Vergence (Lecture supplement #2)

Vergence eye movements are disjunctive movements of the eyes such that the angle between the lines of sight changes. The most common type of vergence to make is Horizontal Vergence, but Vertical and Torsional Vergence movements also occur. With **Convergence** the lines of sight each turn inward toward the nose, with **Divergence** the lines of sight turn outward toward the temples.

One can define an **Iso-Vergence Circle** to represent all points in the visual plane which have the same horizontal vergence angle. This circle is very similar to the Veith-Muller circle (Geometric Horopter) but instead of passing through the nodal points of the eyes, the Iso-Vergence Circle passes through the centers of rotation of the eyes.

One can also define an Iso-Vergence Surface that represents all points in three-dimensional space that have the same horizontal vergence angle. The shape of the surface depends on the coordinate system you choose. Just remember that the measurement of vergence angles depends on the coordinate system for Tertiary positions of the eye.

Purpose of Vergence

Vergence movements serve to keep targets at various distances bifoveated.

In some cases, this involves smooth tracking of a target moving in depth. In other cases this involves gaze changing from a target at one depth to a different target at another depth. Vergence movements thus fit into both categories of eye movements discussed earlier.

Dynamics of Vergence:

Velocity: Vergence movements have a main sequence for velocity, like saccades, but the relationship between velocity and amplitude is not as tight. Vergence velocity is more influenced by stimulus characteristics such as size and contrast than saccades. Typically, vergence responses do not exceed 60 deg / second, about the same limit as for smooth pursuit. The exception to this is when vergence is combined with saccades, in which case different size saccades may occur resulting in a vergence component with saccadic velocity.

Previously it had been thought that the control signal for vergence was a step change in innervation to the muscle, but recordings from motorneurons indicate that there is a pulse component as well.

Latency:

Vergence movements tend to have relatively long latencies, typically on the order of 150-200 msec. This puts them in between pursuits and saccades in terms of latency.

Stimulus for Vergence:

There are four classical types of stimulus for convergence, referred to as the **Maddox Components**.

Disparity-driven (Fusional) Vergence: Vergence changes in response to retinal disparity. This can be horizontal disparity, which gives rise to stereoscopic depth perception. It can also be vertical disparity or torsional disparity. Each type of disparity drives the corresponding type of vergence movement.

Blur-driven (Accommodative) Vergence: This is vergence which occurs secondarily to an accommodative response. When the eye focuses to near targets, a convergence response occurs which tends to bring the lines of sight nearer the target, even if only one eye sees the target. By itself, Accommodative Convergence is not usually sufficient to accurately bifoveate a target, and disparity vergence is required as well.

Proximal Vergence: This is vergence which occurs when a target is perceived to be near to the observer, even if there are no blur or disparity cues to indicate distance. Proximal vergence probably has its greatest importance when making large Gaze Changing vergence movements from targets at different distances.

Tonic Vergence: This is the resting state of vergence when there are no disparity, blur or nearness cues present, such as in the dark. Tonic vergence is not fixed, but is **adaptable** depending on the recent history of vergence responses. For example, after extensive fixating at near, the tonic component of vergence will increase so that resting vergence will be nearer. This has the effect of reducing the demand on the other components of vergence in trying to hold fixation at near.

The resting or tonic vergence of the eyes is not simply the position of total relaxation, but is rather an actively maintained postured, determined by the tonic vergence component. The **anatomical position of rest** is about 20 degrees divergence (each eye is roughly 10 degrees abducted). This occurs in deep coma, in death, and sometimes can be observed in sleeping infants. The **physiological position of rest** is usually around 0 degrees (the lines of sight are parallel). This is what you measure as the far phoria: the alignment of the eyes when accommodation is relaxed and there is no stimulus to fusional vergence.

Phoria (prism) adaptation: The tonic vergence system changes its output based on the recent history of convergence. After a moderate period (one minute or more) of prism adaptation, the phoria will change so that fusional vergence is not required to hold convergence any longer.

> **Global Adaptation:** A concomitant change in phoria, so that the phoria is changed for all positions of gaze. Requires only about 1 minute. Ex: prism adaptation
>
> **Local Adaptation**: A non-concomitant change in phoria, so that the phoria is different for different positions of gaze. Requires an hour or more, depending on how complicated the non-comitant pattern is. Ex: Anisometropic spectacle correction.

Combination of Maddox Components: In normal situations, vergence is controlled by a combination of the four components. Large amplitudes of vergence, usually associated with gaze changes are driven mostly by the Proximal component. More precise alignment is then achieved and maintained with the Fusional component. If one eye's view is occluded, alignment is maintained fairly well by the Accommodative component. Over time, alignment is kept in tune by the Tonic component so that Fusional vergence doesn't have to work against a phoria all the time.

Maddox Components and vertical vergence: Since distance changes correspond only with horizontal vergence, there are no Proximal or Accommodative inputs to vertical vergence. If the eyes become misaligned vertically, however, there is a Fusional component to realign them and there is a Tonic component to adjust the alignment over time. This tonic component can produce non-concomitant adaptation, just as for horizontal. Ex: Superior Oblique paresis (weak, but not paralyzed).

Volitional control of vergence: Horizontal vergence has both voluntary and involuntary (reflex) aspects. Movement of the visual field will produce vergence following movements unconsciously, even if the motion isn't detectable. Vertical vergence has no voluntary aspect, but it is driven involuntarily in much the same way by disparity. Ex: Smooth vergence tracking depends on instruction to "track" or "fixate".

Measurement of Vergence:

Objective recordings: Since vergence is defined as the difference in position of left and right eyes, a complete description of vergence dynamics requires precise measurement of both eyes horizontal, vertical and torsional position: therefore, it requires the search coil method. Most of the important aspects of vergence are horizontal and relatively slow, so a limbus tracker is often sufficient to look at amplitude and velocity. Direct observation can be used to estimate larger angles of deviation.

Subjective measures: Often we are interested in just the vergence position, as in phoria measures, and subjective techniques can give a quite precise measure of eye alignment. The two eyes views are dissociated, as with a Maddox rod (cylinder lens) or red/green glasses as in the Lancaster test, so a subject or patient can easily judge diplopia without there being a stimulus to sensory fusion or fusional vergence.

Accuracy of Vergence: Fixation Disparity

Fixation Disparity

Fixation disparity is a small misalignment of the eyes under binocular conditions. Usually, this misalignment is very small with a magnitude of only a few minutes of arc. That is, fixation disparity is the condition in which the images of a binocularily fixated object are not imaged on exactly corresponding retinal points but are still within Panum's fusional areas. If the lines of sight intersect closer to the patient than the object of regard, an eso fixation disparity exists. If they intersect farther away from the patient, an exo fixation disparity exists. The small vergence error is related to the magnitude of an underlying phoria or misalignment of the eyes. Fixation disparity is a residual error following correction of the phoria by disparity vergence.

Associated Phoria

An associated phoria is the amount of prism required to reduce fixation disparity to zero. The associated phoria should be distinguished from the dissociated phoria, in which binocular fusion is disrupted.

Forced Vergence F.D. Curve Parameters

Fixation disparity is monitored while increasing amounts of prism are used to change fusional vergence demand. Graphic representation of the results are termed forced vergence fixation disparity curves. Curves with steep slopes, large associated phorias, and substantial fixation disparities are found more frequently when testing symptomatic patients.

A fixation disparity curve (FDC) is an *x, y* coordinate plot of the amount of fixation disparity in minutes of arc plotted against the amount of prism through which the patient views. Fixation disparity amount and direction is plotted on the *y* - axis with eso above and exo below the x - axis(min of arc). Prism amount and direction is plotted on the *x* - axis with base-in to the left and base-out to the right (prism diopters). FDC parameters are: curve shape, center of symmetry, associated phoria (X - intercept), Y - intercept (fixation disparity), and slope.

A *Type 1* FDC has vertically ascending and descending segments that asymptote on the base-in and base-out sides and a relatively flat central portion. Type I curves, which are present in about 55% of the population, are usually associated with asymptomatic patients. Other curves (II, III IV) types are frequently associated with patients who have large dissociated heterophorias or unstable binocularity.
A *type II* curve is flat on the base-out side and descends on the base-out side. Type II curves, which are present in about 30% of the population, are usually associated with large esophorias.
A *type III* curve is flat on the base-in side and ascends on the base-in side. Type III curves, which are present in about 10% of the population, are usually associated with large exophorias.
A *type IV* FDC is flat on the base-in side and base-out side and has a higher slope in its central portion. Type IV curves are associated with unstable binocularity.

Center of Symmetry - Center of symmetry refers to the area of the forced vergence fixation disparity curve where vergence adaptation occurs most readily to changes in disparity (fusional) vergence.

Associated Phoria: X - Intercept - The associated phoria is defined as the amount of prism required to reduce fixation disparity to zero. The associated phoria (X - intercept) is the point usually measured clinically. The magnitude of the associated phoria is generally significantly less than the dissociated phoria for exophoric patients and is often greater for esophoric patients. Associated phoria magnitude is influenced by proximal vergence and vergence adaptation.

Y - Intercept: Fixation Disparity - The actual fixation disparity measurement is the point where the curve crosses the Y - axis. Fixation disparity which is not generally measured clinically, except by instruments designed for the purpose such as the Sheedy Disparometer, Woolf card or Wesson card. Fixation disparity exists when images of a bifixated object are not on exactly corresponding points but remain within Panum's area.

Slope - The slope of FDC can be estimated by calculating the change in fixation disparity between prism demands of 3Δ BO and 3Δ BI.

Clinical Use:

When a patient has a flat fixation disparity curve, prism prescriptions based on shifting the center of symmetry toward the Y - axis are generally more successful than those based on either dissociated or associated phoria measurements. These prescriptions optimize responses of vergence adaptation to convergence and divergence demands.

Patients with steep FDC can often be treated using vision therapy. When the curves do not flatten with vision therapy, the patient may be viewed as being resistant to development of vergence adaptation. For these patients prism can be prescribed based on the associated phoria (prism to reduce fixation disparity to zero).2

Patients with vertical vergence anomalies often show steep slopes on their horizontal forced vergence fixation disparity curves. For some of these patients, vertical prism corrections can cause the FDC to have a flatter slope, smaller associated phoria, and smaller fixation disparity. Vertical prism correction is often readily accepted because vergence adaptation is slower and often incomplete for vertical vergences. Prism correction based on vertical associated phoria measures is generally considered to be the treatment of choice.

Pathway for Vergence:

Cranial Nerve nuclei:

Vergence follows the final common path to the extraocular muscles like all other movements, through the cranial nerve nuclei. Cells in the IIIrd nerve nucleus fire for both vergence and version movements, though there may be some specialization.

<u>Convergence</u> requires activation of the <u>medial rectus</u> in both eyes. <u>Divergence</u> requires activation of the <u>lateral rectus</u> in both eyes. Somehow, the abducens interneurons that normally produce yoked changes of gaze must be inhibited or else the eye would retract severely.

Supranuclear control of vergence:

Little is known about the exact pathway for horizontal vergence control, and virtually nothing is know about vertical vergence control. Cells have been found in the <u>Mesencephalic Reticular Formation</u> (MRF), just dorsal and lateral to the Oculomotor nucleus, which fire specifically in relation to horizontal vergence movements. This is near the same area where vertical saccade burst cells are found (riMLF). Thus, lesions here can affect both vertical saccades and convergence.

Vergence tonic cells: increase their firing rate in proportion to the angle of convergence. Some small proportion increase in proportion to divergence. Their activity changes 10-30 msec before the onset of vergence change.

Vergence velocity cells: (aka **vergence burst neurons**) like saccadic burst cells, these fire in proportion to the velocity of vergence. Again, there are more relating to convergence than to divergence.

Vergence burst-tonic cells: show a combination of these patterns, with a burst related to velocity and and increase related to the position (angle) of convergence.

Vergence Pause Cells: have been proposed to be the same as for saccades, and thus these are sometimes called OmniPause Neurons because they release both the vergence and the versional responses at the same time.

Cerebellar influence on Vergence:

The Cerebellum plays a role in vergence, but the exact function is unclear. Speculation is that it may be involved in adaptation and tonic control, by analogy to its role in adjusting the VOR and saccade amplitudes.

Cortical Control of Vergence:

Cells in V1 (area 17) and V2 have been found with **disparity tuning**, both for horizontal and for vertical disparity. These may generate the signals for disparity-driven vergence. Cells in the Frontal Eye Fields will elicit vergence movements as well, perhaps more related to voluntary aspects of vergence and proximal responses.

Still Unknown:

We don't know which cortical disparity-tuned cells actually generate the signals for vergence control. We don't know how accommodative effort gets input to vergence control. We don't know how the abducens interneurons are inhibited to avoid severe retraction.

Disorders of Vergence Control:

Alignment Disorders:

Tropias are deviations of the eyes which occur whether viewing binocularly or monocularly, as distinct from **phorias**, which are deviations that occur when viewing monocularly but disappear with binocular vision. **Eso-** refers to convergent deviations, **Exo-** refers to divergent deviations. **Hyper-** refers to elevated with respect to the other eye, **Hypo-** refers to depressed with respect to the other eye. Deviations are called **concomitant** (sometimes comitant) if they have the same amplitude for all positions of gaze, and **non-concomitant** (or noncomitant) if the deviation varies with gaze.

The causes of many tropias are unknown, though considerable research is being done. **Refractive esotropia** arises from a mismatch between accommodative and disparity vergence, particularly in hyperopes. As they use accommodation to focus in on near targets, their accommodative convergence is strong enough to make them esotropic.

Disorders of Accommodation/Convergence coupling:

Some patients who are orthophoric at far will show a large exophoria at near and complain of blurred or double vision when reading. This **convergence insufficiency** is due to a mismatch between accommodation and convergence. If a patient is orthophoric at near and strongly esophoric at distance, it is referred to as **divergence insufficiency**. Sometimes the opposite may occur, in which there is too much vergence response for the distance change, in which case it is referred to as **vergence excess**.

Neurological Disorders affecting vergence:

Vergence is abolished by some disorders, such as Parkinsonism and Progressive Supranuclear palsy, both of which have large affects on other motor systems. Often, vergence symptoms show up along with vertical gaze symptoms, because of the proximity of their control centers. Other neurological problems may disrupt vergence without abolishing it, or lead to inappropriate or excessive vergence.

Convergence-Retraction Nystagmus is a disorder in which the eyes make rapid convergent movements on attempted <u>vertical saccades</u>. There is also a retraction of the eye into the globe, as if all the extra-ocular muscles were being activated.

pseudo-Abducens Palsy is a disorder in which the eyes make a convergent movement on attempted <u>horizontal saccades</u>, and is also accompanied by a retraction of the globe.

Divergence Nystagmus sometimes occurs in conjunction with downbeat nystagmus, such that the fast phase in each eye is down and somewhat out. This is associated with some cerebellar disorders.

Convergence Spasm is an excessive amount of convergence which may either be organic or functional. <u>Organic</u> cases, due to lesions or disease, produce constant over-convergence whether under monocular or binocular viewing, without associated accommodation or pupil constriction. These are rare compared to the <u>functional</u> cases, in which the convergence is fundamentally voluntary or stress-related. In these cases, there is a full near response (vergence, accommodation and pupillary constriction) and it often disappears on monocular viewing.

Cross links of Vergence and Accommodation

The vergence, accommodative and pupillary systems act together in a **Near Response** and are sometimes referred to as the **Near Triad**. Shifting gaze to a near object, involves convergence, positive accommodation and pupillary constriction simultaneously.

AC/A Ratio describes the amount of Accommodative Convergence (in Prism Diopters) which occurs when the eye Accommodates one Diopter. <u>For perfect yoking, AC/A = IPD (cm).</u>

Calculated AC/A is determined from phoria measures at far and near.

<u>AC/A = IPD(cm) + Near distance(m) * { Near Phoria(Δ - Far Phoria(Δ) }</u>

Where esophoria is positive.

Gradient AC/A is measured more directly, by inducing accommodation with lenses and measuring the change in convergence.

Response AC/A compares the convergence to the actual accommodative response.

Stimulus AC/A compares the convergence to the accommodative stimulus, which may be different from the actual response.

Usually, the Calculated AC/A gives a higher number than the Gradient AC/A, because of the contribution of Proximal Vergence. When phoria is measured with far and near targets, the patient's knowledge that the distance has changed causes him/her to converge a little more than the accommodative convergence alone would.

Usually, the Response AC/A gives a higher number than the Stimulus AC/A because of the Lag of Accommodation.

CA/C Ratio describes the amount of Convergence Accommodation (in Diopters) which occurs when the eye Converges one Prism Diopter. For perfect yoking, CA/C = 1/IPD. CA/C is measured with a target that doesn't stimulate accommodation, such as a photo of a blurred object, or by viewing through pinholes so that accommodation has no effect. Disparity Vergence is stimulated with a fusible target and the amount of Accommodation is measured.

Factors affecting the AC/A ratio: When the ability to accommodate changes, the same effort of accommodation produces less actual accommodation, but it still produces the same accommodative convergence. Thus, if accommodation is limited, the AC/A ratio will be unusually high.

Drug effects on AC/A: agents which paralyze accommodation will tend to elevate the response AC/A because of the added effort to accommodate. Ex. Atropine blocks parasympathetic system, blocking accommodation, leading to very high AC/A.

Age effects on AC/A: onset of presbyopia will sometimes cause AC/A to increase dramatically (e.g. 20 Δ/D). This effect is most pronounced for near targets, where the accommodative response has saturated. AC/A may be normal if measured with more distant targets.

Dynamics of AC/A When target focus changes very slowly, there is usually less accommodative convergence response than if it changes quickly. This is likely due to **tonic accommodation** being adapted. Tonic accommodation doesn't contribute to the AC/A cross-link, so it doesn't stimulate convergence. Since adaptation is a slow process, the tonic system doesn't change with rapid changes in focus, only very slow ones. An analogous phenomenon occurs with CA/C, in that the Convergent Accommodation response tends to be low with very slow changes in target disparity due to tonic vergence adaptation.

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