The Primary Position of the Eyes, The Resetting Saccade, and the Transverse Visual Head Plane

Head Movements Around the Cervical Joints

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Photographic and video analyses show that the primary position of the eyes is a natural constant position in alert normal humans, and the eyes are automatically saccadically reset to this position from any displacement of the visual line. The primary position is not dependent on fixation, the fusion reflex, gravity, or the head position. The primary position is defined anatomically by head and eye planes and lines that are localized by photography, magnetic resonance imaging, and x-rays of the head and neck. The eyes are in the primary position when the principal (horizontal) retinal plane is coplanar with the transverse visual head (brain) plane (TVHP), and the equatorial plane of the eye is coplanar with a fixed orbital plane (Listing’s plane). Evidence is presented to indicate an active neurologic basis for the primary position instead of passive mechanical forces. A different understanding of the primary position and the conception of the TVHP may be valuable in analyzing oculomotor defects. Invest Ophthalmol Vis Sci 33:2501-2510, 1992

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The diagnosis of strabismus and the results of its treatment are quantified by measuring the malalignment of the eyes from the so-called primary or initial position. Helmholtz's definition of this was, “the primary position of the line of fixation is one such that when the eyes turn from it to look straight up or straight down, or straight to the right or left there is no rolling of the eye” (so-called pseudotorsion). This was verified by afterimages projected onto a flat surface. Scobee's definition was “that position of the eyes in binocular vision, when with head erect, the object of regard is at infinity and lies at the intersection of the sagittal plane of the head and a horizontal plane passing through the centers of rotation of the two eyeballs.” Another definition is “that position from which all other ocular movements are initiated, or that position of the eyeball in the orbital socket against which all, rotational, torsional and translatory eye movements are measured.” The primary position is believed to be dependent on an erect head position, the horizon, binocular vision, and fixation at infinity.

In this article, we show that the primary position is a basic postural position not dependent on the horizon, fixation, the fusion reflex, head position, or gravity. In addition, we anatomically localized the primary position with eye and head planes and lines. Finally, we present evidence that the primary position is the result of a basic neurologic oculomotor motor mechanism and not passive mechanical forces.

Materials and Methods

Primary Position and Resetting Saccade

Informed consent was obtained from 18 normal alert human subjects for these experiments. No drugs or invasive procedures were used.

A device fixed to the nose was used to provide reference lines from which eye position in relation to head position could be measured from photographs (Fig. 1). Three fine (0.02 mm) copper wires were soldered to a C-shaped stainless-steel wire frame. This was, in turn, soldered to a thick copper wire that then was soldered to a metal sheet. Two of the wires were parallel and approximately 30 mm long; they were separated by 4 mm. Another fine copper wire length approximately 9 mm long was soldered perpendicular to the two parallel wires. The metal sheet was bent to conform to the nose and was glued to the skin of the bridge of the nose with liquid latex.

The C-shaped frame was adjusted for each subject by bending the thick copper wire to make the fine copper wires as parallel to the iris plane as possible.
Fig. 1. The device used for photographic analysis of eye position in relation to the head. The horizontal and vertical copper wires provide reference lines for measuring eye position. The other eye was occluded.

and to avoid the eyelashes when the eyes blinked. In addition, a 2 × 2 mm tape marker was stuck to the skin nasal to the inner canthus. The other eye was occluded.

Seated subjects were instructed to keep their heads and eyes in a “natural” or neutral position or in a position in which they had no sensation of having moved either their heads or their eyes. No chin rest was used. Then, while holding their heads still and with one eye occluded, they were instructed to fixate an object in their peripheral visual field and, later, to pursue a fixation target into their peripheral visual field. They then were told to allow their eyes to return automatically (to reset) from the gaze position to the position before the gaze. The reset position was photographed in both a normally lighted and totally dark room.

The visual field in which the eye movement took place contained a potential fixation object (the camera lens) or was featureless. In the normally lighted room and in the totally dark room, the camera was placed perpendicular to the eye. The featureless field was formed by a large white cardboard that was parallel to the frontal plane and approximately 50 cm from the eye. The camera was placed at a 45° angle to the visual axis of the eye so that the camera would not serve as an object of fixation. Video recordings of these eye movements were taken in the lighted room.

In three subjects, the eyes were photographed and recorded by video in the initial position and again after their return from various gaze positions with the head in a tilted, dependent, or supine position in both a lighted and dark room. Also, the primary positions and the reset primary positions from various gaze magnitudes and directions were observed with the head flexed or extended. In addition, some subjects fixed on a target directly ahead and then rotated their head horizontally as far as possible to the left or right. They then relaxed their fixation and allowed their eyes to reset to the primary position while keeping their heads laterally rotated.

Photographic and Measuring Techniques

A 35 mm single-reflex Nikon (Tokyo, Japan) camera with 200 mm lens and a 2× teleconverter was used to obtain the photographs (Kodacolor film; Eastman Kodak, Rochester, NY). A fixed focal length was maintained to ensure that the photographs would be the same size (approximately 82% of actual size). The photographs were taken in a lighted room and in a dark room using synchronized strobe flashes (Monsal 2; Balcar, Tekno AG, Switzerland).

A Panasonic (Secaucus, NJ) color video camera (WV-3320) with a Switar 1:1.9 75 mm lens attached to a 20 mm Pallard Bolex (Yverdon, Switzerland) extension tube was used to record eye movements. A video editor (JVC; Tokyo, Japan) allowed frame-by-frame analysis of 30 images per second or at 33 msec intervals.

Two or more photographic exposures were taken of each eye position in the subjects under three field conditions: fixation target (camera lens), featureless, and dark room. Prints from one negative from each subject were used as standards.

Two transparent templates for measuring the photographs were made. The first consisted of concentric circles whose center was also the crossing point of two perpendicular lines. This transparent template was used to identify the center of the pupil in all photographs. It was taped in place on a photographic print so that one of the concentric circles corresponded to the diameter of the pupil. The print (3.5 × 5 inches) then was viewed at 7× magnification through a dissecting microscope. The center of pupil was marked by inserting a pin through center point of the template and the pupil. This produced a pinhole at the center of the pupil in the photograph.

The second template was made from a print from each subject that was chosen at random. It consisted of an acetate sheet on which the reference lines, canthal marker, and the center of the pupil were traced (etched) from the print.

The reference lines and canthal marker of the template were superimposed on the reference lines and canthal marker of the photographic prints. The distance (h) in millimeters between the center of the pupil marked on the template and the center of the pupil (the puncture hole) on the photograph was measured...
with a Vernier caliper (accuracy, 0.002 mm). The angle of variation was calculated by the formula

$$\sin \phi = \frac{h}{\text{magnification}} / 10.07 \text{ mm}$$

where 10.07 mm is the center of the eye measured from the iris plane.

Two negatives of the eye in the primary position from seven subjects were used to evaluate the accuracy of the measuring technique. One print from one negative served as the standard. Four prints were made from the second negative. The center of the pupil of each photograph was identified with the template consisting of concentric circles and marked with a pinhole as describe. A transparent acetate sheet then was superimposed on the standard print. The three lines and canthal marker on the print were traced with a stylus on the transparent sheet. This etched template was used to measure the same picture five times (intrapicture) and to measure four separate prints made from the second negative (interpicture). Measurement variability is shown in Table 1.

**Locating the Transverse Visual Head Plane**

The subjects were instructed to place their heads in the erect position and their eyes in a position in which they denied eye and head movement. This position might be achieved by gazing at infinity (at an object > 20 feet away) and making, if necessary, slight head adjustments. All normal alert subjects were able to assume such a position. A leveled bar indicating the position of the horizon was superimposed below the profile of the head, and a photograph was taken (Fig. 2). A line through the pupil that was parallel to the horizontal bar was drawn on the photograph. Two subjects were laid supine on a table, and a cloth strip was wrapped around their skulls. This represented the surface projection of the visual line. With the cloth strip perpendicular to the examining table, transverse sections of the head were taken by magnetic resonance imaging through the level of the maximum horizontal cross-sectional area of the eye. Scans were repeated with the head turned 35° to the right and left. A sagittal scan of the head was also taken. The scans were done for diagnostic reasons and not specifically for these experiments.

The visual line, the canthomeatal base line joining the external canthus of the eye with the external auditory meatus, and the Frankfurt base line joining the lower rim of the orbit and the upper margin of the external auditory meatus were drawn on the picture of the profile of the head. The angles formed by the visual line and the canthomeatal and Frankfurt lines were measured.

The location of the head plane that was coplanar with the retinal plane when the eyes were in the straight-ahead position was found by photographing the profile of the head and analyzing radiographic images of the head and magnetic resonance imaging scans. The location of the head plane by the latter technique was compared with the transverse section of the head through the maximum cross-section of the eye depicted in a textbook.

**Cervical Joint Movements and Head Rotation**

The amount of flexion, extension, and tilt occurring around the individual joints of the cervical spine was measured on radiographic films in six subjects.
The x-rays were taken on one author and on patients for indicated diagnostic reasons.

The position of the axis pole for lateral rotation of the head with the head upright, in flexion, in extension, and lateral tilt was identified at the apex of the cranium in ten normal bald subjects by placing an adhesive marker on the skull at the axis pole for lateral rotation.

The location of the retinal raphe and the fovea was determined using an ophthalmoscope, fluorescein angiography (also done for indicated diagnostic reasons), and textbook pictures.10

Results

Primary Position and Resetting Saccade

No difference in the natural or primary postural position of the eyes in relation to the head (brain) was observed from subject to subject.

Table 2 shows that the distance between the center of the pupil on the standard photograph and successive pictures of the same subject after resetting to the primary position varied from 0-7.25° (mean, 1.12°) in the normally lighted room containing a fixation object, from 0-3.94° (mean, 1.19°) in a lighted room with a featureless background, and from 0-7.08° (mean, 2.19°) in the totally dark room. (At the iris plane, 1° equals approximately 0.175 mm in the circumference of an eye of normal diameter.) Table 3 shows that there was a significant difference in the results between the lighted rooms and the dark room. Also, directional displacement was greatest in the dark room (Figs. 3, 4, 5).

In Table 3, the variation of the resetting of the eyes to the primary position after a gaze of 30° in normal subjects was 2° or less in 83.7% of the photographs in the experiments in which there was a fixation object in the field, in 85.3% with a featureless field, and in 52.1% in a dark room. Similar results in the resetting of the eyes were obtained in experiments for gaze in all directions and amplitude tested using observation, photographic, and video analysis.

The resetting eye movements were saccades. They were completed between one and two video frames or between 33-66 msec from a lateral gaze of 30°. Assuming that the gaze movement was completed in 50 msec (midway between 33 and 66 msec), the eye was resetting at a velocity of 600° per second for a gaze amplitude of 30°.

The data for the reset position and resetting saccade were the same with the head supine, dependent, flexed, extended, or tilted. Keeping an eye fixed and moving the head in any direction produced a sensation of having gazed in a direction opposite the head.
movement. When uninhibited, the eye resets to the primary position in relation to the head (brain) regardless of the position of the head.

Anatomic Localization of the Primary Position

The head and the eyes were placed in the natural posture, i.e., that head and eye posture in which the subject could detect no conscious movement of the head and the eyes, with the subject sitting, erect, or supine (Figs. 2, 6). In these positions, the principal retinal plane of the eyes was coplanar with the same head plane in all subjects. This head plane, designated the transverse visual head plane (TVHP), was identified by magnetic resonance imaging (Figs. 7, 8) and compared with the transverse head plane through the maximum diameter of the eye in a textbook. They were the same. The TVHP transected the eye, the midbrain at the level of the oculomotor nucleus, and the calcarine cortex (Fig. 7). The angle between the TVHP and the canthomeatal plane averaged 14.95° and between the TVHP and the Frankfurt plane, 4.13° (Table 4, Fig. 6).

The principal retinal plane is defined by either one of two sets of three points: the fovea, the centrum of rotation of the eye and any point on the horizontal retinal raphe or the fovea, and any two points on the retinal raphe (Fig. 9).

The equatorial plane of the eye is perpendicular to the principal retinal plane that is formed by the greatest circle of the eye that passes through the center of rotation of the eye. The principal retinal plane and the equatorial plane are the only planes that are ever coplanar with their fellows in the other eye. The visual line is fixed in the principal retinal plane and connects the fovea with the object of regard. It moves with the eye.

Fig. 3. Polar plot of the points of resetting of the eye after lateral gaze. There is no significant difference between the lighted fields, but there is a significant difference between the lighted fields and dark field. (A) Field with fixation target. (B) Featureless fields. (C) Dark room.

Fig. 4. Stack graphs showing the accuracy in degrees of the return from lateral gaze with the head in the erect position. The data was not significantly different with the head in the supine, flexed, extended, or tilted positions.

Fig. 5. Directional displacement of the resetting points. More directional displacement occurs in a dark room.
Listing's plane is, by definition, a fixed head plane that is perpendicular to the TVHP through the centers of rotation of the eyes. The index line for eye movement is that line fixed in the TVHP, which is parallel to the midsagittal plane of the head and passes through the center of rotation of the eye (Fig. 10).

Measurements of the movements in individual cervical joints shown in Table 5 demonstrated that the axes for flexion, extension, and lateral tilt of the head are diffused throughout the cervical spine but mainly located in the midecervical region (Fig. 11). These axes do not traverse the brainstem or cerebrum. Lateral head rotation occurs around the odontoid process of the atlantoaxial joint. A marker placed on the apex of the skull (easily placed in bald subjects) showed that the axis pole for lateral rotation of the head is constant in all head positions and that it traverses the brainstem and the midbrain. The TVHP then can be

Fig. 6. The angular relationship between the transverse visual head plane and the canthomeatal and Frankfurt planes. The position of transverse visual head plane can be estimated if the position of either of the other planes is known.

Fig. 7. Magnetic resonance images of the transverse visual head plane with the head in the supine, face-up position and with the face turned to the left and turned to the right. Superimposition of these images indicates the location of a point on the axis for horizontal rotation of the brain (arrow). This point is located 99.9 mm from the root of the nose (nasion) in the midbrain at the level of the oculomotor nucleus (18-year-old male).
Fig. 8. The mid sagittal section of the head and the neck by magnetic resonance image scanning. The odontoid process (arrow) forms a stable axis for horizontal rotation of the head. The transverse visual head plane is formed when the axis for horizontal rotation of the head meets a plane arising from the centers of rotation of the eyes at a right angle. TVHP, transverse visual head plane.

Defined as the plane through the centers of rotation of the two eyes that is perpendicular to the axis for horizontal rotation of the head arising from the odontoid process of the atlantoaxial joint.

**Discussion**

When the eyes in an alert normal human subject are deviated voluntarily to pursue a target or the head rotates with the eyes held fixed, there is a sensation that the eyes have rotated from a natural position in relation to the head (brain). Unless a conscious effort is exerted to maintain the deviation, the eyes will be reset automatically and saccadically to a homeostatic index position that is constant for any individual. In this position, there is no sensation that the eyes have moved. The return of the eyes to the natural position occurs with the eyes closed and with the head supine, prone, depressed, or turned on its side. It also occurs when subjects are standing on their heads. Readers can test these observations for and on themselves.

This position is the primary position. It is characterized by a fast (saccade) resetting eye movement that is independent of head position, gravity, and vision. It is defined as that position of the eyes, independent of vision and of the location of the head, in a

**Table 4.** The angle between the transverse visual head plane (TVHP) and the canthomeatal and Frankfurt planes in 28 normal subjects

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>±SD</th>
<th>95% Confidence interval</th>
<th>Min</th>
<th>Max</th>
<th>Intersubject variability*</th>
<th>Intrasubject variability†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Angle between the TVHP and the canthomeatal plane</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14.95°</td>
<td>±4.02°</td>
<td>13.46°–16.44°</td>
<td>6.5°</td>
<td>23.5°</td>
<td>3.97°</td>
<td>1.06°</td>
</tr>
<tr>
<td><strong>Angle between the TVHP and the Frankfurt plane</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.13°</td>
<td>±4.48°</td>
<td>2.47°–5.79°</td>
<td>−8°</td>
<td>13°</td>
<td>4.44°</td>
<td>1.23°</td>
</tr>
</tbody>
</table>

* Expressed as the square root of the variance from the mean of four pictures of each subject from the primary position taken at 5 min intervals.
† Expressed as the square root of the average variance of four pictures from the same subject.
‡ The angle is positive if its apex is anterior, negative if posterior.
 Axis for Horizontal Rotation of Head

Mid-sagittal Line of Head

Fig. 10. The transverse visual head plane (TVHP), Listing's plane, and the principal retinal plane. In this drawing, the index lines (I'L and I'L') correspond with the Y axis and the visual line. C and C', centers of ocular rotation. XX', axis for vertical rotation. Z and Z', axes for horizontal rotation. R and R', retinal raphes. I'L and I'L', index lines in transverse visual head plane parallel to the mid-sagittal plane passing through C and C'. (Inset) The visual line (VL) no longer coincides with the index line of the head (I'L') when the eye turns out of the primary position.

Fig. 11. Percent of movement around the cervical joints. Flexion, extension, and lateral tilt occur diffusely throughout the cervical spine but mainly in the mid cervical region.

Table 5. The movements around the joints of the human cervical vertebrae measured from x-ray images in six subjects

<table>
<thead>
<tr>
<th>Joint</th>
<th>Flexion (mean SD min-max)</th>
<th>Extension (mean SD min-max)</th>
<th>Lateral tilt (mean SD min-max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-C1</td>
<td>2.3° ± 0.6° 8.8° ± 15.5°</td>
<td>1.8° ± 0°-5° 6.3° ± 3.8°</td>
<td>0°-6.0° 0°-15.5° 0°-3.8°</td>
</tr>
<tr>
<td>C1-C2</td>
<td>6.4° ± 2.6° 7.0° ± 3.6°</td>
<td>1.7° ± 1.8° 1.5°-11°</td>
<td>0°-6.0° 0°-15.5° 0°-3.8°</td>
</tr>
<tr>
<td>C2-C3</td>
<td>4.2° ± 2.6° 3.9° ± 2.3°</td>
<td>1.8° ± 1.2° 2.3°-9.0°</td>
<td>0°-6.0° 0°-15.5° 0°-3.8°</td>
</tr>
<tr>
<td>C3-C4</td>
<td>2.0°-10.5° 2.3°-7.0°</td>
<td>0°-7.8° 2.3°-7.0°</td>
<td>0°-7.8° 2.3°-7.0°</td>
</tr>
<tr>
<td>C4-C5</td>
<td>1.0°-18.5° 1.5°-7.0°</td>
<td>0°-7.8° 2.3°-7.0°</td>
<td>0°-7.8° 2.3°-7.0°</td>
</tr>
<tr>
<td>C5-C6</td>
<td>0°-4.4° 5.1°</td>
<td>6.9° 2.3°</td>
<td>2.3°</td>
</tr>
<tr>
<td>C6-C7</td>
<td>3.0°-10.0° 6.0°-13.0°</td>
<td>1.5°-7.0° 2.4°-10.0°</td>
<td>0°-7.8°</td>
</tr>
<tr>
<td>C7-T1</td>
<td>4.4° ± 1.9° 8.0° ± 4.7°</td>
<td>3.5° ± 2.7° 15.0°-20.0°</td>
<td>0°-7.8°</td>
</tr>
<tr>
<td>Total</td>
<td>2.2° ± 10.5° 2.6°-10.0°</td>
<td>1.8° ± 2.3° 5.3°-8.8°</td>
<td>0°-7.8°</td>
</tr>
</tbody>
</table>

alert normal human to which the eyes are reset automatically after any ocular movement.

The averaged data in Table 3 show that the resetting saccade brought the eye back to within ± 1.12° in a normally lighted room and within ± 1.19° in a lighted room without a fixation target. Both these means are significantly different from the mean of ± 2.19° found in the totally dark room. We conclude that light affects the brainstem arousal mechanism, which then affects the precision of the resetting saccade.

We suggest that the resetting saccade produces a gross postural alignment of the eyes. The precise
alignment or fine tuning of the eyes is accomplished by the fixation and fusion reflexes.

Many reference head planes have been defined by anthropologists, physiologists, neuroanatomists, and neurosurgeons to compare skulls and facilitate the orthogonal and angiographic localization of brain structures from skull landmarks. Lines and planes such as the anthropologic baseline, orbitomeatal line, vestibular orientation, Sylvan plane, and Frankfurt plane have been described (Fig. 6). To standardize computed tomographic analysis of cross-sectional orbital anatomy, a neuroocular plane has been defined as a plane that includes both lenses, optic nerve heads, and optic canals in the primary position of gaze. The investigators found this plane valuable to evaluate the three-dimensional accuracy of computerized imaging in orbitocephalic disease.

Because eye movements are integrated with head movements, a reference head (brain) plane from which to measure eye movements might be useful both theoretically and practically. To define a reference head (brain) plane, four planes were defined. Two were fixed in the eye: the principal retinal plane and the equatorial plane. Two were fixed in the head: the TVHP and Listing's plane. Two lines were defined: the visual line, fixed in the principal retinal plane that rotates with the eye, and the index line for eye movement, fixed in the TVHP, that moves with the head (Figs. 9, 10).

The principal retinal plane is the eye plane of greatest functional significance in both foveate and nonfoveate animals with horizontally oriented eyes. In humans, it is associated with the greatest oculomotor excursions and the largest fusional amplitudes. This plane is the same as the so-called horizontal plane of the retina referred to in textbooks, but in most visual situations, the principal retinal plane is not parallel to the horizon.

The TVHP is a new concept (to the best of our knowledge). The reason for this terminology is that this is the plane of maximum horizontal range associated with reading. In cultures that read downward, there is a vertical or sagittal visual head plane.

Our purpose in studying the articulations of the head and cervical spine was to find an objective reference point or line in the head on which to construct the TVHP. We observed that the only axis that traversed the brain and remained stable in all head positions was the axis for lateral head rotation. Using this stable axis and the centers of rotation of the two eyes, we were able to define the TVHP objectively as that plane arising from the centers of rotation of the eyes that was perpendicular to the axis for horizontal rotation (Fig. 10).

Our clinical observations and experimental work indicate that the eyes are oriented and reset to the TVHP. This plane transsects the centers of rotation of the eyes, the midbrain at the level of the oculomotor nucleus, and the calcarine cortex. It is located in the center of the head and includes the largest transverse cross-sectional area of brain. Head (brain) movement can be described in terms of movement of TVHP.

These observations and measurements provide an anatomic definition of the primary position of the eyes as follows: the position in which the principal retinal plane is coplanar with the TVHP and the equatorial plane of the eye is coplanar with Listing's plane. It is the homeostatic or basic postural position of the eyes. In computer terminology, it would be the default position, which is an active programmed function.

This definition has one exception. Counterrotation of the eyes, when it occurs in response to head tilt (gravity or inertia), results in the principal retinal plane not coinciding with the TVHP but remaining within the sensory fusional field of its fellow. The equatorial plane of the eye coincides with Listing's plane, and the visual line coincides with the index line for eye movement. In this instance, the primary position is the position in which the visual line coincides with the index line in the TVHP.

For any person, the centers of rotation of the eyes and the axis for horizontal rotations of the head may be determined by magnetic resonance imaging scanning and video recordings. Also, the canthomeatal and Frankfurt planes can be used to estimate the position of the TVHP (Fig. 6).

An important question is whether or not the primary position is the result of elastic orbital restoring forces, a neurologic mechanism, or both? We believe that the evidence we provided suggests that the resetting of the eye to the primary position is caused by a fundamental and phylogenetically early neurologic mechanism and that the anatomic form merely provides the basic support matrix. All vertebrates, even those with no, occasional, or small ocular excursions, keep their eyes in the primary position and prefer to move their heads or bodies when observing the panorama.

A passive mechanical hypothesis for eye centering cannot adequately explain: (1) the precision of the resetting saccade, (2) the constancy of the primary position of the eye before the onset of any eye movement, (3) the presence of tonic activity in the extraocular muscles in the primary position during the waking state and the high discharge rates of the oculomotor units during steady gaze, (4) the recovery of eye alignment after the breaking of the fusion reflex with the cover test, (5) the ocular microtremor and microsaccades, and (6) the muscle tone in the primary position in humans of 12–17 g.
ditional evidence that connective tissues of the orbit play little or no role in the centering saccade. In acute oculomotor nerve paralysis, the eye is in the abducted position. In attempted conjugate gaze to the contralateral side, the paralyzed eye does not move toward the midposition but remains fixed in the abducted position even though the functioning lateral rectus is inhibited (reciprocal inhibition). There is insufficient elastic tissue in the medial rectus and orbit to bring the paralyzed eye toward the midposition.

We hypothesize that the eye movement that brings the eye back to a stable initial position is the result of an inherent primitive reflex. It consists of a saccade that restores the eye to a constant position in relation to the brain. This saccade probably explains the rapid component of the vestibuloocular reflex and optokinetic nystagmus. Also, it is responsible for the automatic saccadic return to the primary position after exploratory, pursuit, and emotionally induced eye movements. The normal sequence is probably as follows in humans. A primitive reflex originating in the reticular formation of the brainstem and associated with the arousal mechanism restores the eye to the primary position independent of a visual input. The fixation and fusion reflexes then fine tune fixation and binocular coordination.

The paramedian pontine reticular formation and adjacent subdivisions of the reticular formation are known to generate saccades in the same direction as the impulse and to be the final premotor input into the oculomotor nuclei. These areas are next to and associated with the arousal areas of the brain, ie, the reticular activating system.

Reticular formations that encompass the ocular motor nuclei and arousal areas are found in all vertebrate brains. These complex formations include synaptic pathways projecting to and from all higher oculomotor regions. All impulses to and from the oculomotor nuclei must pass through these formations.

Impulses generating tonus start from the reticular formation from both sides of the brainstem in the awake state. These tonuses produced in opposing muscles normally balance each other and maintain the eyes in a steady postural position in relation to the brain. The neurons that mediate deviation from the primary position have either an inhibitory or excitatory affect on the paramedian pontine reticular formation. When these impulses are modulated or eliminated, the eyes return to the primary position by means of a saccade.

In other words, the paramedian pontine reticular formation may function as an inherent central pattern generator to maintain a homeostatic or steady-state position of the eyes in regard to the brain. Deviation of the eyes is a reaction to inhibition or excitation of this region from diverse oculomotor control areas. This might explain why no focal area in the brain has been found in which eye centering is an exclusive function.

**Key words:** primary position of eyes, resetting saccade, visual head plane

**References**