Yokohama City University lecture
INTRODUCTION TO HUMAN VISION
Presentation notes
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1. INTRODUCTION TO HUMAN VISION
Self introduction
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In today's talk, I would like to give you a simple overview of the eye and the visual system.

2. IMPORTANCE OF VISION
Most of us see well most of the time. Our visual systems work well, so it's easy to take vision for granted. But if we pause to think about it, we can easily see that vision is one of the most important aspects of life.

Vision is the most important of our senses. It's so important that about 50% of the cerebral cortex is involved in processing vision.

Vision is critical to all aspects of life.

Can you think of examples of how important vision is to us in daily life?

3. TODAY'S PRESENTATION
In today's talk, I plan to briefly discuss ...
- Simple anatomy of the eye
- and describe the two main parts of the visual system.
- Finally, I'd like to introduce you to some details you must consider if you will be doing vision-related research.

4. ANATOMY - FRONT VIEW
You are probably familiar with these parts of the eye, since you see then everyday.
- Lids, lashes
- Iris, pupil
- Why is the pupil black?
- Sclera (white of the eye)
- Notice the little bright spot on the front of the eye. What is that?
- Notice the half ring of light. What is that?

5. CROSS-SECTIONAL VIEW
You have all probably seen a figure like this before, that shows a cross-sectional view of the eye.

Note the parts we saw in the previous photo, now seen from the side.
- Iris
- Pupil

We can see other structures that were not visible in the previous figure.
- Cornea - clear front lens of the eye. Usually not visible, since it's clear. But we see the reflection off the front surface of the cornea. That was the bright spot we saw before.
- Lens. This is the 2nd lens of the eye, and it has a special purpose.

- The large space is filled with a clear gel-like material.
- Retina - inner surface of the inside back of the eye
- It receives the optical image formed by the eye's two lenses.
- The figure shows a magnified view of the retina.
- Choroid
- Sclera

6. RETINA - CLOSE UP
The retina is a very thin layer, only about 100 μm thick, but it is a very important structure in the eye. The retina is very important for vision.

It has a very complex structure, with 10 layers containing millions of neurons. The neurons make up complex networks within the retina.

Near the back (bottom here) of the retina are highly specialized neurons know as photoreceptor cells. These cells absorb light, and then convert the light into an electrical signals that are relayed to the brain.

This is a very important step at the beginning of the visual process.

7. THE VISUAL SYSTEM
Human vision is a very sophisticated, complex process performed by the visual system.

The eye is an important part of the visual system, but vision requires more than just the eye. It also requires a complex system of neuron and the brain, which process the image and create vision.

The visual system can be broken down into two main parts:
1. Part I: Optics and formation of an optical image by the eye.
2. Part II: Image process by neurons and the brain

8. VISUAL PATHWAYS DIAGRAM
This figures shows the entire visual system.
- Part I, consists of the eyes, which view scene, and form an optical image of the scene on the retinas.
- The retinas convert the optical image to electrical signals that are relayed to the brain for image processing.
- Part II of the visual system consists of the neurons between and including the retina and the brain.
- Part I is optical, and forms an optical image. Part II relays the signal and processes the image.

9. PART 1: OPTICS (THE EYE)
This figures show how the eye works like an optical instrument, like a camera, which forms an optic image of a scene on an image plane.

Notice the similarities between a camera and the eye.
- Mulitple lenses focus light
- A pupil or aperture that controls light entering the system.
- The pupil also affects image quality.
- The internal lens of the eye adjusts its shape to adjust the eye's focus, when viewing objects located at different distance, like an autofocus lens in a camera.
- The retina at the back of the eye, like the sensor in the back of a camera, receives the image, and converts it into electrical signals.

- The electrical signals are relayed to the brain for processing.

10. OPTICAL IMAGE
This figures shows that the two lenses of the eye, the cornea and internal lens, focus light onto the retina and form an image of the object the eye is looking at.

Notice that the image is focused onto the retina, which is a surface, like a screen.

Notice the following features of the retinal image.
- It looks much like the object.
- It is inverted, and is also flipped R/L relative to the object.
- Note that the image extends across a large area of the retina.

Why is the retina image inverted and reversed? Demonstrate with plus lenses.

Just as the object in a scene is located at one specific distance from the lens, its image will also be located at one specific distance from the lens. If this distance matches the distance to the retina, then the retinal image will be clearly focused.

However, if the focal distance is not exactly right, then the image on the retina will be blurred.

Demonstrate also how the image is clearly focused in only one plane, by moving the projector screen.

11. FOCUS ERRORS
A blurred retinal image will, of course, cause blurred vision. This figure illustrated different degrees of blur.

12. REFRACTIVE ERRORS
The retinal image will be blurred if the power of the eye's lenses are either too strong or too weak, or if the eyeball is either too long or too short as shown here.

The upper left figure shows the focal power of the lenses is just right, so the light comes to focus exactly on the retina.

The upper right show an example in which the light comes to focus in front of the retina, and it is blurred on the retina. This is an example of myopia.

The lower left shows that, relative to the retinal distance, the focal distance is too long, and the retinal image will be blurred. This is an example of hyperopia.

The lower right shows that sometimes the light can be distorted in other more complicated ways that cause a blurred image.

These kind of focusing errors referred to as "refractive errors," and they cause blurred vision.

13. CORRECTING REFRACTIVE ERRORS
Refractive errors can be corrected by
- Eyeglasses
- Contact lenses
- Refractive surgery, or
- Orthokeratology

Any questions?

14. VISUAL FIELD
We see object within a wide field of view.

Close one eye, look straight ahead, and estimate how wide is your horizontal field of view. [Demonstrate with the iPhone camera.]

Repeat with both eyes open.

Explain the figure.

- Vision with each eye extends from about 90° temporally to 60° nasally.
- With two eye, the field is about 180° wide.
- How can you extend your field of view? Move eyes, head, body.
- Centrally the two field overlap.
- So objects are seen by both eyes with this area.
- This creates unique advantages, especially for depth perception.
- But is also creates problems.

Press-the-eye demo

Why do you see two?

15. VISUAL DIRECTION SLIDE
This slide shows several things. Note that this is an overhead view of the left eye.

- An extended scene is imaged across a broad area of the retina.
- Because the image is reversed/flipped, ...
- An object in the left field is image onto the right retina.
- An object on the right field is imaged onto the left retina.
- If you are looking at an object straight ahead, it's image will be on the center of the retina.
- The optic nerve is located slightly nasal to the center of the retina. It gathers data from the retina and sends the signals to the brain.
- Note that in this one spot, there is no retina, therefore this part of the image will not be seen.
- Which part of the visual field would be imaged on the optic nerve?
- Note that an object located in this part of the monocular visual field will not be seen. This is referred to as the blind spot.

16. BLIND SPOT DEMO

Blind spot demo (monocular)

What happend to the blind spot if you open the other eye? Why?

17. PART II: IMAGE PROCESSING
Review the main points listed on the slide:

- Photoreceptors convert the optical image to electrical signals.
- Neurons relay the image data to the brain.
- The data must include:
- Image details (Size, shape, color, brightness, contrast, etc.)
- Image position data too
- In addition, data from the two eyes must be merged into one image.
- This requires complex data organization and processing.

18. PATH OF LIGHT ONTO THE RETINA

This figures again shows a side view of the eye. The two lenses, the cornea and lens, focus light onto the retina, which receives the image. Note the direction of light and the magnified view of the retina.

The lower figure shows an enlarged cross sectional view of the retina. Note the image has been rotated 90° relative to the other figure. In this case, light would be striking the retina from above, as shown by the yellow arrow.

The retina is a complex structure that contains 10 layers. The photoreceptors are located near the back side of the retina. Note that the light must path through the upper layers of the retina before reaching the photoreceptors.

The photoreceptor cells captures the light, convert it to electrical signals, and then send the signals to the neurons above it, as shown by the blue arrows in the figure. The data is then sent to the brain.

19. DATA FLOW: RETINA TO BRAIN
Explain

20. VISUAL PATHWAYS FIGURE
Trace image from right visual field to both left retinas.

- Trace OS temporal fibers/ OD nasal fibers back through the optics nerves to the optic chiasm.
- Nasal cross, temporals don't
- Synapse in left LGN.
- Second-neuron fiber to left visual cortex.

Likewise, trace image from left visual field to right retinas.

- Trace OS nasal/ OD temporal retina through optic nerves to chiasm.
- Nasal cross, temporals don't
- Synapse in left LGN.
- Second-neuron fiber to left visual cortex.

Note that because of this organization, corresponding data from the two eye merge.

Right visual field data goes to the left half of the brain. Left visual field data goes to the right side of the brain.

21. PATHWAY LESION
Suppose you have damage to the nerve fibers in the brain somewhere along the visual pathways. How will it affect vision? Consider the following possibilities:

- Normal, healthy visual system: Test each eye's visual field.
- In the following, both eyes are healthy, but there is a problem in the brain.
- Right optic nerve lesion - OS fine. OD blind.
- Cut optic chiasm in center - both nasals cut - bitemporal field loss
- Cut right optic radiations - loose input from OS nasal and OD temporal

By analyzing the type of VF anomaly, doctors can figure out the location of the lesion in the brain.

22. MANY VISUAL FUNCTIONS
Vision is very complex, and includes many functions that work together. Read list.

When you are doing research that involves vision, you are usually interested in measuring or using just one aspect of vision.

23. FAMOUS VISION EXPERIMENT
In order to understand how complex vision, let's review a famous experiment, done by Selig Hecht, in about 1941 at Columbia University.

He wanted to answer a simple question: "What is the minimum amount of light a human eye can detect?"

This might seem like a simple question. Can you think of how you might answer it?

24. EXPERIMENTAL DESIGN
In this experiment, he was not measuring visual acuity, or color vision, but simply how well the visual system could detect light.

Hecht had to understand the visual system and all the variables that might affect his results.

The he had to design the test conditions to optimize sensitivity of the eye.

He also had to design an apparatus that could produce a dim spot of light and control its properties.

25. VARIABLES AFFECTING SENSITIVITY
He had to consider the following experimental variable.

- How long should he let the subject be in the dark before starting the experiment? This is called dark adaptation.
- Where should the test be located in the visual field?
- How big should the test light be?
- How long should the light be left on?
- What color should the light be?

26. DARK ADAPTATION
Your eyes become more sensitive for detecting a dim light if you wait in the dark.

For example, if you walk into a dark theater on a bright sunny day, when you first enter the theater, you probably won't be able to see anything. But if you wait, and let your eyes adjust to the dark, you vision will gradually improve. Soon you will be able to see things inside the dark theater. This is referred to as dark adaptation.

This plot shows how the eye's sensitivity increases as a function of time. Note that the function levels off after about 30 minutes in the dark. Beyond 30 minutes, sensitivity does not improve, so they decided to let their subjects dark adapt for at least 30 minutes.

27. RETINAL SENSITIVITY
Where should he present the small spot of light in the visual field? Does it matter? In fact, yes, it does.

This is because sensitivity differs for different parts of the retina. Under dark adapted conditions, the retina is most sensitive where it has the highest density of photoreceptor cells.

This figure shows that photoreceptor density is greatest about 20° on either side of the center of the retina. So he decided to position the test light about 20° off center in the visual field so the image would fall on this part of the retina.

28. SPATIAL SUMMATION

How big should the test light be? If a small light is bigger than about 10 arc minutes, it requjires more light to be seen. Therefore he decided to make the test light 10 arc minutes in diameter. This is related to a principal in visual perception called **spatial summation**

29. TEMPORAL SUMMATION
How long should the light be left on? If a small light is left on for longer than 100 msec, it requires more light to be seen. Therefore he decided to flash the light for 1 msec.

30. COLOR SENSITIVITY
What color should the test light be? The eye's sensitivity varies for different wavelengths of light as shown here. Under dark adapted conditions, the eye is most sensitivity to light with a wavelength of 550 nm, which is green. Therefore he decided to use a green light.

31. TEST CONDITIONS
Hecht therefore conducted the experiments with the following conditions.

- dark adapted subjects for 30 minutes
- stimulus (test spot) was located 20° nasal to fixation
- test spot diameter was 10 arc minutes
- test light was flashed for 1 millisecond
- wavelength was 510 nm (green)

32. APPARATUS
This figure from his paper shows the apparatus they used to create the test light and do the experiment.

33. RESULTS & CONCLUSION
After making careful measurement, he discovered that the minimum amount of light necessary to stimulate a photoreceptor cell is ONE photo of light!

This is amazing, considering that this is the minimum quantity of light that can exist in the physical world.

This shows that the human eye is an amazingly well designed optical instrument!

34. CONSIDERATIONS WHEN TESTING VISION
If you will be doing vision-related research, you should carefully consider the following:

Which visual function will you be meauring.

Then you will probably also have to decide how you will control many variable, which will affect vision, including those shown here. [Read list.}

35. THANK YOU!