visual-motor coordination, higher order attentive or visual-cognitive processes
## What can infants see? – Contrast and Acuity

<table>
<thead>
<tr>
<th>Age</th>
<th>Contrast Characteristics</th>
<th>Acuity Characteristics</th>
</tr>
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<tbody>
<tr>
<td>Newborn</td>
<td>25 x less contrast due to inefficient luminance sampling</td>
<td>Adultlike.</td>
</tr>
<tr>
<td>1 month</td>
<td>25 x less contrast</td>
<td>4 x blurrier than adults</td>
</tr>
<tr>
<td>2-3 months</td>
<td>2.5 x less contrast</td>
<td>3 x blurrier</td>
</tr>
<tr>
<td>6 months</td>
<td>Contrast is adultlike</td>
<td>2 x blurrier</td>
</tr>
<tr>
<td>12 months</td>
<td>Adultlike.</td>
<td>Acuity is slightly worse than adults</td>
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<tr>
<td></td>
<td></td>
<td>until 4 years of age</td>
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### What can infants see? - Stereopsis

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<td></td>
<td>No depth perception. No ability to accommodate (focus) on a target in depth</td>
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<td></td>
<td>can focus on objects or faces 8-12 inches away.</td>
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<td></td>
<td>Sometimes crosses eyes – causes diplopia.</td>
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<tr>
<td></td>
<td>sensitivity to flicker adultlike</td>
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<td></td>
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<td></td>
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<tr>
<td></td>
<td>Eyes rarely cross now. If they do, may have strabismus (esotropia)</td>
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<tr>
<td></td>
<td>Adultlike stereopsis and motion detection</td>
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