LEARNING OBJECTIVES

1. To better evaluate the patient at the bedside with the complaint of vertigo.
2. To better evaluate the patient at the bedside with a cerebellar disturbance.
3. To better evaluate the patient at the bedside with the complaint of oscillopsia.

KEYWORDS

1. Vestibular
2. Cerebellum
3. Saccade
4. Pursuit
5. Nystagmus

INTRODUCTION

Here we present a bedside approach to patients with vestibular and cerebellar disease emphasizing clinical examination based on pathophysiology. The differentiation between peripheral and central vestibular disorders and precise anatomical localization within the cerebellum are emphasized. A number of specific manoeuvres are illustrated and evaluation of each of the different subcategories of eye movements is emphasized. The material is based upon two comprehensive and detailed review chapters on these issues cited in the reference list.

PART 1: BEDSIDE EXAMINATION OF THE PATIENT WITH A VESTIBULAR DISORDER

The successful diagnosis of a patient with vertigo or oscillopsia depends upon a careful, physiologically and anatomically based, examination of the vestibular system. The examination is guided by several key anatomical and physiological features which lead to several rules that enable one to better localize lesions. Here we concentrate upon vestibuloocular reflexes as they are relatively easy to evaluate at the bedside. The functions of the vestibuloocular reflex are clear: to stabilize the position of the eye in space, and so ensure clear vision, when we move our heads. Two reflexes are elaborated depending upon the type of head movement. If the head rotates, its motion is detected by the semicircular canals which sense angular acceleration (around all three axes, horizontal (yaw), vertical (pitch) or torsion (roll)). If the head translates or tilts (away from the direction of the pull of gravity), its motion or change in position is detected by the otolith organs, which sense linear acceleration along all three axes (side to side, up and down, or fore and aft) with gravity being the most ubiquitous form of linear acceleration.
BASIC PHYSIOLOGY
The labyrinthine receptors have a tonic discharge even when the head is still. This gives them the flexibility to either increase or decrease their discharge rate when the head motion is directed such as to excite or inhibit, respectively, the receptor within a given labyrinth. This ability to work in “push-pull” while a clear advantage because it allows one labyrinth to detect motion in any direction (albeit not as effectively as when both are working together (see Ewald’s second law below)) comes with a price since with the head still the tonic level of activity in the two labyrinths (and specifically in coplanar canals such as the right anterior/left posterior (RALP) and the left anterior/right posterior (LARP)) must be perfectly balanced. If not an illusion of motion with consequent inappropriate compensatory responses can arise. In the canal system this leads to a spontaneous nystagmus with the head still and in the otolith system this leads to an oculor tilt reaction (head tilt, vertical (skew) misalignment of the eyes and ocular counterroll).

STATIC IMBALANCE IN THE CANALS: SPONTANEOUS NYSTAGMUS.
A first goal of the bedside examination then is to look for signs of ‘static’ imbalance. Three features of spontaneous nystagmus due to a canal imbalance help determine its cause. First is its direction (or vector). Because of the anatomical arrangement of the semicircular canals within the labyrinth (each vertical canal responds to mixtures of vertical and torsional (roll) rotation of the head and the lateral canals respond to horizontal rotation), a unilateral peripheral lesion almost never gives arise to a pure vertical or pure torsional nystagmus. In fact a complete unilateral peripheral lesion usually gives rise to a mixed horizontal torsional nystagmus. On the other hand, a pure vertical or pure torsional nystagmus is almost always central. Secondly is the effect of visual fixation on spontaneous nystagmus. When peripheral in origin, spontaneous nystagmus is suppressed by fixation. Conversely, a central nystagmus is usually unaffected by fixation. This ‘Romberg’ test of the vestibular system can be tested at the bedside using Frenzel lenses or occlusive ophthalmoscopy (alternating covering and uncovering one eye while watching the fundus of the other to look for the appearance, or increase in intensity of a spontaneous nystagmus. Thirdly is the effect of eye position in the orbit on the intensity of the nystagmus. With peripheral lesions the intensity of the nystagmus (slow-velocity velocity) increases when the eyes are directed to a position in the orbit opposite the direction of the slow phase (Alexander’s law). When central lesions the position effect is variable but a central lesion is suggested when slow-phase velocity increases when the eyes are directed to a position in the orbit in the same direction as the slow phase.

STATIC IMBALANCE IN THE OTOLEIS: OCULAR TILT REACTION (OTR).
Imbalance in static otolith inputs also leads to characteristic ocular motor sign: a skew deviation with ocular counterroll. When coupled with a head tilt this is known as the ocular tilt reaction (OTR) and reflects a phylogenetically old pattern of eye deviation to lateral tilt may. Recall that in intact lateral-eyed animals the response to a lateral tilt of the body is a ‘righting reflex’ comprised of a compensatory tilt of the head toward the opposite (higher) ear and a readjustment of the vertical alignment of the eyes (physiological skew deviation), in which case the eye in the relatively lower orbit (lower ear) elevates and the eye in the higher orbit (upper ear) depresses. When there is an otolith imbalance in humans the ocular tilt response (OTR) emerges as if there is a compensatory response to a lateral head tilt. The OTR consists of a vertical misalignment of the eyes (skew deviation), ocular counterroll (torsion of both eyes toward the side of the lower eye) with a consequent tilt of the visual world, and a head tilt toward the side of the lower eye.

A tilt of the subjective visual vertical (SVV) is a sensitive sign of a static disturbance in the otolith-ocular pathway,. Normal individuals can position a visual linear marker in an otherwise completely dark room within 2° of true vertical. Most patients with acute vestibular neuritis show an ipsilateral deviation of the SVV. Lesions in the caudal pons and rostral medullary tegumentum of the brainstem cause ipsilateral tilts (as part of the OTR) and lesions in the rostral pons and caudal mesencephalic tegmentum cause contralateral SVV tilts The so-called bucket test(adjusting a vertical line looking into a bucket) is another way to evaluate the SVV at the bedside. Along with measures of the subjective visual vertical one can evaluate the associated torsion with ophthalmoscopy looking at the relative position of the blind spot and fovea. Visual field testing with a perimeter can also be used to yield the same information. Differentiation from a superior oblique palsy is usually not difficult since the higher eye is relatively extorted in SOP and intorted in skew deviation. The vertical deviation in SOP is relatively independent of whether the patient is upright or supine whereas with skews it is diminished in the supine position.

DYNAMIC IMBALANCE IN THE CANALS: DYNAMIC VISUAL ACUITY (DVA) AND THE HEAD IMPULSE SIGN.
The second part of the bedside examination focuses on ‘dynamic’ abnormalities of vestibular reflexes during movement. Dynamic measures of acuity with the head moving (DVA) are important for evaluating patients who complain of oscillopsia, an illusion of visual motion often described as blurred, jumping or ‘wobbly’ vision. The vestibular system is usually involved when oscillopsia is brought on or exacerbated by motion of the head. DVA is measured by asking the patient to read the letters of a visual acuity chart with the head still and then oscillating horizontally, vertically, and in the roll plane from ear to shoulder, at a relatively high frequency of about two cycles per second. At this frequency visual tracking systems are too slow to help stabilize gaze, and therefore the function of the VOR can be assessed acting alone. While oscillating the head, the patient should not be allowed to stop or slow down too much at the turnaround points to 'sneak’ a look at the acuity chart. Normal individuals may lose one line of acuity with head rotation, whereas patients with vestibular
abnormalities often lose more than two lines. Roll movements of the head (ear to shoulder) do not displace the fovea far from the visual target, and so cause smaller decreases in visual acuity even when vestibular function is completely lost.

Objectively, one best evaluates the amplitude (and direction) of the VOR using the head impulse maneuver. The patient is instructed to fix on the nose of the examiner, and a brief, high acceleration but low amplitude (10 or 15 deg) is applied to rotate the head. Head-impulse testing is based upon Ewald’s second law which states that a better response is elicited with excitatory than inhibitory stimulation, especially at high accelerations and velocities. A corrective catch-up saccade is the sign of an underactive VOR response. An abnormally directed VOR response, for example, an upward slow-phase component followed by a downward corrective saccade with horizontal impulse testing is a sign of a cerebellar lesion. In patients with acute vestibular symptoms and a spontaneous nystagmus, a normal head impulse test suggests a central etiology whereas an abnormal head impulse occurs with both peripheral and central lesions.

The head impulse test is most consistently positive when there is a complete loss of labyrinthine function involving the lateral canal. The test, however, can be positive with a partial loss of function. Patients with chronic loss of labyrinthine function may appear to have an intact impulse response because very early in the head movement they have learned to trigger preprogrammed compensatory saccades which is complete by the time the head stops moving, making them hard to discern (covert saccades).

**DYNAMIC IMBALANCE IN THE OTOLECTHES: THE HEAD HEAVE SIGN.**

The head heave maneuver (a high acceleration side to side translational movement), is used to evaluate the translational VOR and in turn the function of utricle. The finding of an asymmetric response to horizontal translation is more useful for identifying an abnormality Because normal individuals frequently show a corrective saccade, in both directions, an asymmetrical response is of better diagnostic use.. Unlike the head impulse sign, which is permanent if there is a complete loss of labyrinthine function, the head heave asymmetry is usually rapidly compensated and so only apparent in the first days after unilateral loss of function. A positive head heave sign, however, predicts a delayed or less complete recovery.

**PROVOCATIVE TESTS: VIBRATION-INDUCED NYSTAGMUS.**

Vibration applied to the mastoid tip may bring out nystagmus in patients with unilateral loss of vestibular function. Vibration on either mastoid or on the vertex can elicit a nystagmus with a slow phase toward the paretic ear. This direction of nystagmus usually is independent of the site of stimulation as the vibration impulses are transmitted throughout the skull to both labyrinths. Because of this symmetry, normal individuals show little or no vibration-induced nystagmus. In patients with a unilateral loss of labyrinthine function, stimulating with a vibrator is comparable to a hot water caloric irrigation to the intact ear. When vibration elicits a vertical nystagmus following horizontal head shaking usually indicates a cerebellar disturbance.

**PROVOCATIVE TESTS: HEAD-SHAKING INDUCED NYSTAGMUS (HSN).**

Head-shaking induced nystagmus (HSN) is a useful sign of imbalance of dynamic vestibular function. To perform the head-shaking maneuver, after establishing a comfortable range of motion of the head and while wearing Frenzel goggles, the head of the patient is shaken rapidly back and forth from side to side, but through a small excursion, for about 10 -15 seconds. Immediately afterwards the examiner looks for the induced nystagmus. With a unilateral loss of vestibular function, a vigorous nystagmus with slow phases directed initially toward the affected side will usually appear followed by a reversal phase with slow phases directed toward the intact side. In patients with vestibular imbalance, there is an asymmetry of peripheral inputs during high-velocity head rotations (Ewald’s second law) which lead to an unequal accumulation of activity in the central velocity-storage mechanism within the vestibular nuclei. Immediately after head shaking, the initial phase of HSN appears as a result of a decay of activity within the velocity-storage mechanism. HSN can be also induced in the vertical and roll planes. With unilateral peripheral lesions, vertical head shaking may cause a small-amplitude horizontal nystagmus with slow phases directed toward the intact ear (away for the affected side). Immediately after a unilateral loss of labyrinthine function there may be no horizontal HSN. because the velocity storage mechanism is inhibited centrally much as one may lose the caloric response on the intact side in the first few days after a unilateral loss of labyrinthine function. Some patients with peripheral lesions may show horizontal HSN with slow phases directed away from the affected side. The mechanism may be related to ‘recovery’ nystagmus which refers to the appearance of a nystagmus with slow phases emanating from the lesioned ear. When there has been a prior adaptive rebalancing of vestibular tone after a unilateral lesion, and the tone from the paretic side is suddenly restored or increases as peripheral function recovers, the new level of spontaneous activity on the paretic side becomes excessive relative to the central state of compensation. This leads to a new imbalance causing a spontaneous nystagmus with slow phases directed toward the intact ear. As with the horizontal head impulse sign, a cross-coupled HSN such as a vertical nystagmus following horizontal head shaking usually indicates a cerebellar disturbance.

**PROVOCATIVE TESTS: HYPERVENTILATION.**

Hyperventilation may induce a variety of symptoms in patients with anxiety and phobic disorders but usually does not produce nystagmus. Patients with demyelinating lesions of the vestibular nerve due to compression by a tumor( e.g., acoustic neuroma) or small blood vessels (microvascular compression) or with demyelination in
central pathways (e.g., in multiple sclerosis) may develop nystagmus with hyperventilation. The alkalosis and change in ionized calcium caused by hyperventilation can improve conduction on demyelinated axons leading to a recovery nystagmus (slow phases directed toward the intact ear). Hyperventilation may induce nystagmus in patients with a prior labyrinthitis (with the slow phase usually directed toward the paretic ear) which may reflect a decompensation of adaptive rebalancing of vestibular tone. Hyperventilation may also enhance spontaneous downbeat nystagmus in cerebellar patients which is likely mediated through metabolic effects on calcium channels of Purkinje cells. Moreover, hyperventilation may induce nystagmus by changing intracranial pressure in patients with cranio-cervical junction anomalies or with abnormal connections between the subarachnoid space and the inner ear as occurs with a perilymph fistula or canal dehiscence.

PROVOCATIVE TESTS: VALSALVA MANEUVERS. The Valsalva maneuver can induce nystagmus either by increasing intracranial pressure (straining against closed glottis as with lifting weights) or by increasing pressure in the middle ear (attempting to blow out against pinched nostrils). The nystagmus may be induced in patients with Ménière’s disease, cranio-cervical junction anomalies such as Arnold-Chiari malformation, ossicular chain abnormalities, perilymph fistula, or superior canal dehiscence. Tragal compression can also provoke nystagmus by changing the middle-ear pressure (Hennebert’s sign). Increasing the pressure in the middle ear, however, is better with a pneumatic otoscope.

PROVOCATIVE TESTS: POSITIONAL MANEUVERS. Benign positional vertigo of the posterior semicircular canal due to misplaced otoconia is the most common cause of vertigo. Positional vertigo may also be a prominent feature of migraine induced dizziness, perhaps the second most common cause of vertigo. For positional testing the patient is first moved from the sitting position to the Hallpike position (the head is turned 45 degree to the left and then the patient is moved backward) to stimulate the left posterior SCC and look for the pattern of nystagmus (mixed vertical torsional with the quick phases directed upward and counterclockwise (using the patient as the reference)). The patient is then brought back to the sitting position. The maneuver is repeated with the head turned 45 degree to the right to stimulate the right posterior SCC. Finally, the head is placed in the straight back hanging position to look for a vertical nystagmus and then the patient is turned 90 degree to the left ear down and then 180 degree to the right ear down positions to stimulate the lateral canals. Characteristics which point to a central cause of positional nystagmus are a lack of a latency, lack of fatigability with repetitive testing, an unusual direction of the nystagmus which sometimes change direction, and a pure vertical or pure torsional nystagmus, though other more typically peripheral patterns of positional nystagmus are very occasionally associated with a central lesion.

PART 2: OCULAR MOTOR DISORDERS ASSOCIATED WITH CEREBELLAR DISEASE: The cerebellum plays a central role in the control of every type of eye movements it has both immediate, on-line functions to make each individual movement accurate, and long-term, adaptive functions to keep ocular motor responses correctly calibrated for optimal motor behavior. Here we take an anatomical approach to the types of eye movement disorders that appear with lesions within specific parts of the cerebellum.

VESTIBULOCEREBELLM: FLOCCULUS/ PARAFOCCULUS (TONSILS). The flocculus and paraflocculus (or tonsil) together with the caudal portions of the cerebellar vermis (nodulus and uvula) are part of the archicerebellum, also called the vestibulocerebellum. Lesions of the flocculus/paraflocculus impair many ocular motor functions. First, smooth tracking of a moving target, either when the head is still or moving (VOR cancellation) can be impaired. A second cardinal feature of lesions of the flocculus/paraflocculus is impaired gaze holding with the eyes drifting centripetally after eccentric eye movements, resulting in a gaze-evoked nystagmus. Thus the flocculus/paraflocculus functions in the control of the brain stem circuits (nucleus prepositus and medial vestibular nuclei for horizontal movements and superior vestibular nuclei and interstitial nucleus of Cajal for vertical eye movements) that convert (mathematically integrate) velocity into position commands for all types of conjugate eye movements; the ocular motor integrator. The paramedian tracts and their associated neurons may also be part of this integrator network, and there are rich interconnections between the cerebellum and these structures. A third distinctive feature of lesions in the flocculus/paraflocculus is downbeat nystagmus, in which the eyes drift up (slow phase) and are brought back to the fixation target by a corrective downward saccade (quick phase). This form of nystagmus can be linked to the damage of physiologic ‘up-down’ asymmetry of the floccular Purkinje cells (with predominant downward facilitation) resulting in upward slow drift or the tonic inhibition by the flocculus upon the upward VOR (by inhibitory projections to the superior vestibular nucleus), and lack of corresponding projections from the flocculus to the brain stem structures that mediate downward vestibulo-ocular responses. The upward drift waveform is variable from subject to subject and occasionally may be velocity increasing. These variable waveforms suggest that for the vertical integrator the flocculus/paraflocculus has a more subtle, modulator role, possibly related to the long-term adaptation capability of an individual animal. In other words, based upon the animal’s own ocular motor history (e.g., trauma or disease) and genetic makeup, the inherent brain stem vertical neural integrator could be relatively leaky or relatively unstable, and the cerebellar lesion then unmask the ‘default’ behavior (3,4-Diaminopyridine (3,4-DAP) and 4-Aminopyridine (4-AP), potassium channel blockers, can diminish downbeat nystagmus associated with cerebellar lesions). Rebound nystagmus is also typically seen in patients with cerebellar syndromes is rebound nystagmus.
The nystagmus is short-lived and occurs when the eyes are returned to the central position following sustained eccentric gaze. The rebound nystagmus beats oppositely to the prior gaze-evoked nystagmus, i.e., the slow phase is toward the prior eccentric gaze position. Similar to gaze-evoked nystagmus, rebound nystagmus is linked to the gaze-holding neural integrator controlled by the vestibulocerebellum. In extreme cases the mechanism producing rebound nystagmus becomes unstable leading to a centripetal-beating nystagmus on eccentric gaze in which slow phases are directed outwards. Postsaccadic drift, a brief drift of the eyes lasting several hundred milliseconds following each saccade, is another feature of the floccular/parafloccular syndrome. The postsaccadic drift reflects a mismatch between the pulse (phasic) and the step (tonic) components of innervation that produce saccades. The flocculus and paraflocculus are not critical for generating a compensatory response to head rotations since the VOR is still present after a lesion there but its amplitude and direction may be incorrect. This implicates the flocculus and paraflocculus in the adaptive mechanism that keeps the VOR properly calibrated in response to changing environmental conditions.

During rotation of the head around an earth-vertical axis, patients with diffuse cerebellar lesions may show a dynamic upward bias so that the eyes move up as well as horizontally, producing a ‘cross-coupled’ VOR. There are also inappropriate torsional components and the responses in the two eyes are disconjugate. A release of inhibition upon anterior semicircular canal pathways within the brain stem (which produce upward slow phases) is a possible explanation. In line with this hypothesis, patients with cerebellar disease have an asymmetric vertical VOR with higher gain for downward head impulses (consistent with increased anterior semicircular canal stimulation). These results implicate the cerebellum, and likely the flocculus/paraflocculus, in generating movements of each eye that have the correct amplitude and direction for perfect VOR compensation.

VESTIBULOCEREBELLUM: NODULUS/VENTRAL UVULA. These structures mainly contribute to the control of the rotational and the translational VOR though pursuit deficits, especially vertical, may also be seen with lesions in this region. Lesions in the nodulus/ventral uvula commonly lead to spontaneous downbeat nystagmus and periodic alternating nystagmus. The nodulus/ventral uvula projects directly to the brain stem velocity storage mechanism which is dependent upon Purkinje cell inputs for its proper actions. The velocity storage mechanism has several functions. First it extends the duration of the VOR response beyond that expected from the mechanical properties of the cupula-endolymph system within the semicircular canals. This perseverating (integrating) action slows the decay of nystagmus that normally occurs during a constant-velocity rotation in the dark. Secondly, during sustained ‘off-vertical axis’ rotation of the head, when there is an imposed changing linear acceleration due to the continuous reorientation of the head relative to the pull of gravity, the velocity-storage mechanism modulates the direction of compensatory slow phases, reorienting the axis of eye rotation towards earth vertical. It thus serves an orienting function so the brain can know the position of the head relative to the pull of gravity, as well as determine whether a sensed linear acceleration of the head is from gravity or an imposed translation of the head. Lesions of the nodulus/uvula alter the velocity-storage mechanism for the horizontal VOR and increase the duration of vestibular responses to a constant-velocity input around an earth-vertical axis (i.e., the VOR time constant is increased). Lesions of the nodulus/uvula also disrupt the spatial orientation function of the velocity-storage mechanism; the VOR no longer reorients the axis of eye rotation toward upright during off-vertical axis rotation. With nodulus/uvula lesions, there is also a loss of the normal habituation of the time constant of the VOR to repetitive stimulation as well as loss of tilt suppression of post-rotary nystagmus, the mechanism by which the decay of post-rotary nystagmus is hastened with pitching the head down immediately following the end of a constant-velocity rotation. Periodic alternating nystagmus (PAN), a horizontal jerk nystagmus that changes direction every few minutes, may appear following lesions of the nodulus and its adjacent paravermal region. PAN reflects the combined actions of a (1) disinhibited brain stem vestibular velocity-storage mechanism (due to loss of inhibition from Purkinje cells in the nodulus that project to the vestibular nuclei) and (2) an intact adaptive mechanism that acts to null any sustained unidirectional nystagmus, thus allowing PAN to change direction. Because Purkinje cell inhibition is mediated through GABA\textsubscript{A} receptors, treatment with baclofen (a GABA\textsubscript{B} agonist) disengages the velocity-storage mechanism and stops PAN. Memantine may also be of use in treating this disorder. Note that as for rebound nystagmus, the adaptive mechanism that leads to the reverse of the direction of PAN is intact or possibly increased after lesions in the cerebellum. Downbeat nystagmus is also reported with nodulus and uvula lesions. The slow-phase velocity of this nystagmus, unlike that with flocculus lesions, is independent of orbital position (i.e., nystagmus does not change intensity with up and down gaze nor increase with lateral gaze) and can be suppressed with visual fixation. Changing the orientation of the head with respect to gravity may also alter the nystagmus. Thus the downbeat nystagmus with nodulus/uvula lesions could be due to a bias in the vestibular system (either the t-VOR or r-VOR mechanisms) and need not reflect changes in the gaze-holding neural integrator.

DORSAL VERMIS AND FOR (FASTIGIAL OCULOMOTOR REGION): SACCADES. The dorsal vermis (lobules V–VII, also called the oculomotor vermis; OMV) and the underlying posterior fastigial nucleus (also called the fastigial oculomotor region; FOR) is especially important for the control of saccades. Lesions in the OMV cause changes in the accuracy, latency, trajectory, and dynamic properties (speed and acceleration) of saccades. Purkinje cells in the OMV discharge before saccades, and
stimulation of this same area can elicit saccades. Transcranial magnetic stimulation (TMS), functional magnetic resonance imaging (fMRI), and mapping of lesions supports a role for the participation of the OMV in the generation of saccades. The OMV also plays an important role in saccadic adaptation, a mechanism that detects errors in motor performance and updates saccade commands to accurately move the eye toward a target. OMV lesions impair adaptation of saccade amplitude. Neurons in the FOR also discharge in relation to saccades and supply a presaccadic burst for contraversive saccades and a ‘braking’ discharge, late during the saccade, for ipsiversive saccades. Thus, each FOR acts to facilitate contraversive saccades and contributes to the termination of ipsiversive saccades. Consequently, lesions in the FOR cause ipsiversive saccadic hypermetria (overshoot) and contraversive hypometria (undershoot) and bilateral FOR lesions cause bilateral hypermetria. Purkinje cells in the OMV behave similarly to those of the FOR, though, as predicted from their inhibitory nature, their ‘sign’ is opposite. Thus, each side of the vermis acts to facilitate ipsiversive saccades and contributes to the termination of contralateral saccades. Accordingly, OMV lesions lead to hypometric ipsiversive and hypermetric contraversive saccades and bilateral lesions in OMV cause hypometric saccades in both horizontal directions. Vertical saccades show ipsipulsion (oblique trajectory toward the side of inactivation) with experimental lesions of the FOR. Ipsipulsion is also a feature of Wallenberg’s syndrome, presumably due to a functional lesion of the FOR resulting from interruption of the climbing fiber input (within the inferior cerebellar peduncle) to the OMV and a consequent increased inhibition by Purkinje cells upon the underlying FOR. Other areas, such as the interposed nucleus (emboliform and globose) and paraflocculus (tonsils), may also be important in the generation of vertical saccades. The central role of the cerebellum in the control of saccades is reflected in the different ways it can influence the trajectory of the saccade but how does the cerebellum modulate the brain stem circuits that generate saccades? There are many targets in the brain stem by which the cerebellar output, via the FOR, could influence saccades including excitatory burst neurons (EBN) for saccade initiation and inhibitory burst neurons (IBN) and omnipause neurons (OPN) for saccade termination. Projections to the fixation zone of the rostral pole of the superior colliculus are another route by which the FOR could help bring the saccade to an end.

**DORSAL VERMIS AND FOR (FASTIGIAL OCULOMOTOR REGION): PURSUIT.**

The OMV and FOR also participate in the generation of pursuit eye movements. Electrical stimulation of the OMV in monkeys can enhance contraversive or impair ipsiversive pursuit, and transcranial magnetic stimulation of the skull over the posterior cerebellum in humans can influence pursuit eye movements in the same pattern. There are neurons in the FOR that discharge early during contraversive pursuit and late for ipsilateral pursuit, analogous to activity associated with saccades. Thus, each FOR can facilitate contraversive pursuit and can contribute to the termination of ipsiversive pursuit. Purkinje cells in the OMV probably behave in a similar way to those of the FOR, though, as predicted from their inhibitory nature their ‘sign’ is opposite. Each side of the vermis would act to facilitate ipsiversive pursuit and contribute to the termination of contralateral pursuit. The pursuit deficits reported after experimental lesions in the OMV and the FOR are largely in accord with the physiological findings. With a lesion in the FOR contralateral pursuit is impaired, and with a lesion in the OMV ipsilateral pursuit is impaired. Vertical pursuit is little affected following OMV lesions whereas FOR lesions reduce downward pursuit more than upward pursuit. Bilateral lesions of the OMV in monkeys produce horizontal pursuit deficits in both directions though bilateral FOR lesions leave pursuit relatively intact; this is also seen in patients with bilateral FOR lesions. These finding suggest the pursuit deficit is due to imbalance between opposing drives of the two FOR. Therefore, with bilateral FOR inactivation, and no FOR imbalance, the pursuit movements remain intact. Lesions of OMV and FOR mainly affect eye acceleration during the initial period of pursuit (the first 100 ms of tracking after a target has started moving or has changed its speed) and have a smaller effect during the sustained tracking period. As noted above the flocculus/paraflocculus contribute to smooth pursuit. One possible division of labor between these two regions is that the OMV/FOR is more concerned with the initiation and termination of the preprogrammed initial ‘open-loop’ portion of pursuit (when retinal slip is high), and the vestibulocerebellum is more concerned with pursuit during sustained tracking.

**CEREBELLUM AND BINOCULAR CONTROL.**

Patients with cerebellar damage sometimes show a skew deviation, a vertical misalignment of the eyes that cannot be attributed to a simple ocular muscle weakness. Most commonly the abducting eye is higher as the patient looks from far right to far left. The source of the skew may be an imbalance in otolith-ocular reflexes and patients with cerebellar skew deviation have reduced and disconjugate counterroll gains that depend on the direction of the head tilt. Note that a skew deviation is commonly observed in Wallenberg’s syndrome but this is probably attributed to involvement of the caudal portions of the vestibular nuclei in the brain stem. The dentate nucleus has been also implicated in cerebellar skew deviation based on MRI/CT lesion analysis. Patients with cerebellar lesions can also show misalignment of the eyes during the r-VOR and during saccades. An esotropia (the eyes turn inward), sometimes attributed to a divergence paralysis since the esodeviation is usually greater at distance, also occurs in cerebellar disease and probably reflects involvement of the dorsal vermis. Patients with acute cerebellar lesions can show impaired slow but relatively intact fast vergence. Moreover, divergence, but not convergence, can be affected particularly with the lesions in the OMV. Patients with vestibulocerebellar lesions may also show a divergence-beating nystagmus (convergent slow phases with divergent quick phases. These abnormalities
hint at an excess of convergence tone with some cerebellar lesions. In sum, the cerebellum is involved in almost every facet of the control of eye movements and a careful examination of the different subclasses of eye movements in patients with cerebellar disease provides precise localizing diagnostic information.

CME ANSWERS
1. a
2. c
3. d

REFERENCES