MOTOR FUSION & VERGENCE

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INTRODUCTION TO MOTOR FUSION

Isolated innervations to an extraocular muscle of the eye do not occur, nor can the muscles from one eye alone be innervated. Impulses to perform an eye movement are always integrated, and all ocular movements are associated. Dissociated ocular movements are seen only in pathologic states. Whenever an impulse for the performance of an eye movement is sent out, corresponding muscles of each eye receive equal innervations to contract or relax. This is the basic law of equal innervation ... first proposed by Hering. (von Noorden, p. 65-66)

Similarly, in normal binocular vision the actions of the six muscles of both eyes are coordinated such that both visual axes point toward the object of regard. Based on the laws of visual direction, we know that both primary visual lines must intersect on the object if it is to be seen as single. The movement of the eyes to line up both visual axes on the objective of regard is known as **motor fusion**. Motor fusion is a prerequisite for **sensory fusion**, which is the neuro-physiological process by which the visual system combines the visual data from the two eyes into a single percept.

BINOCULAR EYE MOVEMENTS

Motor fusion can be broken down into two broad classes of eye movements: versions and vergences. Each of these appears to be controlled by different oculomotor systems in the brain.

<table>
<tr><td>VERSIONS</td><td>These are the movements that cause the eyes to change direction to the right or left, with no change in the stance of the fixated object. They are known as conjunctive eye movements, since both eyes rotate an equal angle to the right or left.

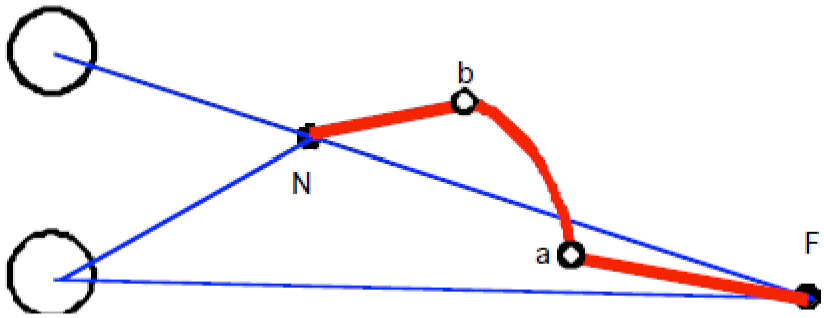
According to Hering’s Law of Equal Innervation, during version movements, equal innervation is sent to both eyes, telling them to rotate at the same speed, through the same angle, in the same direction. Fixation then shifts to a new point to the right or left.</td></tr>
<tr><td>VERGENCES</td><td>In these movements, the visual direction remains unchanged, but distance to the fixation point changes. The eyes rotate in opposite directions; both may rotate inward (convergence) or outward (divergence), so these are called disjunctive movements.

Hering’s Law of Equal Innervation

This law applies during vergence movements also, but in a different way from versions. During convergence, the right eye rotates left and the left eye rotates right. In divergence, the opposite occurs. The innervations controlling vergence movements are equal in terms of speed and angle, but opposite in direction.

Latencies and velocities

The different latencies and velocities of versions versus vergences support the theory that they are controlled by different neurological systems.
Versions move the eyes at a higher velocity than vergence movements. For example, a 3° horizontal saccade has a latency of about 200 msec, then moves the eyes at a velocity of about 150°/sec.
Vergence eye movements proceed at a lower velocity than versions. When both eye converge 3°, the latency is about 175 msec and the peak velocity is only about 10°/sec. (Ono, 1991, p. 3, in Regan, 1991)</td></tr>
</table>

VERGENCES	**Combined movements** In natural situations the eyes must often shift fixation to a new object that is located in both a different direction and different distance. In these cases, vergence and versions are not completely integrated into a single smooth movement, but the two types of movements are performed separately, as shown in Figure 4.1.  ***Figure 17.1*** *Redrawn from Ono's Fig. 1.2, p. 3 in Regan, 1991.* At the start of the movement both eyes are fixating point F. After a brief latency, the convergent movement begins, rotating both eyes inward equally to point a. Shortly after, the version begins; both eyes rotate left at the same velocity, pointing the visual axes toward point b. Finally, the eyes converge together from point b to point N. *Thus, the two eyes do not constitute two separate oculomotor subsystems. Rather, there are separate systems for version and vergence, and it is the operation of these two systems that brings the two visual axes to an object, thus enabling an observer not only to see it as one but also to see it as distinctly as possible by stimulating the [foveas of both eyes]. Failure of either subsystem leads to double vision because the intersection of the visual axes will not coincide with the object. (Ono, 1991 p. 3, in Regan, 1991)*
IMPORTANCE OF HORIZONTAL VERGENCE MOVEMENTS	Between the two main types of eye movements (versions and vergences), anomalies of the vergences, rather than versions usually cause clinical problems. You have already studied the link between accommodation and convergence. Because of its importance in binocular vision and clinical problems, we will study the horizontal vergence movements in greater detail. The main reference for today's lecture material is: McCormack GL. Chapter 5 - Fusion and Binocularity, in Borish's Clinical Refraction (1998), 133-146.
TYPES OF HORIZONTAL VERGENCES	The horizontal vergences can be broken down into six sub-types. They are: • Disparity vergence (also called fusional vergence) • Accommodative vergence • Tonic vergence • Vergence adaptation • Proximal vergence • Voluntary vergence While Goss' book on Ocular Accommodation, Convergence, and Fixation Disparity refers to four types of convergence, he does not mention vergence adaptation and voluntary vergence.

TYPES OF HORIZONTAL VERGENCES

Disparity Vergence
From our study of visual direction, we may conclude that in normal binocular vision, and for objects located on the midline:

1. Objects located on the intersection of the two visual axes will appear single.
2. Object at any other distance will appear double. Those beyond the fixation point will be seen in **uncrossed diplopia**; objects nearer will be seen in **crossed diplopia**.

You can demonstrate this with a simple experiment such as that shown in **Steinman, Fig. 2-20** (p. 35). Hold two fingers or pens in front of you, one near and one far, and fixate on one. When fixating on the near object (visual axes intersecting there), the far object will appear double, and vice versa. Recalling Hering's laws of visual direction, we can predict that the non-fixated object will appear double because it has a different visual direction in each eye.

Figure 17.2 shows an object located closer than the fixation point. It will stimulate temporal points on both retinas. Transferring oculocentric visual lines (**local sign**) from both eyes to the cyclopean eye, we can see that the visual direction information from each eye is different. The visual lines don't correspond because they fall on non-corresponding retinal points (points in the two eyes that have different visual directions). There is therefore a mismatch, or **disparity** in the visual directions associated with the retinal image in the two eyes.

Like images, which fall on non-corresponding retinal points, cannot be fused because they have a **retinal disparity**, or differences in their oculocentric visual directions. This retinal disparity stimulates a neurological reflex known as disparity vergence.

Because disparity vergence is the only form of vergence innervation that directly responds to retinal disparity, it is primarily responsible for maintaining binocularity by reducing retinal disparity (for the object of interest) to a minimum. All other forms of vergence innervation play a support role for disparity vergence. Disparity vergence is a psycho-optic reflex controlled by the magnitude and sign of retinal disparity associated with the intended fixation point. The reflexive behavior of disparity vergence frees attention from the act of convergence, allowing attention to be concentrated on visual information processing. (McCormack, p. 1328).

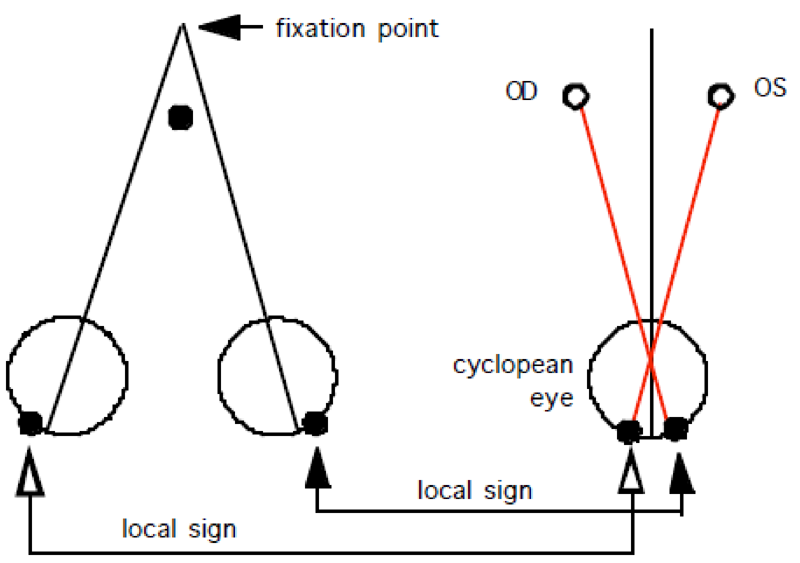


Figure 17.2 *Crossed disparity*

Figure 17.2 illustrates an example of **crossed disparity**, which gives rise to crossed diplopia. Retinal disparity for a non-fixated object means its image falls on retinal locations that have different visual directions in the two eyes. Crossed diplopia occurs whenever an object is located nearer than the fixation point.

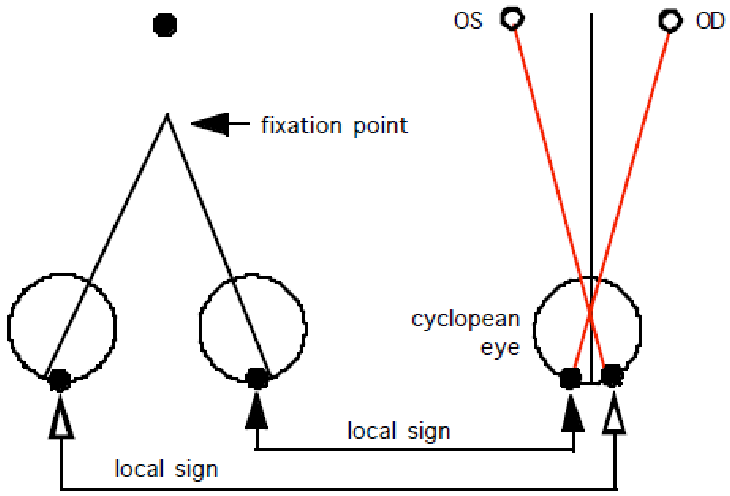


Figure 17.3 *Uncrossed disparity*

Figure 17.3 shows how an object located beyond the fixation point is seen with **uncrossed disparity**. This results in uncrossed diplopia.

The presence of either crossed or uncrossed disparity in the two retinas is detected by a disparity vergence control center in the brain, whose job is to maintain motor fusion and single binocular vision. When retinal disparity is detected, it stimulates a disparity vergence response, and innervation is sent to the extraocular muscles to make them either converge or diverge, as necessary, to eliminate the disparity. The disparity is constantly being monitored by a feedback loop. This is summarized in **Fig. 5-10 in McCormack** (**Borish**).

TYPES OF HORIZONTAL VERGENCES

Accommodative Vergence

If an object of interest is located nearer to the person than the fixation point, it will be blurred. Accommodation is required to focus on the near material, and when attention is shifted to the near object, reflex accommodation is unconsciously stimulated. Similarly, reflex vergence will also be stimulated. The parallel between the two mechanisms is illustrated in **Fig. 5-13 in McCormack**..

Note that the reflex convergence and reflex accommodation systems are linked. The Disparity Vergence center (DV) sends out two signals. One is disparity vergence innervation, but it also sends a signal to stimulate accommodation. This is known as Convergence Accommodation Innervation (CAI) and combines with the Reflex Accommodative Innervation (RAI) to stimulate the Ciliary Muscle (CM).

Likewise, accommodation helps converge the eyes. The Reflex Accommodation center (RA) sends a signal to stimulate Reflex Accommodation Innervation (RAI) and a signal to stimulate Accommodative Vergence Innervation (AVI). These innervations are summed and stimulate the Extraocular Muscles (EOMs).

The amount of accommodative vergence (in prism diopters) associated with a diopter of accommodation is known as the AC/A ratio, and is typically about 4:1. It can range from about 1:1 to 7:1. Analysis of the AC/A ratio is important in diagnosis and management of binocular vision anomalies.

Similarly, the ratio of the accommodation (diopters) stimulated per prism diopter of reflex vergence is the CA/C ratio, and is typically about 1:10 for a young adult.

Tonic Vergence

If you were to cut all innervation to the extraocular muscles, the eyes would diverge about 17 prism diopters beyond parallel (exo posture). This is known as the **anatomic position of rest**. This is also the position of the eyes during anesthesia.

TYPES OF HORIZONTAL VERGENCES	When you supply normal innervation to the muscles, but have no visual stimulus (i.e, in the dark, or with the eye closed), normal muscle tone brings the eyes to a nearly parallel (or slightly eso) orientation. This is known as **tonic vergence**. It is also called **dark vergence**. This makes the job of disparity vergence easier because most of the work of converging the eyes from their anatomic rest position to parallel is done by tonic vergence. Tonic vergence receives no visual input, and it provides no synkinetic innervation to any other mechanism. A small amount of **tonic accommodation** is also present. When the eyes are perfectly relaxed (i.e., with the eyes closed), the ciliary muscle is still accommodating slightly. McCormack says that tonic accommodation is about 1 diopter. Tonic vergence is closely correlated to the distance phoria. Goss (p. 11) says, “Tonic convergence represents the physiological position of rest. The distance phoria with the subjective refraction in place is taken to be a measure of tonic convergence”. Other references say that the position of the eyes associated with tonic vergence is not the distance phoria, though they are closely related. They point out that tonic vergence usually leaves the eyes slightly convergent (3-5 prism diopters), but the far phoria is usually a bit more divergent (exo). This may be because during tonic vergence (non-fixating), the eyes are converged and accommodated toward a point about 1.2 meters away. During phoria measurements, however, the eyes are fixating a far object. In that case, negative reflex accommodation along with negative accommodative vergence will be at work, causing the eyes to move to a more exo posture. **Vergence Adaptation** Vergence adaptation is the type of vergence that slowly builds up several minutes after the eyes have shifted fixation to a new point. It is not stimulated directly by any visual input from the retina, but rather by disparity vergence and accommodative vergence. With steady fixation at some near distance (i.e., reading), the disparity vergence and accommodative vergences gradually decrease and are replaced by vergence adaptation. Disparity vergence and accommodative vergence respond quickly to changes in fixation distance. Vergence adaptation requires several minutes to build. Vergence adaptation varies from person to person. Some people have a strong vergence adaptation mechanism. Some have very little vergence adaptation. The degree to which vergence adaptation responds to disparity vergence or accommodative vergence also varies from person to person. Vergence adaptation can complicate clinical management of heterophoria. Some patients with a near exophoria can benefit from base-in (BI) prism for near. BI prism allows the person to comfortably maintain bifoveal fixation of near objects. After wearing prism for several minutes, some patients adapt to the BI prism, and show a larger than original exophoria. In that case, the amount of prism that was originally prescribed has less (or no) effect. McCormack suggests that prior to prescribing prism, you should retest the patients after they have been wearing the prismatic correction for about 15 minutes. If the patient has not adapted to the correction, the two phoria measurements should be equal. If the phoria increases after wearing prism, it indicates that vergence adaptation will interfere with prismatic correction of the heterophoria. A similar kind of adaptation can occur with vertical prism and with plus or minus lenses. To summarize, vergence adaptation is a mechanism that helps the disparity and accommodative vergence systems by taking over their task when the person must maintain a certain amount of vergence for more than a few minutes.

TYPES OF HORIZONTAL VERGENCES	**Proximal vergence** is an oculomotor mechanism, distinct from the other types of vergence, which is stimulated by the perceived distance of a near object. It is not stimulated by the retinal disparity. When the convergence demand is large, such as when shifting fixation from far to near for reading, proximal vergence initiates the vergence sequence with one large convergence step. This puts the target within range for disparity vergence to act. The perceived distance to a near object also stimulates **proximal accommodation**. Proximal vergence and accommodation are stimulated automatically whenever the brain assumes that objects are nearer than the original fixation point. **Instrument convergence** and **instrument myopia** are examples of this. Microscopes, stereoscopes and other instruments are designed to simulate vision at far. That is, the optics of the instrument creates a virtual object at infinity, straight ahead. Your brain knows, however, that the object is close. For example, you may be manipulating a microscope slide, and tactile feedback tells you that the object you are viewing is close. The perception of nearness stimulates proximal convergence; the eyes may then converge and diplopia may result. The image may also blur due to the proximal accommodation. This can cause eyestrain for some people when using instruments such as microscopes. **Voluntary Vergence** This is the vergence that a person can apply consciously. For example, when trying to fuse a stereogram, you may have to adjust your vergence in and out to achieve fusion. Another familiar example is when people deliberately cross or uncross their eyes. Voluntary vergence is difficult to maintain for long. If the person has to maintain voluntary fusion for very long, it can interfere with visual information processing, Voluntary vergence can be useful in vision therapy, because it allows the patient to start fusing certain training targets when their other vergence mechanisms may still be weak.

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