

Vestibular Physiology and Testing Approached

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Introduction:

Balance disturbances and Vestibular testing are among of the most encountering issues in the ENT clinic.

Vertigo and balance disorders affect 30% of the general population before the age of 65 years. With the elderly it is a serious condition as fall is a major cause of death, the percentage in this age group is higher and it is estimated that 33% of aged between 65 and 75 with no history of Vestibular dysfunction encounter a significant fall annually, comparing to 40% of the people aged over 75. Early detection and intervention in these cases can improve the quality of life, as well as decrease the disability and reduce the health care costs (1).

It is important for the treating Physician to establish a systemic process for taking the history of the patient, and to implement a structured ENT and Neurologic examination, in order to administer a rational treatment.

Physiologic overview:

The Balance function depends on several sensory organs to maintain, which includes the vestibules of Inner ears, Vision, and the somatosensory systems.

Processing and Interpretation of this information is done in the central nervous system including the Brain stem, the Cerebellum, throughout the vestibular nuclei.

When seeing VDU (Vertigo, Dizziness, Unsteadiness) patients we must think of all the pathways of balance, starting with the peripheral sensory input, the central processing of the input, and the neuro-muscular pathways that are responsible for maintaining the balance of the body and stability of the vision. The cause of balance disturbance can be a malfunction of one or more of the mentioned factors.

The peripheral part of the Vestibular System consists of three semicircular canals (SCC): (lateral LSCC, superior SSCC, posterior PSCC). And two Otolith organs (Utricle and Saccule).

The function of the SCCs is to sense the angular acceleration of the body, while the Otolith organs sense the linear acceleration and gravity, both systems accomplish the eyes compensatory movements by the Vestibulo-ocular reflex (VOR), and the body

posture correction by the Vestibulo-spinal reflex (VSR), mediated by the Vestibular Nuclei.

The central parts of the Vestibular system consist of the Vestibular Nerves, Vestibular Nuclei, and the Cerebellum.

The anatomy of the semicircular canals and the (Utricle\Saccule) is unique to insure the sense of movements in all directions.

The SCCs are orthogonal (perpendicular) to each other in one side.

The PSCC and SSCC are 45 degrees off the sagittal plain, and the Posterior canal on one side is parallel (paired) to the Superior canal on the other side, and vice versa Fig. 1, that means when one canal is excited the other pairing canal is inhibited, this can be an explanation of restoring function after unilateral vestibular loss, as there will be compensation of function by the pairing semicircular canal on the other side. (1)

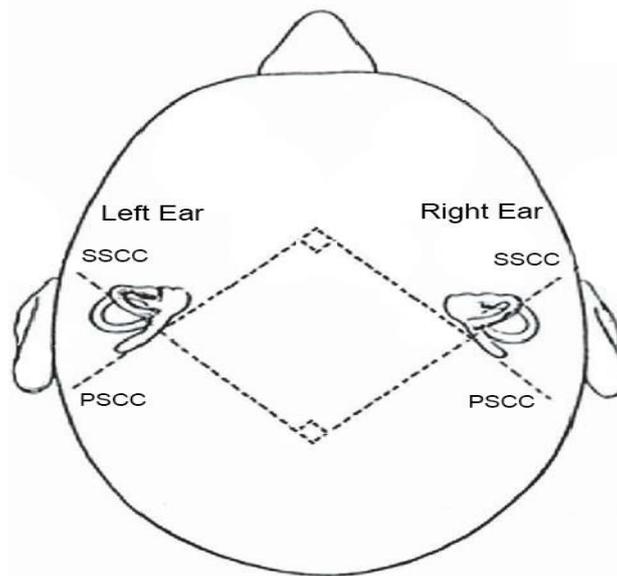


Fig 1 SCCs Perpendicular in each side, Pairing SCC.

The Lateral canal on both sides are on the same plain and are inclined 30 degrees, so as the anterior crus of the semicircular canal is higher than the Posterior crus when the head is in upright position, when we extend the patient's head 60 degrees backwards (patient sitting upright), the Lateral Canals will be in a vertical plain, and this is useful for the Caloric Test as will be explained later. Fig 2

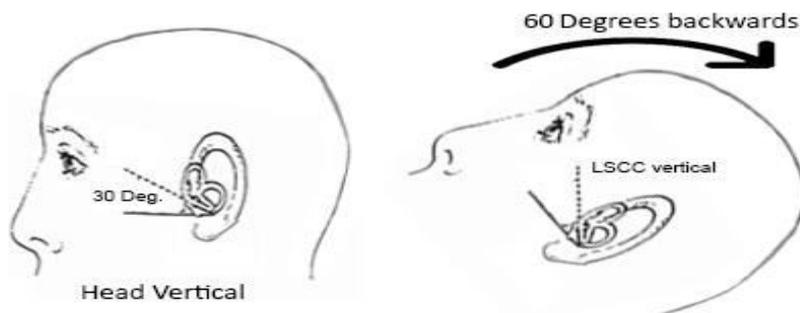


Fig 2 LSCC's Position for Caloric Test

The Utricle's organ of balance is in a horizontal plain (responsible for the sense of movement in the horizontal plain), and the Sacculle's organ is in vertical plain (responsible for the sense of movement in the vertical plain). Fig 3

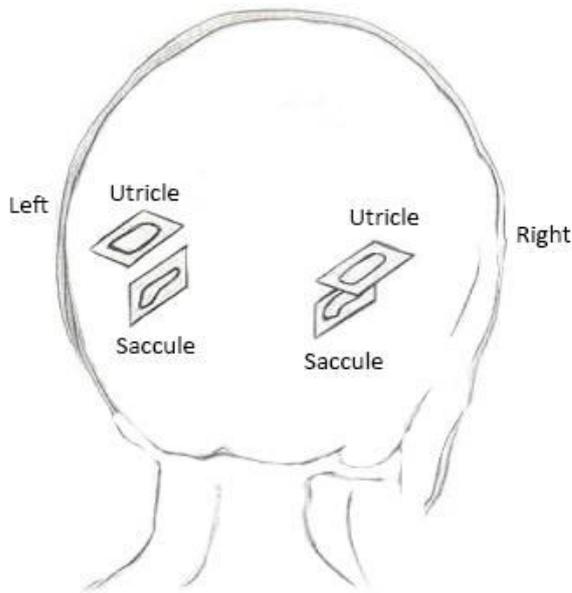


Fig 3 Utricles and Saccules

The sensory structure in the Semicircular Canals is the Cupula, located in the dilated end of the SCC called the Ampulla. The Ampulla is at the anterior end of the LSCC, at the anterior end of the SSCC, and at the inferior end of the PSCC. Fig 4

Ewald's three laws:

First law: The path of nystagmus generated by a SCC is in the same plane of that particular SCC.

Second law: Based on experiments conducted on the LSCCs states that ampullopetal (endolymph flow from the SCC through the Ampulla to the Utricle) is excitatory to the vestibular nerve, and ampulofugal (endolymph flow from the Utricle to the semicircular canals through the ampulla) is inhibitory.

Third law: Based on experiments conducted on the vertical (SSCCs and PSCCs), found that ampulofugal endolymph flow is excitatory, and ampullopetal endolymph flow is inhibitory. (2) Fig 4

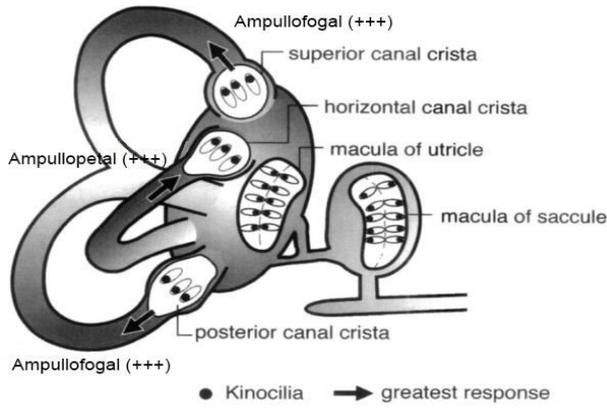


Fig 4 SCCs response to rotation

We must know that each afferent neuron from these balance sensory organs in the Inner Ear has a baseline firing rate, the excitement of this neuron causes increase of this firing, and the inhibition causes decrease in the firing, so if we compare both vestibules of the body to an airplane engines, when there is (a unilateral vestibular loss) it acts as if one airplane engine is working less or stopped, so the body and eyes shift to the vestibular deficient side, and the airplane to the side of the deficient engine. This rule helps a lot in determining which vestibule is less functioning.

Nystagmus is the repetitive, uncontrolled movements of the eyes in response to vestibular or neurological pathologic stimulation; it can be Jerk (has fast and slow components), or Pendular (same speed in both directions). It can also be described as (Horizontal, Vertical, and Torsional). The direction of the Jerk Nystagmus is (by definition) the fast component movement of the eyes following the slow component movement. Actually the slow component represents the balance between the firing of the two vestibules (the eyes shift to the weakened firing side), while the fast component is the eye's compensatory movement to restore the original vision field, mediated by central nervous mechanism, (4) In other words the stimulation of a vestibule in a specific direction drives the eyes and the body to the opposite direction in the same plane of the stimulated SCC.

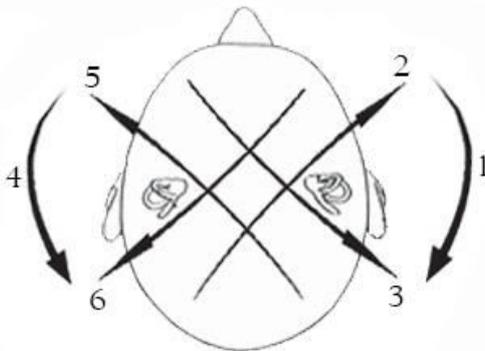


Fig. 5 explains the directions of head movements in relation with the excitement of the relevant SCC:

Head movement 1 causes ampullopetal excitement in the Right LSCC, drives the eyes and body to direction 4 (to preserve the fixation of vision field and posture, and this would be the slow component of nystagmus if present in pathologic conditions like overexcitement of Right LSCC or inhibition of Left LSCC).

Head movement 2 causes ampullofugal excitement in the Right SSCC, drives the eyes and body to direction 6 (pathologic overexcitement of Right SSCC or inhibition of Left PSCC).

Head movement 3 causes ampullofugal excitement in the Right PSCC, drives the eyes and body to direction 5, (pathologic overexcitement of Right PSCC or inhibition of Left SSCC).

Same applies for movements 4, 5, 6.

Physiologic inhibition of one canal is accompanied with excitement of the pairing canal, while pathologic inhibition of any one of these canals shifts the neural firing balance to the other pairing (normal firing) SCC, and so gives the patient a false feeling of head rotation in the relevant direction of the arrow representing this pairing SCC (Fig 5).

Example if the Right LSCC is pathologically inhibited, the newly dominating Left LSCC will give the patient a feeling of head rotation in the direction of arrow No. 4 (to the left), so the patient will fall and have a slow component of nystagmus to the right (arrow 1).

Vestibular Testing:

Vestibular testing implies enforcement of external effects on the Vestibules and observing the balance function regarding the (Posture, Eyes movements and fixation). Eyes observation is best accomplished by using (Frinzel Glasses) to prevent the voluntary eyes fixation.

The following is simplified Qualitative testing technique of the vestibular function; it is qualitative as it is aimed to the primary evaluation of the patients in the General ENT or Family Medicine Clinic, which has to be followed by more Quantitative Vestibular evaluation in the specialized VDU Clinic. This primary evaluation helps for identifying the peripheral Vestibular causes, and the dangerous signs for acute or chronic central causes of vertigo.

Vestibular Tests:

Examination	Method	Interpretation
Spontaneous Nystagmus (3), (4)	Patient sitting in upright position and looking in the Primary gaze position (looking straight ahead 0 degree and horizontal) to a fixed target, first with the eyes best corrected vision (glasses if needed), then	Normal: fixed gaze Vestibular pathology: Horizontal—torsional, jerk nystagmus, suppresses with visual fixation Central pathology: changing in direction, horizontal, vertical, torsional, or pendular nystagmus,

	with Frinzel glasses.	enhances with visual fixation
Gaze-evoked Nystagmus (2), (3), (4)	Patient's head fixed ahead, eyes looking in eccentric gaze (off the Primary gaze position) to a point within 0 to 30 degrees right and left	Normal: fixed gaze Vestibular pathology: Direction-fixed nystagmus, increases while gazing in the direction of the fast phase (better vestibule)/ (Alexander law) Central pathology: Direction-changing nystagmus, fast-phase movement in the direction of gaze, or rebound nystagmus in neutral gaze
Eyes Saccades (2), (3), (4)	Alternate patient's eyes fixation (head fixed straight ahead), on the nose of the examiner in the Primary gaze position and his finger in 15 degrees right, left, up, and down	Vestibular pathology: normal fixed Central pathology: Abnormalities in eyes movement (Accuracy, conjugate movement, velocity, and initiation)
Smooth pursuit (2), (5)	Examiner positions his index finger directly in front of the patient and moves the target smoothly 20 to 30 degrees per second fast, first in the horizontal plane and then in the vertical plane. The testing area is restricted to 30 degrees to the left, right, up, and down from Primary gaze position	Normal patients, Vestibular pathology: Normal smooth movement. Central pathology: catch-up saccades
Head Shaking Test (6) (safety concerns regarding the patient's cervical spine and large vessels)	Patient's head tilted 30 degrees forward to make the LSCC horizontal, head is rotated 30 degrees alternating to both sides, in a 2HZ frequency for 20 seconds, then sudden stop the head and observe the eyes fixation. Test can be repeated in vertical plane	Normal patient or equal vestibular loss on both sides: fixed gaze. Asymmetric vestibular pathology (> 50% unilateral damage): nystagmus (in plane of damaged canal with fast phase toward stronger ear). Central pathology: cross-coupling of nystagmus,

		(nystagmus appears in a plane other than that being stimulated), prolonged nystagmus and disconjugate nystagmus, extremely more fast and large nystagmus
<p>Head impulse test (HIT) (7), (8) (safety concerns regarding the patient's cervical spine and large vessels)</p>	<p>To test the SCCs The patient is asked to fixate his eyes on the examiner's nose, while the head is impulsively (suddenly) and unpredictably moved 20 to 30 degrees in one direction. The velocity of the head movement must exceed 200 degrees/second, examiner should start at low speed and gradually increase to the test speed *(More detailed instructions after the table)</p>	<p>Normal: fixed gaze Vestibular pathology (> 50% unilateral damage): Re-fixation saccade generated when doing rotational head thrusts in a direction supposed to stimulate the pathologically inhibited SCC Central Pathology: Test negative (most of the time)</p>
<p>Head heave test (HHT) (8) (safety concerns regarding the patient's cervical spine and large vessels)</p>	<p>To test the Otolith organ in the Utricles. The examiner applies linear head heaves(slides) on an axis that pass through both vestibules (intervestibular), in a way that maintains the head orientation in the space fixed, and maintaining the patient's visual fixation on the examiner's nose</p>	<p>Normal: fixed gaze Vestibular pathology (> 50% unilateral Utricular damage): Re-fixation saccade generated with linear head heaves toward the damaged side</p>
<p>Positioning testing (9) (10) (Nystagmus induced by actual movement of the head from one position to another) Dix-Halpike for</p>	<p>Observe the eyes when taking these head positions See ** for more details</p>	<p>Normal: fixed gaze. Vestibular Pathology: Nystagmus that has a brief latency (5 to 20 sec.), less than 30 sec. duration, fatigable with repeated positioning, and sometimes reversal nystagmus when returning to the original upright position, see ** for more details</p>

<p>(Posterior SCC) Supine roll test for (Lateral SCC)</p>		<p>Central Pathology: Immediate without latency, persists more than 1 min, no fatigue, no reversal nystagmus, direction changing, usually no vertigo sensation</p>
<p>Limb coordination Tests (11) Finger to nose test Finger nose finger test Hand rapid alternating test Fine finger movement test Past pointing test</p>	<p>Observe the Smoothness and accuracy of Limb coordination See *** for more details</p>	<p>Normal: Limb coordination accurate. Vestibular Pathology: (2) All limb coordination tests, except past pointing, are normal Past pointing: arms shifting toward the side of the pathologic vestibule. Central Pathology: abnormalities (dysmetria or dysdiadochokinesia) in any of these tests</p>
<p>Posture Romberg tests</p>	<p>patient is asked to stand with his feet together and arms down</p>	<p>Normal: Normal posture Vestibular Pathology: Fall to the weak side with eyes closed, balance improves when eyes open Central Pathology: Falls with eyes open</p>
<p>Gait Tandem gait, Unterberger (Fukuda) stepping test</p>	<p>Tandem gait: Patient walks in line with his heels touching toes, eyes open and closed Unterberger (Fukuda): Patient marches in place with his arms extended in front for 2 minutes eyes open and closed stepping test: Patient walks 2 steps forward and backward repeatedly eyes open and closed</p>	<p>Normal: Normal gait Vestibular Pathology: Abnormal tandem gait with eyes closed, rotation to side of lesion. Gate improves with eyes open Central Pathology: Gait abnormalities (e.g., ataxia, shuffling, etc.) with eyes open and closed</p>
<p>Mastoid vibration (2), (12)</p>	<p>Vibrator on the mastoid, and Frenzel glasses used</p>	<p>Normal: No Nystagmus Vestibular Pathology (> 50% unilateral damage): Nystagmus in</p>

		the plane of the inhibited SCC toward the stronger ear
Pressure-evoked eye movements (2), (13)	Apply pressure on the Middle ear by tragal compression, pneumatic otoscopy, or Valsalva maneuvers, and observe the eyes with Frenzel glasses	Normal: No Nystagmus Vestibular Pathology : Nystagmus and vertigo in case of: Oval window (perilymph fistula, excessive footplate movement), round window perilymph fistula, enlarged cochlear aqueduct), lateral SCC (perilymph fistula), and superior SCC (dehiscence).
Sound-evoked eye Movements (2), (13)	Apply high sound pressure on the middle ear by Pure tones (100 dB), and observe the eyes with Frenzel glasses	Normal: Fixed gaze Vestibular Pathology : Same as above (Pressure-evoked..)
Test of Skew (2), (14)	Ask the patient to look straight ahead to the examiner's nose, then quickly and alternatively cover one patient's eye	Normal or Vestibular Pathology: Fixed gaze Central Pathology: Abnormal vertical (covered eye) movement often associated with vertical diplopia
Caloric Test	Patient sitting upright, head extended 60 degrees backwards(to make the LSCC vertical), Irrigate the External Auditory Canal with cold (30 degrees C), or hot (44 degrees C) water or air.	Cold stimulation causes ampulofugal inhibition in the tested ear (cool heavier endolymph goes down by gravity, and so nystagmus away from the tested ear

***Head Impulse (Thrust) Test: (7)**

To test the lateral semicircular canals (LSCC), we must tilt the patient's head 30 forward to put the LSCC in a horizontal plane, so to test the Right LSCC turn the head 30 degrees left then thrust it back to midline, this gives ampulopetal stimulation in the Right LSCC and ampulofugal inhibition in the left LSCC.

To test the vertical canals we need to align each one of them with the Sagittal plane, and create a stimulus ampulofugal movement, so to test the right SSCC turn the head 45 degrees to the left then thrust it downwards to create ampulofugal stimulation in the canal. Same applies for PSCCs.

In each one of these tests the eyes of the normal patient is supposed to stay fixed on the examiner's nose (or a target), and there will be saccades in the impaired SCC. Test is repeated 5 to 10 times to document fixation failure.

****Positioning Testing(9)(10)**

Dix-Halpike Test: Used to identify Posterior SCC Benign Paroxysmal Positional Vertigo (BPPV). The patient is sitting and examiner turns his head 45 degrees to the right then put the patient in supine position, head hanging out the table between the hand of the examiner, 20 degrees beneath the plane of the table, observe for nystagmus and vertigo, wait 30 seconds (some authors recommend waiting for 60 seconds) (9B), then put the patient upright again while maintaining the head 45 degrees turned right, wait 30 second and observe for nystagmus and vertigo again, repeat the exam head turned 45 degrees the left. The nystagmus seen when the affected ear down, and should be up beating, geotropic (upper pole of eye moving toward the ground), torsional, Nystagmus lasts 5 to 20 seconds. Fading dizziness with repetition of Dix-Halpike to one side without nystagmus might be appropriate to be considered as positive test. (10)

To test the SSCC put the patient sitting upright, turn the head 45 degrees to the other side (opposite the tested ear), tell the patient to bend down 90 degrees, watch for nystagmus.

Modified Positioning Test (Supine Roll Test): for identifying LSCC BPPV. Put the patient in supine position, head lifted up 30 degrees on a pillow (to make the Lateral SCC vertical), roll the patient's head 90 degrees to the right and left. Nystagmus (horizontal, geotropic) will appear when the pathologic ear down.

*****Limb coordination Tests (11)**

Finger to nose test: The patient closes his eyes, extends his arm horizontally both sides, and then touches his nose repeatedly and alternately with both arms.

Finger nose finger test: The patient touches the examiner's finger then his own nose then back to the examiner's finger while the examiner moves his finger to new points in front of the patient.

Hand rapid alternating test: the patient should tap on his thigh alternately with the back and front of his hand.

Fine finger movement test: The patient touches quickly by his thumb the four fingers of his same hand

Past pointing test: The patient points with his both index fingers arms extended up to the ceiling, and then he puts his arms front to touch the examiner index fingers (sitting in front of the patient with his both index fingers pointing up).

HINTS to INFARCT: Are a battery of tests for identifying acute central nervous pathology in patients with Persistent vertigo and nystagmus for hours or days. (15)

Test	Result in Central Acute Pathology
Head Impulse	Impulse Normal
Nystagmus	Fast-phase Alternating
Test of Skew	Re-fixation on Cover Test

Red Flags that might indicate central nervous system issues:

Numbness, Tingling, muscle weakness, Slurred speech, Loss of consciousness, Rigidity, Visual field loss, Memory loss, Cranial nerve dysfunction, Progressive hearing loss, Tremors, Poor coordination, Upper Motor Neuron (UMN) signs (Spasticity, Clonus, Babinski), Vertical Nystagmus fail to stop on eyes fixation.(16) (17)

Summary

Qualitative Vestibular testing are useful tools for primary evaluation of VDU patients, they can direct the physician to the differential diagnosis of the case, and sometimes can be lifesaving when early diagnosed serious central nervous system conditions, these tests are to be followed by more quantitative tests in the VDU, or Neurology specialized clinics.

Resources

- (1) Dizziness and Vertigo, An Introduction and Practical Guide, by Rahul G Kanegaonkar, FrcS(ORL-HNS) Consultant in otolaryngology, Medway Maritime Hospital, Kent, UK, Honorary senior Lecturer in otorhinolaryngology, Anglia Ruskin University, Chelmsford, UK, James Tyrone MA, PhD, FrcS(ORL-HNS) Consultant in otolaryngology and skull Base surgery, Addenbrooke's Hospital, Cambridge, UK
- (2) Bailey's Head and Neck Surgery, Jonas Johnson MD
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- (6) Head Shaking Nystagmus, <https://www.dizziness-and-balance.com/research/hsn/Head%20Shaking%20Nystagmus.htm>
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- (15) H.I.N.T.S. to Diagnose Stroke in the Acute Vestibular Syndrome—Three-Step Bedside Oculomotor Exam More Sensitive than Early MRI DWI, doi: [10.1161/STROKEAHA.109.551234](https://doi.org/10.1161/STROKEAHA.109.551234)
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- (17) Red flag symptoms: Dizziness, By DrSuneetaKochhar on the 10 September 2018, <https://www.gponline.com/red-flag-symptoms-dizziness/neurology/neurology/article/1334374>