Clinical physiology of the balance system

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Maintenance of balance

- CNS collects information about static / dynamic position of the body in relation to the ground and the surroundings from certain sensors in different parts of the body.
- Information from different sensors integrated in the brain and compared with previously stored experiences.
- A very precise, coordinated and accurately timed motor output generated reflexly which contracts some specified muscles and restores balance.
Physiology of Balance

- Afferent SENSORY system (inputs to the brain from):
  - Vestibular labyrinths
  - Eyes
  - Proprioceptors

- Efferent MOTOR system (output generated by the brain):
  - Directed to-
    - Muscles of LIMBS / TRUNK /NECK through VESTIBULOSPINAL system.
    - Muscles of the EYES through VESTIBULO-OCULAR system.

- Cerebellum fine tunes the motor output
- Cognitive system determines the nature of the response
- Higher centers in the brain modulate the motor response
Parts of the CNS majorly involved in modulating the motor output

- Pyramidal & Extra-pyramidal systems
- Basal ganglia
- Reticular formation
- Thalamus
- Cerebellum
- Ascending / descending tracts in spinal cord
The Reflex Pathway

Afferent sensory organ
vest. labyrinth/ eyes/ proprioceptors

Afferent neural pathway
vestibular nerve/ optic nerve/ ascending column in spinal cord

Center of the reflex
Vestibular nucleus

Efferent motor pathway
MLF to oculomotor nuclei 3/4/6h cr nv
Descending vestibulo-spinal tract
Ant. horn cells – peripheral

Effector motor organ
Extra-ocular / skeletal muscles
Parts of the vestibular labyrinth and its different functions -
ROLE of the OTOLITH organs in maintenance of balance

- **semicircular canals** transduce angular & rotational accelerations.
- **otolithic organs** transduce
  - linear acceleration, esp. horizontal (utricule) and vertical (saccule) displacements.
  - the force of gravity acting on the body and any movement away from gravity (graviception)...

_in otolithic dysfunction, this information does not reach the brain_

**In practice**

Most VFTs evaluate semicircular canal function; otolith function, although very important in our daily activities for maintaining balance, are rarely evaluated...the **Subjective Visual Vertical test** evaluates the perception of the horizontal and vertical which is an otolithic function.
OTOLITH FUNCTION in real life

The utricle, saccule and semicircular canals in action...
Some hard facts

• The vestibular labyrinths are **NOT** the only system that control balance

• **Visual** system, **CNS** esp. the **oculomotor** system and the **cerebellum**, peripheral NS, musculo-skeletal system, somatosensory system, **cognitive system** & the **psychic system** have significant influence on the functioning of the balance system

• In the vestibular labyrinth too, the **otolith organs** and the **ant. & posterior semicircular canals** have a very major role to play which is no less important than the **lateral** semicircular canals
Some hard facts

- Motor output is controlled by:
  - cerebral cortex / subcortical centers
  - cerebellum
  - brainstem

- Acts through:
  - pyramidal / extrapyramidal pathways
  - oculomotor system
  - descending columns in spinal cord
Role of the Nervous System in maintaining balance

- **Pyramidal & Extra-pyramidal systems**
  - cortical influence of lower motor centers
- **Basal ganglia**
- **Reticular formation**
  - somatic motor control through reticulospinal tracts to maintain muscle tone, posture, balance, motor movement
- **Thalamus**
  - acts as a relay station in the neural pathway between the cerebrum/cerebellum before they enter the spinal cord
- **Cerebellum**
- **Ascending / descending tracts in spinal cord**
Extra pyramidal disorders

- **Parkinsonism**
  - rigidity, bradykinesia, tremor, postural deficit
- **Dystonia**
  - torsion spasms of limbs, trunk and neck
- **Tardive dyskinesia**
- **Chorea**
- **Athetosis**

**Clinical Pearl**

*In the initial stages, all of these present with imbalance only, as motor activities are affected; anti-vertigo drugs like prochlorperazine and cinnarizine only aggravate the disorder*
Functions of the Balance System (1 of 3): Gaze stabilization

**Goal:** maintenance of a stable & clear image of the visual surroundings when

- *head is moving*
- *visual surroundings / target is moving*
- *both head & visual surroundings/target are moving*

- Very complex mechanism involving vestibular & oculomotor systems
- Needs very complex tests for evaluation e.g., VHIT, Saccade test, OPK test, SPS test, gaze test
Gaze stabilization achieved by

**VOR** - vestibulo-ocular reflex
**SPS** - smooth pursuit system
**SCS** - saccadic system
**OPK** - optokinetic system

- These reflex systems are facilitated by the **OCULOMOTOR** system
- Cerebellum fine tunes the oculomotor response
- Cortical / subcortical centers modify the response
OCULOMOTOR SYSTEM

- the motor system to move the eyes in different ways so as to FIXATE / STABILISE images of surrounding objects in the fovea under all circumstances.

Purpose:

1. Provide good visual acuity / spatial orientation
2. Prevent oscillopsia when subject moves the head or surrounding objects move in 3D space.

Very complex process & involves many mechanisms any of which if jeopardised, leads to CENTRAL VERTIGO; hence thorough evaluation of oculomotor system is mandatory in all patients presenting with balance disc...
OCULOMOTOR mechanisms involved in FIXATING images in fovea

- Saccadic system
- Convergence system
- Smooth pursuit system
- Visual fixation with gaze holding
- VOR and suppression of VOR by Visual Fixation
- Optokinetic system

Some examples from real life
Supranuclear OCULOMOTOR centers in the brain

rMLF - Rostral interstitial nucleus of medical longitudinal fasciculus (upper midbrain)
INC - Interstitial nucleus of Cajal (upper midbrain)
PPRF - Paramedian Pontine Reticular Formation
NPH - Nucleus Praeepositus Hypoglossi
PC - Posterior Commissure (connects the rMLF of 2 sides)

All structures have SPECIFIC functions
Functions of the Oculomotor centers

rMLF - Vertical saccades
PPRF - horizontal saccades
INC - gaze holding in vertical axis
NPH - gaze holding in horizontal axis
PC - abnormal convergence nystagmus
Vestibulo-ocular reflex (VOR)

Stabilise images in the fovea
- when the target moves
- when the head moves
- achieved by

moving the eyes smoothly in a direction of the target when head is stationary but target moves and opposite to the movement of the target when target is stationary but head moves and at a speed which is equal to the speed of the target/head movement
Maintenance of VOR

- All 6 semicircular canals are involved through ampulo-ocular reflex evaluated by Video Head Impulse test (VHIT)

- Otolith organs (utricle & saccule) of both sides involved through maculo-ocular reflex evaluated by ocular VEMP
Smooth Pursuit System (SPS) - for stabilizing the image of a visual target moving smoothly and continuously at a speed less than 1.2Hz on a predictable trajectory e.g.
- a bird flying across the sky
- swinging pendulum
Saccadic System (SS)

- for stabilizing image of a visual target at the end of the visual field in the fovea by a rapid single eye movement.
- facilitates visual tracking when SPS fails and when speeds are more than 1 Hz.
Perfection of saccade determined by

- Velocity of the saccadic eye movement
- Conjugacy of eye movement
- Latency of the movement
- Accuracy / precision with which the eyes fixate the image on the fovea.

An example of smooth pursuit and saccade
## Saccadic System disorders

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<tr>
<th>Examination Finding</th>
<th>Conclusion</th>
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| Slowing of saccades/hypometria       | • Intoxication  
• Neurodegenerative disorders                                                                                                          |
| Slowing of horizontal saccades       | • suggests brain-lesions usually in ipsi PPRF (paramedian pontine reticular formation)                                               |
| Slowing of vertical saccades         | • suggests mid-brain-lesions usually in riMLF (rostral interstitial medical longitudinal fasciculus) like Progressive Supranuclear Palsy |
| Slowing of adducting saccades        | • suggests inter nuclear ophthalmoplagia                                                                                               |
| Hypermetric saccades                 | • suggests cerebellum (vermis) lesions or lesions in the cerebellar pathway, e.g. Wallnberg’s syndrome due to damage to the inferior cerebellar peduncle |
VISUAL FIXATION

sub-served by gaze function

- for maintaining the stable position of gaze after the saccadic system has placed image of the target at the periphery of the visual field on the fovea

Normal persons can hold the gaze, but in central vestibular disorders GAZE HOLDING FUNCTION is JEOPARDISED

INC controls gaze holding in vertical axis & NPH - gaze holding in horizontal axis
Optokinetic System (OPK): *combination of*

**SPS** + **Saccadic system**

Stabilizes gaze when:-

- a) the entire visual field moves
- b) repeated movements of a visual target across a stationary subject’s visual field
- c) moving the subject in a stationary visual field
- d) both visual field & subject are moving
Optokinetic system

- for gaze fixation during movement of the entire visual field
CEREBELLAR lesions

- cerebellum basically has an inhibitory function
- most balance disorders are due to problems in Floculus
- usually ipsiversive lesions

-Vermis
lesions cause
- dysmetric saccade
  like hypermetria

Flocullus
lesions cause
- defect in smooth pursuit
- impaired VOR suppression
- downbeat nystagmus
- gaze evoked nystagmus
- rebound nystagmus

Nodulus
lesions cause
- periodic alternating nyst.
- central positioning
- and / or positional nyst
- downbeat nystagmus
- rebound nystagmus

This is only the OPTIC / VOR manifestation of a cerebellar lesion; cerebellar defects also have manifestation in the skeletal muscles / VSR
Functions of the Balance System (2 of 3): Postural stabilization

Goal: maintenance of erect posture in static & dynamic conditions both in
- routine daily activities
- complicated activities like cycling / playing badminton / other sports activities / dancing etc.

Spontaneous balance correction response to stabilize body when there is a destabilizing force

Volitional balance stabilizing response in sporting activities, dancing etc.

Evaluated by posturography e.g., CDP, Stabilometry, CCG
Functions of the Balance System (3 of 3): Graviception

Goal: Perception of the vertical & horizontal / graviception -
- orientation relative to gravity
- determining direction /trajectory & speed of movement of a visual target

Evaluated by Subjective Visual Vertical (SVV) test
OTOLITH FUNCTION

Maculo-spinal reflex
Maintain postural balance
E.g. train suddenly stops but subject does not fall.

Maculo-ocular reflex
Stabilizes gaze during head movement laterally & vertically.

Maculo-spinal reflex & Maculo-ocular reflex both become defective in otolith dysfunction.
Deranged transduction of linear movement in the horizontal & vertical planes.

Results:
- Otoliths provide erroneous information for control of posture + gaze stabilisation in horizontal / vertical planes

- Incorrect sensation of upright posture
- Self-motion
- Incorrect spatial orientation of body

Pts. complains:
- Strange feeling of disorientation rather than rotating / spinning
- Instability
- Psychological disturbances like panic / anxiety
VESTIBULO-SPINAL REFLEX (VSR)

- Function of VSR - to stabilise the head on the shoulders and also the body on the ground

- Tested by:
  - Posturography
  - Craniocorpography
  - Stabilometry
  - Vestibular Evoked Myogenic Potentials
Vertigo has a strong psychic component... pleasurable for some, dreadful for others
Thanks for enduring this presentation on the complexity of the physiology of balance.

What is your state???
confused? relieved? bored? dizzy?