ACCOMMODATION (LECTURE SUPPLEMENT #1)

Comparative methods of accommodation

Because the eye has several optical elements there are a number of ways that the conjugate focus can be altered, and various creatures exploit most of these mechanisms

Axial length: Changes in length of the eye have the effect of changing its optical power. Ex. Statically, The horse has a "**ramp retina**" which provides for a static difference in conjugate focus for different directions of gaze. On a longer time scale, Chickens show a change in axial length during development that depends on their refractive error. Monkeys have recently been shown (By Dr. Smith's group) to have a similar mechanism. Dynamically, certain eels can shorten their axial length by constriction of a muscle.

Corneal Shape: The cornea is the most powerful optical element in the eye, so small changes in its shape can produce significant changes in conjugate focus. Ex: Owls change the shape of their eye as a means of accommodating.

Lens Position: The power of the eye's optics is determined in part by the distance from lens to cornea, and many mammals, such as cats and raccoons, accommodate by simply moving the lens forward. Ex: The Lamprey lens is moved backwards by its cornealis muscle, resulting in active negative accommodation. The human lens moves forward somewhat during accommodation, contributing to the overall change in dioptric power.

Lens Shape: Altering lens shape is the principal mechanism of primate accommodation. Among mammals this is rare, however. Dynamically, some birds and turtles constrict the lens using a combination of ciliary muscle and iris, causing the anterior surface to bulge forward. Statically, some creatures have a lens with an oblong shape so that power of the lens is different on different axes. Ex: The Anableps,. a South American Trout, has a **bifocal eye** with two pupils that allows clear vision above and below the water.

Pupil Size: Although it doesn't change the dioptric power of the eye, reducing the size of the pupil does increase the depth of focus. Thus, pupil constriction is part of the near response, and presbyopes tend to have small pupils as partial compensation for loss of accommodation.

Refractive Index: In principal, changes in the refractive index of any part of the eye could produce a change in conjugate focus, but there is no evidence of this being used by any creature.

Mechanism of human accommodation

Unlike most muscular efforts, accommodation does not have an antagonist pair of muscles. The Ciliary muscle acts against a passive elastic restoring force produced by **Bruch's membrane** and the **Zonule of Zinn**. Contraction of the Ciliary Muscle relieves the tension in the Zonule of Zinn, allowing the lens to assume a more rounded shape. Most of the change in shape occurs in the anterior surface, so the overall position of the lens is slightly more forward. Relaxation of the Ciliary Muscle allows the elastic fibers to pull on the lens capsule and flatten it.

This **relaxation theory of accommodation** was originally proposed by Helmholtz and is now the accepted view. As the muscle constricts, the lens relaxes into its more natural shape. An alternative, **tension theory of accommodation** was proposed by Tscherning, who thought that the ciliary muscle put the lens under tension, forcing it back against the vitreous and thus causing it to bulge.

During positive accommodation, several changes occur:

The lens thickens by about 0.5 mm.

The lens diameter is reduced slightly.

The radius of curvature of the anterior surface decreases (i.e. it gets more rounded).

The radius of curvature of the posterior surface decreases.

The choroid is pulled forward, stretching the retina slightly.

The lens drops slightly under influence of gravity.

Effect of Age on Accommodation: Presbyopia

Loss of Range: Accommodative range at birth is about 18.5 Diopters, but is reduced continually throughout life. Based on data from subjects between 8 and 30 years, Hofstetter proposed a linear formula

Amplitude = 18.5 - age / 3

So that one Diopter is lost every 3 years. Range reaches the working distance of 40 cm (2.5D) at around 48 yrs (functional presbyopia), and reaches zero at around 55 yrs (absolute presbyopia). Usually, the <u>near point recedes</u> and the far point is stable.

Causes of Presbyopia: Several proposals have been made for the cause of presbyopia. We really don't know if there is one cause, so a combination.

Lens Sclerosis

Ciliary Muscle weakness.

Loss of elasticity in Bruch's Membrane, zonules.

This explains loss of range, but why is there no myopia?

Stiffening of lens/ lens capsule. Again, this would predict myopia.

Increased size of lens, so that zonules become slack. Again, there should be myopia.

Recent evidence suggests that the lens remains pliable in presbyopia, and it is the continual growth of the lens throughout life that causes presbyopia. The lack of myopia suggests there is a compensating factor, such as change in refractive index, that offsets the increased curvature.

Treatment of Presbyopia: Currently, <u>bifocals</u> are the standard method. Some patients may tolerate <u>monovision</u> prescription in which a different power contact lens is prescribed for each eye. Experimental techniques involving <u>surgery</u> may become more prevalent in the future.

Measurement of accommodation

Objective: Scheiner Pupil: When light enters the eye from two pinholes it forms a double image on the retina unless the source is conjugate with the retina. Scheiner in 1619 first demonstrated accommodation with this technique. Many automated optometers use this principal to find the conjugate focus of the eye, providing a dynamic record of accommodation. It can <u>underestimate absolute accommodation</u> by as much as one diopter because the reflections it uses come from the anterior surface of the retina, not from the photoreceptors.

(added after) **3rd Purkinje image**: Formed from the anterior surface of the lens, this reflection changes its size and focus with changes in accommodation and can be used to look at time-varying aspects of accommodation.

Subjective: Badal Optometer As an example of a simple optometer, this allows the subject to adjust a target to be conjugate with the retina. It is limited by the subject's criterion, and is slow, but can be quite accurate.

Dynamics of Accommodation:

Latency: Accommodation has a very long latency, up to 500 msec. Saccades reduce the latency by half.

Velocity: The Peak Velocity of Accommodation (Diopters/sec) depends on the stimulus amplitude, being about 5-10 Diopters / sec per Diopter of stimulus. However, Accommodation is slow to complete so that it starts out with a high velocity but slows at the blur decreases. Often it takes as long as a second to complete the change. Saccades double the velocity.

Prediction: Accommodative responses are <u>not</u> usually predictive, so even with a predictable sinusoidal change in blur, the accommodative response will lag behind by about one latency period.

Maddox Components of Accommodation:

The same four components described for convergence also apply for accommodation, with some modification:

Blur-driven Accommodation:

Fine control of accommodation occurs through the detection of blur on the retina. Blur is detected principally as a <u>loss of contrast</u> in fine details of a target. This by itself does not indicate the direction of the error. Several proposals have been made as to how we get the "odd-error information" about blur:

Hunting cycle: Accommodation is constantly fluctuating, and perhaps the visual system keeps track of the change in blur with small changes in accommodation.

Astigmatism: If the eye has any significant astigmatism, then the orientation of blur provides a cue as to the direction of the error.

Chromatic Aberration: Different wavelengths focus at different distances from the lens, and there is evidence to suggest that the color fringes produced may drive accommodation in the correct direction: Accommodation is difficult with monochromatic light; and the eye can be fooled by changes in wavelength composition.

Convergence Accommodation:

When the eyes make a fusional convergence movement, there is a corresponding change in accommodation. Usually it is not enough to bring focus in to the point of regard. The extent of coupling is described by the **CA/C ratio**, Convergence Accommodation/Convergence, measured in Diopters per Prism Diopter.

Proximal Accommodation:

Just as with convergence, a perception of nearness will stimulate a change in accommodation.

Tonic Accommodation:

Accommodation has an adaptive component like vergence does. Sustained near work will change the resting focus to reduce the demand on blur-driven accommodation. Resting focus is usually around +1.5 D for an emmetrope, reflecting a balance of sympathetic and parasympathetic innervations.

In some cases, tonic accommodation can appear to be myopia, if the eye fails to reach its relaxed state under distant viewing. In **Empty Field Myopia**, the lack of contrast causes accommodation to move to its tonic state, so that if distant targets do appear they will be out of focus. Ex: flying a plane in fog, looking through a high plus lens.

Instrument Myopia is a condition in which distant objects appear blurred after prolonged viewing through a microscope or other optical instrument. The optics of the instrument reduce the effectiveness of accommodation, and so the eye tends to drift toward its resting focus.

Night Myopia is a related condition in which a correction which is acceptable in daylight becomes too weak at night. The lack of patterns to focus on probably makes accommodation move toward the tonic state. Additional factors in Night Myopia are the **Purkinje Shift**, where visual sensitivity moves toward shorter wavelengths at low light levels and **Spherical Abberation** due to the enlarged pupil, where more rays are focused in front of the retina

Measurement of Accommodation (add-on): in addition to the Scheiner Pupil method, the dynamics of accommodation can be measured <u>objectively</u> from the **3rd Purkinje Image** which is formed by the anterior surface of the lens. The size and focal plane of the reflex changes with accommodation, but it doesn’t give an absolute measure the way the Scheiner Pupil does.

A Badal Optometer is a device to measure accommodation by having a subject adjust the focus of a target until it is conjugate with the retina. The Conjugate Focus reflects the sum of the subject’s <u>refractive error</u>, any <u>lenses</u> before the eye, and the <u>accommodative response</u>. Thus, accommodative response can be determined by subtracting the other two components from the measured Conjugate Focus.

Lag & Lead of Accommodation: (sidebar on lab topic for this week)

Accommodative Response reflects the change in dioptric power of the intraocular lens in response to defocus. Because of **Depth of Focus**, the accommodative response is not perfect and there is a **lag of accommodation** (not enough accommodative effort, conjugate point behind retina) or a **lead of accommodation** (too much accommodative effort, conjugate point in front of retina). Factors which increase the depth of focus will tend to increase the amount of error. These include spherical aberration, chromatic aberration and astigmatism, all interacting with pupil size.

Typically, there is accommodative lead for distant targets (> 1 meter) and a lag for near targets. The lag is usually constant for most of the accommodative range, and then the response saturates at the near point.

Yoking of Accommodation: Accommodation is a consensual response, and normally both eyes will accommodate by the same amount even if only one is stimulated. Thus, Hering's Law applies to accommodation. If one eye is cyclopleged and presented with an accommodative target, the other eye will make an excessive accommodative response, driven by the extra effort required for the viewing eye to focus.

Under some conditions, however, subjects will make Differential Accommodative Responses in order to keep both retinal images clear. This can be as much as one Diopter difference in some people, but individual differences are large.

Pathway for Accommodation

The tone of the ciliary muscle is determined by the balance of innervation from **Parasympathetic** and **Sympathetic** inputs. Current thinking is that the parasympathetic inputs act to contract the muscle, and that sympathetic inputs act to inhibit the parasympathetic. So the push/pull antagonism is opposing innervation to one muscle, not an opposing pair of muscles.

The **ciliary ganglion**, located inside the orbit, contains cells which generate parasympathetic signals for both accommodation and pupillary constriction. More than 90% of the cells are driving accommodation. The sympathetic innervation to intraocular muscles passes through the ciliary ganglion without synapsing.

Parasympathetic input to the ciliary muscle comes from the Edinger-Westphal Nucleus of the Oculomotor Nucleus complex. Most fibers project from the E-W by way of the **ciliary ganglion**, but a small number may project directly to the ciliary muscle. The functional distinction between these is unknown.

Cells in the Edinger-Westphal Nucleus and other nearby regions are somewhat segregated with respect to control of lens and iris, so that stimulation of a localized region can produce accommodation without pupil constriction or *vice versa*.

Supranuclear control of accommodation has not been studied to a great degree, so relatively little is known about the specific pathway. Stimulation of occipital cortex can produce bilateral accommodation, usually as part of the near reflex. Since accommodation and convergence are linked, it is difficult to determine whether an evoked accommodation is just a side effect of disparity vergence, making isolation difficult.

Sympathetic input to the ciliary muscle follows the same general pathway as for pupil dilation. Nerve fibers ascend from the **Superior Cervical Ganglion** at the base of the skull, with some passing through the ciliary ganglion without synapsing. Preganglionic signals arise from cells in the Hypothalamus *via* cells in the cervical spinal cord.

Note that the Parasympathetic innervation to accommodation could be inhibited at different levels; at the muscle by the Sympathetic system or at the level of the Oculomotor Nucleus. It is still unknown which is more important in voluntary accommodation.

PUPIL CONSTRICTION AND DILATION

Purpose of Pupil Control

Light Adaptation: over the full range of typical pupil sizes, from 2 to 8 mm, there is about a factor of 16, a little over one log unit change in retinal illuminance. Vision operates over a range of about 10 log units, so the change in pupil size accounts for only a small fraction of our adaptive ability.

Depth of Focus: As the pupil becomes smaller, the depth of focus increases, allowing clear vision for more widely spaced objects and allowing more tolerance of accommodative error. Thus, increased accommodation (Near Response) and presbyopia are accommpanied by pupil constriction.

Reduction of Aberrations: Both spherical and chromatic aberration are reduced when the pupil constricts, producing sharper retinal images. The optical benefit of a small pupil reaches a limit at around 2.5 mm, when the eye becomes diffraction limited.

Dynamics of Pupil Response

Range: the normal pupil can vary in size from about 2 mm to as much as 8 mm in some individuals. Range peaks in the teen years and declines steadily throughout later life.

Latency: The latency for pupil responses to light varies with the intensity of the stimulus, usually from about 200 msec to 500 msec.

Dynamic Changes in Pupil Size

Hippus: aka Physiological Pupillary Unrest. The pupil is constantly oscillating in size, with a higher rate of oscillation in the light than in the dark. Typically the rate is around 2 Hz. It is unknown if Hippus serves a functional role in vision.

Fatigue Waves: Because the reactivity of the pupil depends on arousal and alertness, under conditions of fatigue one may see fluctuations in pupil size that correlate to periods of drowsiness and arousal.

Edge-light oscillations: If a bright light enters the eye near the pupil margin, then constriction of the pupil reduces the illumination and leads to a feedback driven oscillation. This is sometimes confused with Hippus during clinical exams.

Pathway for Pupil Control:

Parasympathetic and Sympathetic systems control constriction and dilation respectively. This parallels the control of accommodation, where these same systems control positive and negative accommodation, respectively. The control pathways are substantially the same for Accommodation and Pupil Control.

Pupillary Light Reflex: The pupil responds to light through a subcortical pathway involving the accessory optic system. Optic Nerve fibers from **BOTH EYES** leave the Optic Tract and synapse in the **Pretectal Nucleus.** Cells there send axons to the Edinger-Westphal Nucleus on BOTH SIDES, resulting in a Consensual Pupil Response to Light.

If the retina or Optic Nerve is damaged, the damaged eye cannot respond directly to light, but will show the consensual response. If the Optic Chiasm is damaged, each eye can still show a direct and consensual response through the ipsilateral visual pathway. If the Optic Tract is damaged, only half the visual field will be effective in generating pupillary responses.

Disorders of Pupil Control: Horner's Syndrome

Suggested Readings:

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5. Scheiman M, Wick B. Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders. Philadelphia: J. B. Lippincott Co. 1994: 19-26.

6. Scheiman M, Wick B. Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders. Philadelphia: J. B. Lippincott Co. 1994: 339-378.

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