Vestibular Function In Neurodevelopmental Disorders

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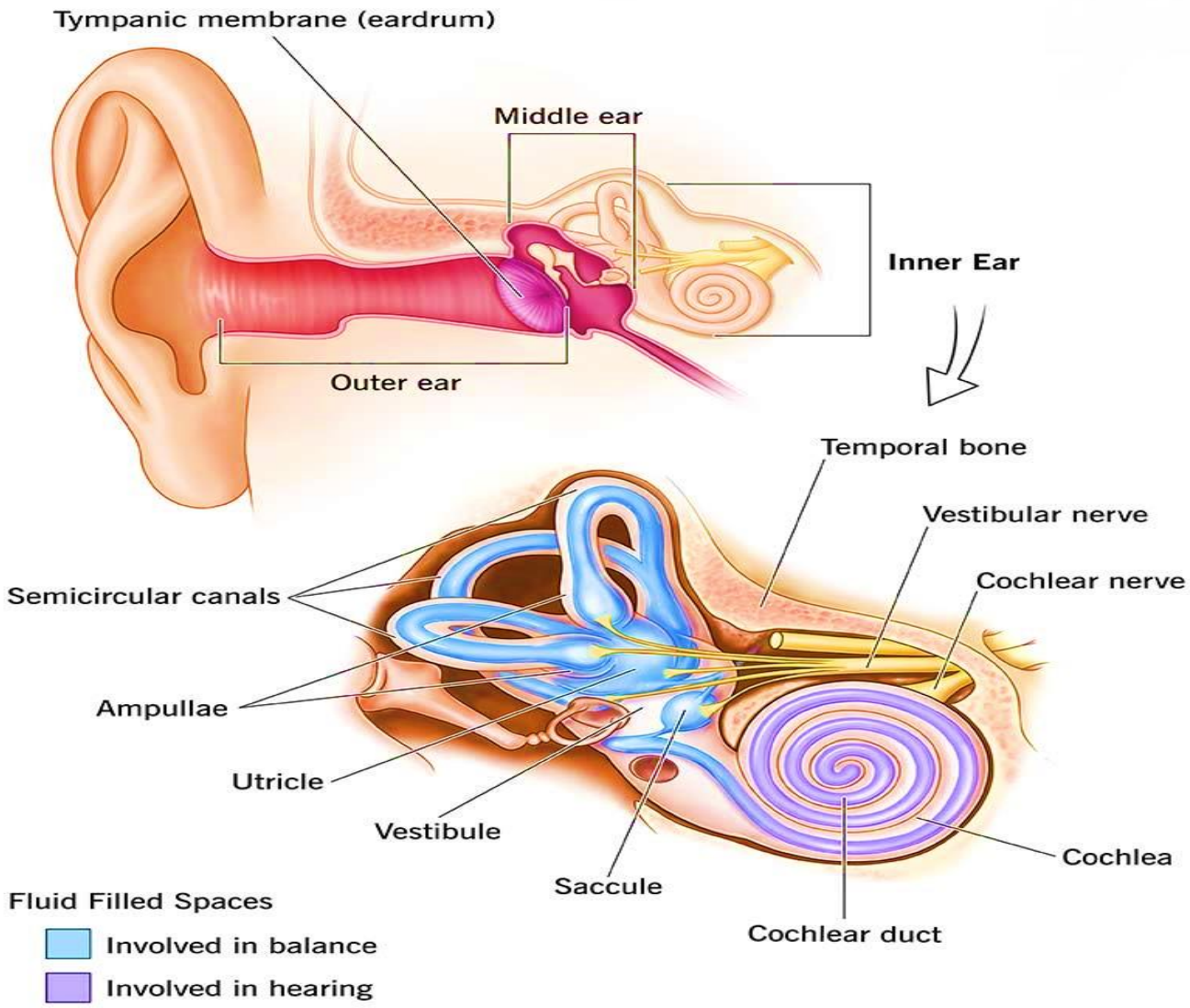
Vestibular System Function

Neurodevelopmental disorders

Vestibular dysfunction in children with neurodevelopmental disorders

Conclusion

STRUCTURE OF EAR



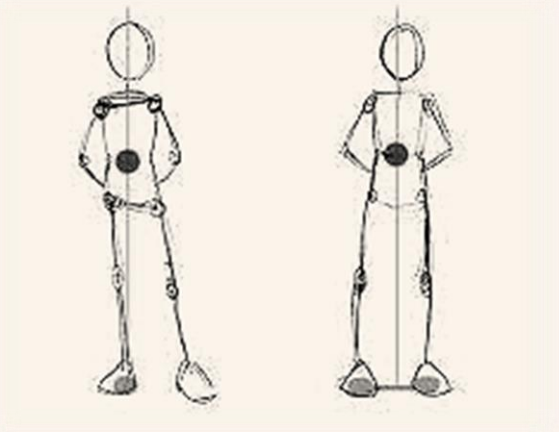
Balance System

Balance is the ability to maintain the body's center of mass over its base of support.

Center of mass: Center point of each body segment combined

Center of gravity: Vertical projection of center of mass

Base of support: Area of object that is in contact with the ground



Balance System

A properly functioning balance system allows humans;

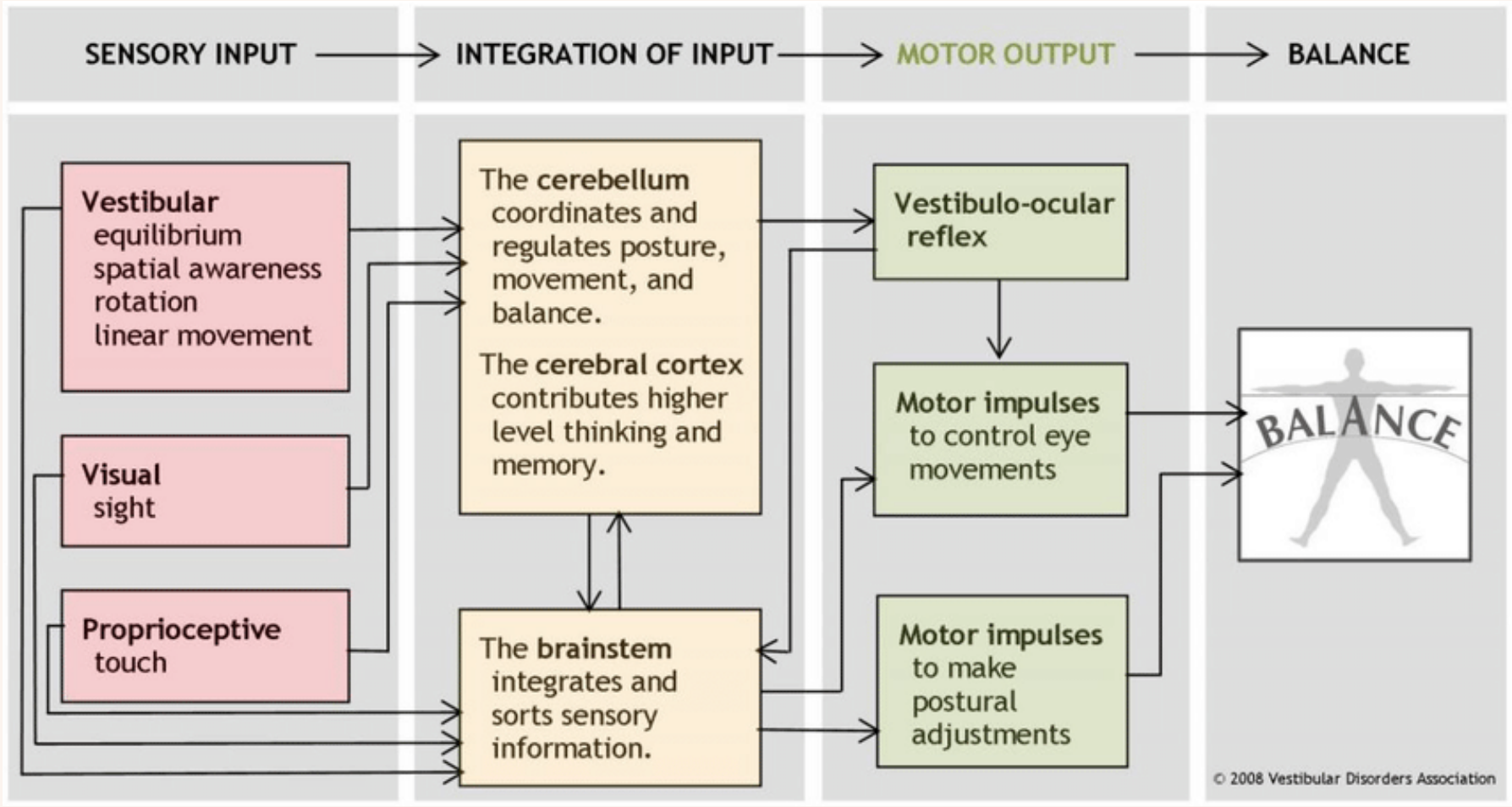
- to see clearly while moving
- identify orientation with respect to gravity
- determine direction and speed of movement
- automatic postural adjustments to maintain posture and stability in various conditions and activities

Balance can be classified in to:

Static Balance: the ability to maintain postural stability and orientation with center of mass over the base of support and body at rest.

Dynamic Balance: the ability to transfer the vertical projection of the center of gravity around the supporting base of support while the body parts are in motion (dynamic balance is more challenging)

Balance System




AGE
VERTIGO
problem
balance
ear
CANALITHS
migraine
dizzy
pressure
BRAIN
HEADACHE
particles
changing
signal
head
unbalanced
vestibular
system

VESTIBULAR SYSTEM

- The vestibular system is the most sensitive and one of the most important sense organs.

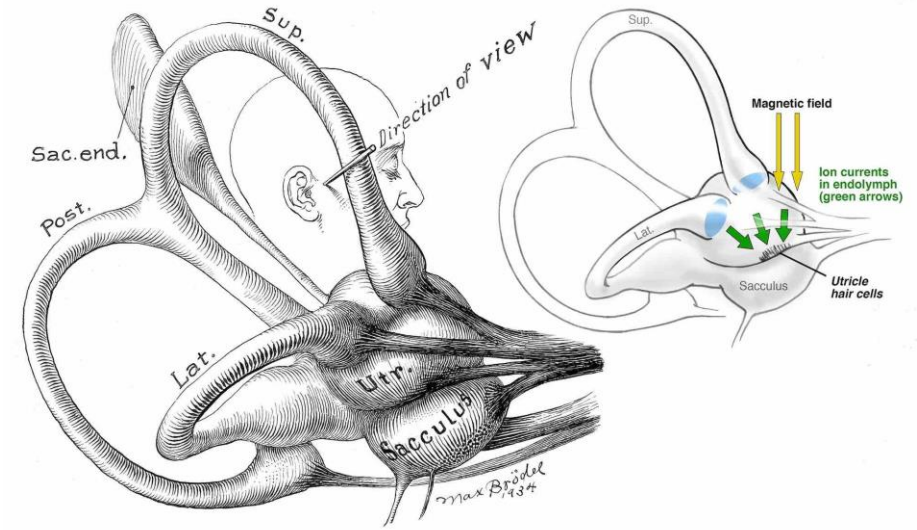
✓ detect head motion and position relative to gravity

✓ fine control of visual gaze, posture

✓ spatial orientation

✓ Navigation

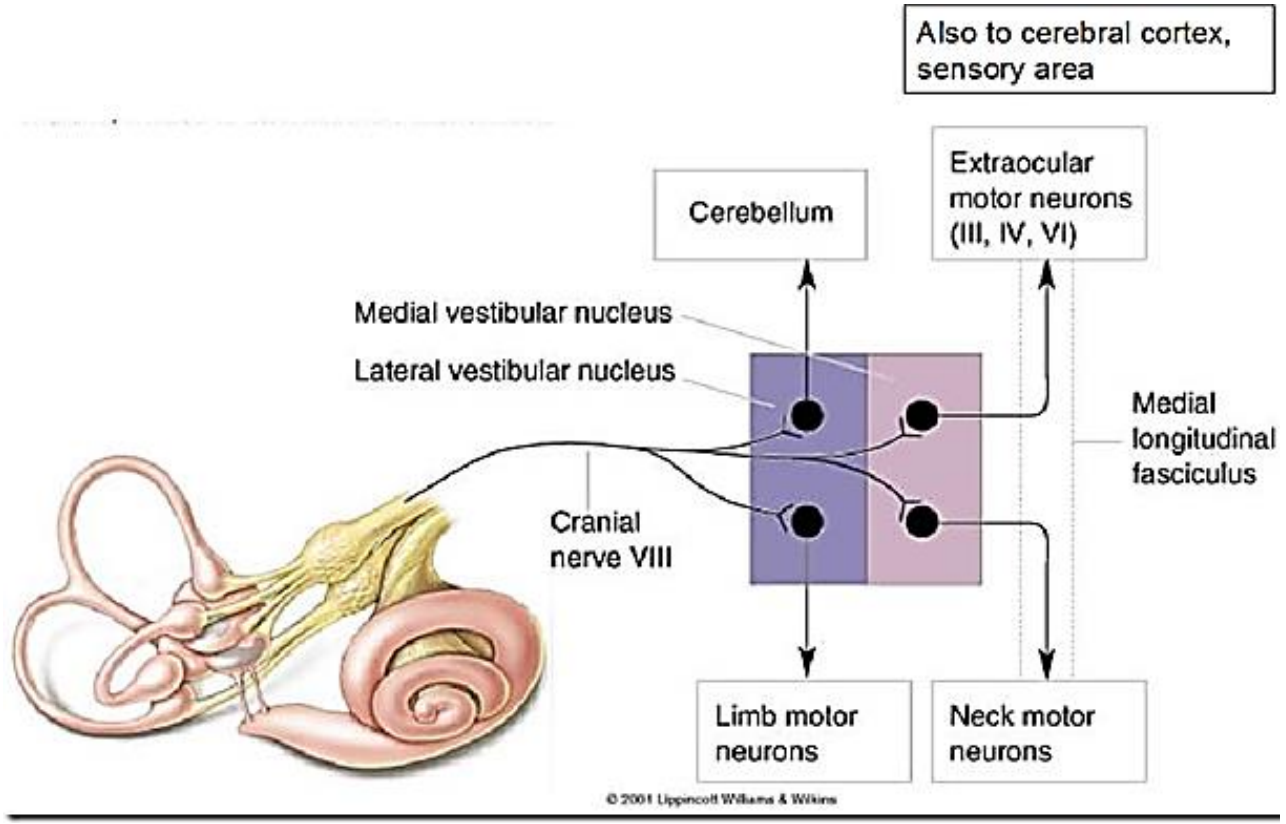
- The vestibular system provides the sense of balance and the information about body position that allows rapid compensatory movements in response to both self-induced and externally generated forces.
- Together with the cochlea, a part of the auditory system, it constitutes the labyrinth of the inner ear in most mammals.



Vestibular System

The components of the system can be divided into three parts:

1. Peripheral apparatus
2. Central processors
3. Motor outputs



Peripheral apparatus ➡ **Central processors** ➡ **Motor outputs**

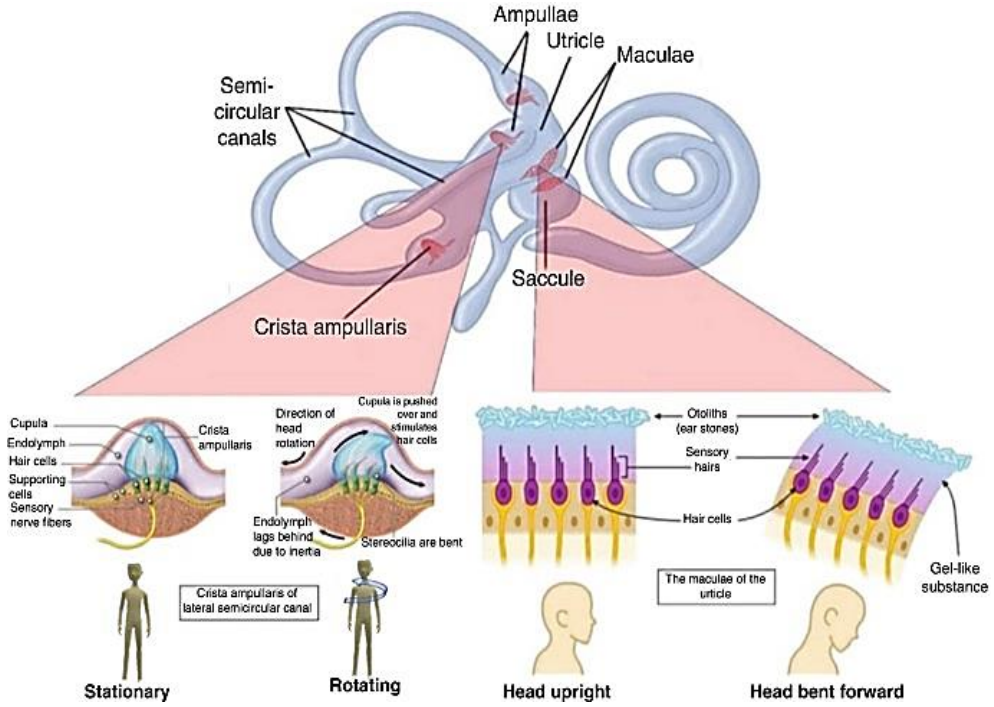
Vestibular System (Peripheral apparatus)

- The peripheral vestibular system is composed of five sensory organs housed in the inner ear – three semi-circular canals and two otolith organs (utricle and saccule).
- It is stimulated by movement of fluid in the structures of the inner ear, in response to movement by the head.

movements consist of rotations and translations

the vestibular system comprises two components:

- semicircular canals, which indicate rotational movements.
- otoliths, which indicate linear accelerations.



➢ **detects & relays information about head rotational & linear velocity to central processing system**

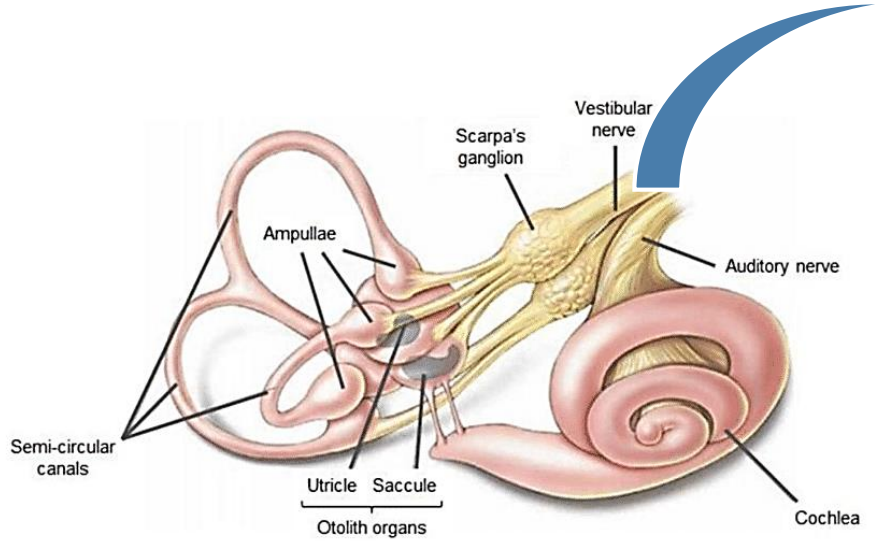
➢ **orients the head with respect to gravity**

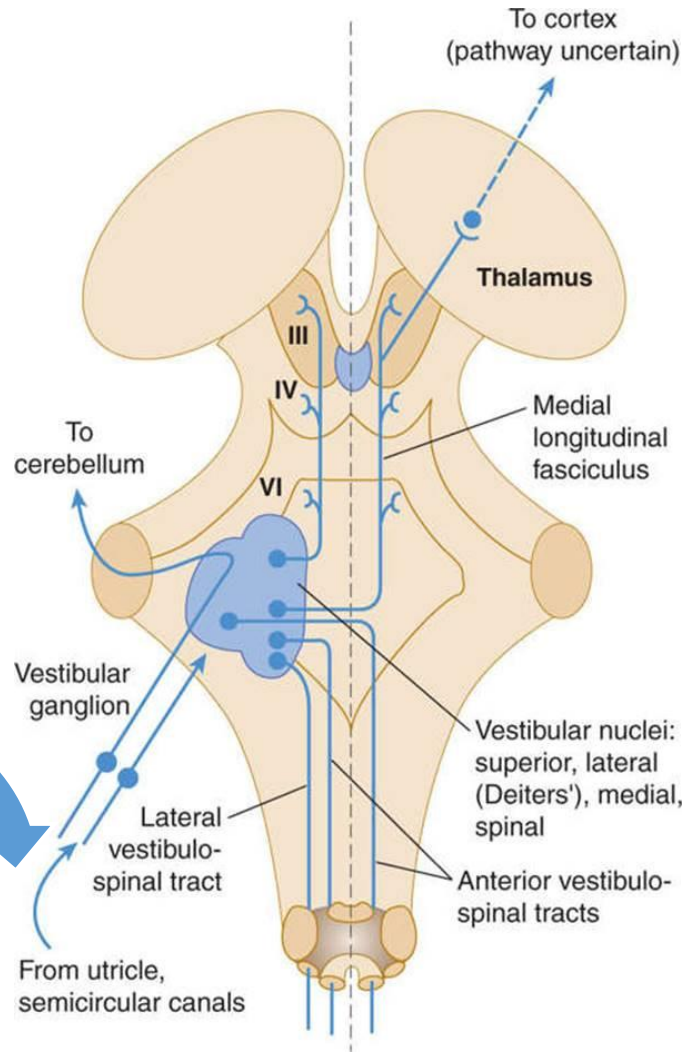
VESTIBULAR SYSTEM (CENTRAL PROCESSORS)

- **Vestibular nuclei:** on either side of the brainstem exchange signals regarding movement and body position.
- **Cerebellum:** Signals sent to the cerebellum are relayed back as muscle movements of the head, eyes, and posture.
- **Nuclei of cranial nerves III, IV, and VI:** Signals sent to these nerves cause the vestibular-ocular reflex. They allow the eyes to fix on a moving object while staying in focus.
- **Reticular formation:** Signals sent to the reticular formation signal the new posture the body has taken on, and how to adjust circulation and breathing due to body position.
- **Spinal cord:** Signals sent to the spinal cord allow quick reflex reactions to both the limbs and trunk to regain balance.
- **Thalamus:** Signals sent to the thalamus allow for head and body motor control as well as being conscious of body position.
- **Cerebral cortex:** contributes higher level thinking, memory,…

➢ **processing and interpretation of afferent signals with other sensory inputs for position and movement of head in space and the output of efferent signals.**

Vestibular System (Central processors)





VESTIBULAR SYSTEM (MOTOR OUTPUTS)

The main sensorimotor vestibular pathways in mammals:

vestibuloocular reflex (VOR)

- **gaze stabilization** during short and fast rotational head movements, stable visual image, despite changes in head orientation

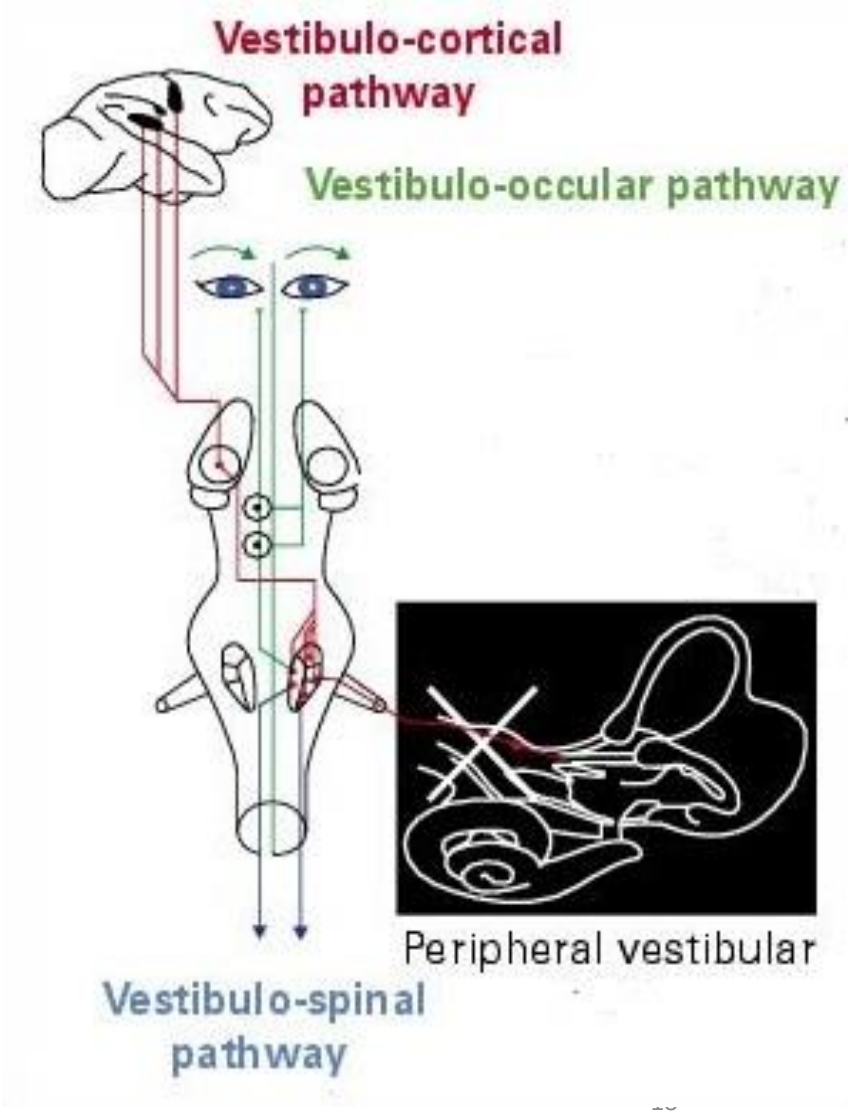
vestibulospinal reflex (VSR)

- **posture stabilization** in response to stimuli that alter equilibrium

vestibulo-collic reflex (VCR)

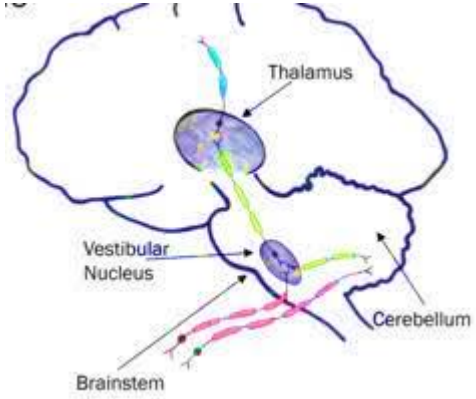
- **both gaze and posture stabilization** co-contraction of the cervical muscles in the neck to stabilize the head while the body is moving (predictable or unpredictable movements)

➢ **generates compensatory eye movements and compensatory body movements during head & postural adjustments**



VESTIBULAR SYSTEM

- Many signals are sent from the vestibular nucleus to either the thalamus, cortex, or cerebellum that help to process and adjust efferent signals to postural or ocular muscles.

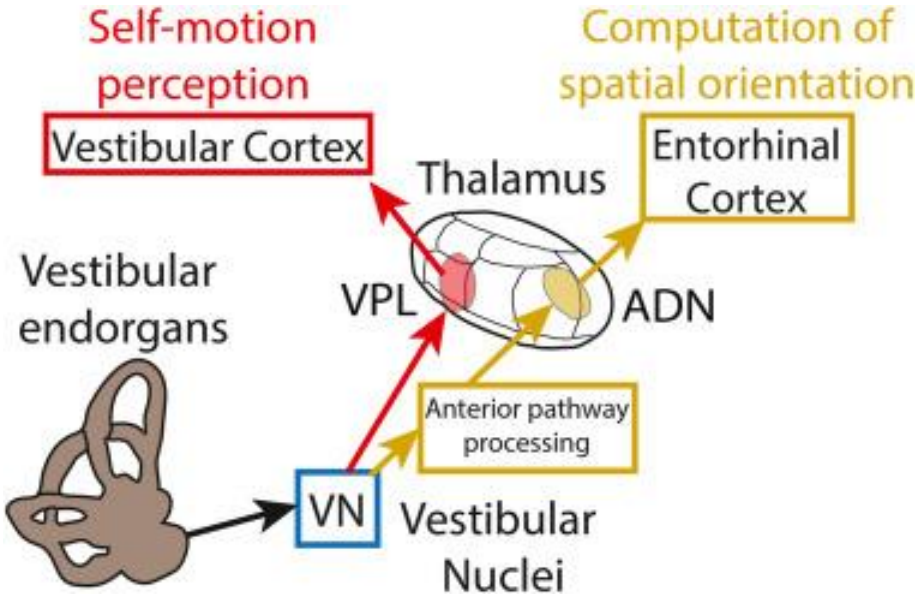


The central vestibular connections include:

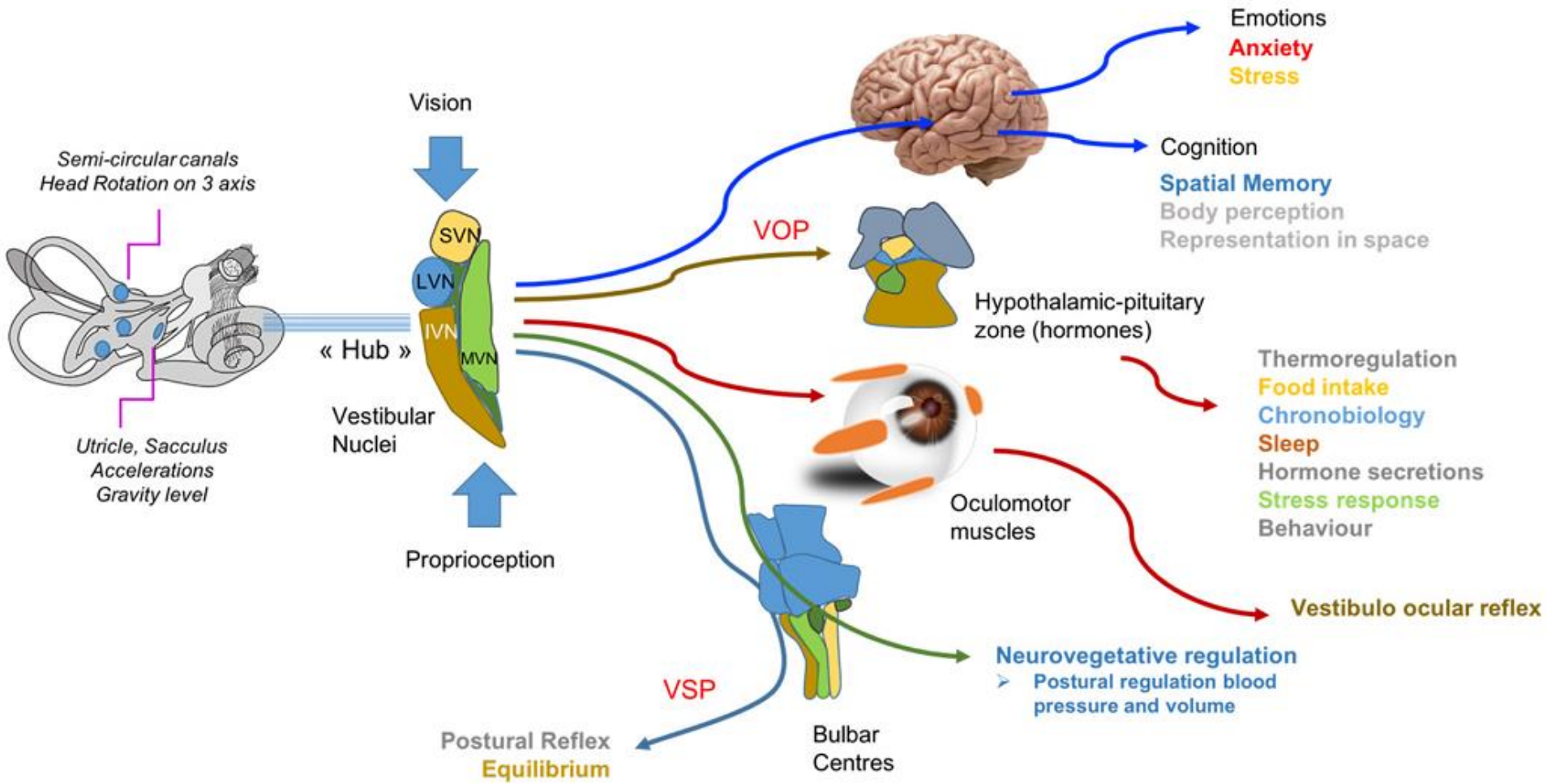
- **vestibulo-thalamo-cortical tract**
- **dorsal tegmental nucleus to entorhinal cortex tract**
- **nucleus reticularis pontis oralis to hippocampus tract**

These tracts play a functional role in;

- **self-motion perception**
- **spatial navigation**
- **spatial memory**
- **object recognition memory**



Vestibular System Pathways



Vestibular System

Since the vestibular system has such a widespread influence what happens when it fails?

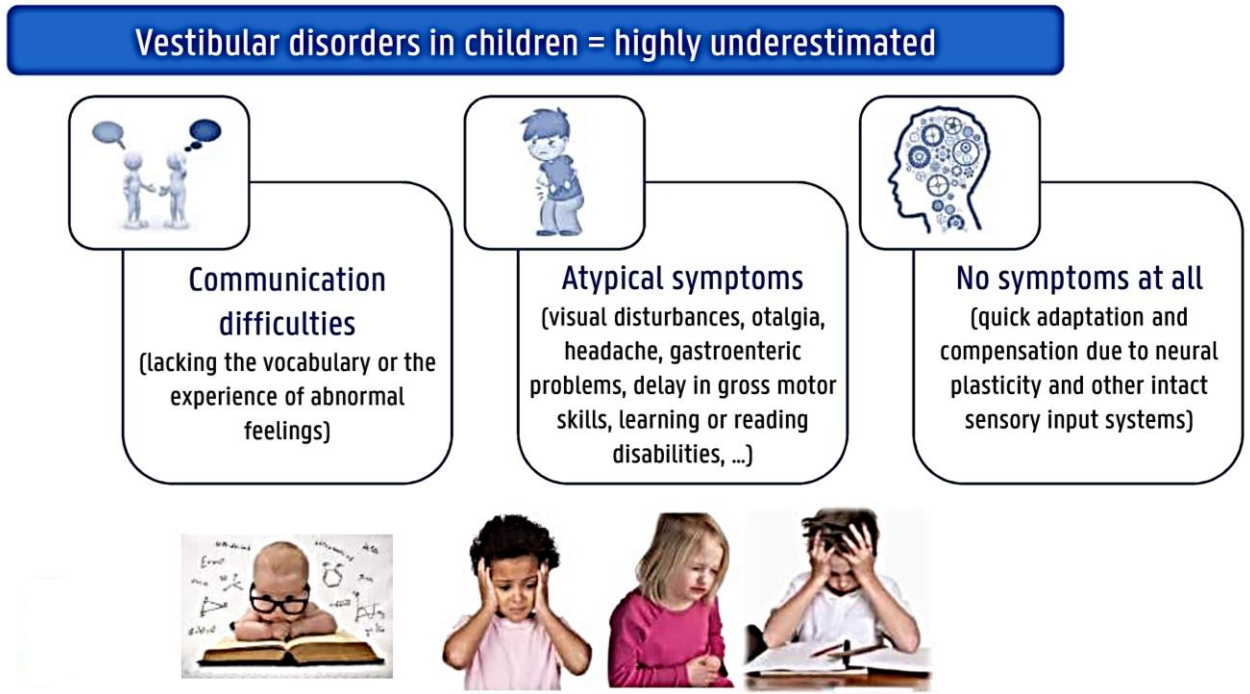
Possible problems:

- Dizziness and/or vertigo
- Spatial disorientation
- Imbalance
- Distorted vision unless head is held perfectly still
- Motion sickness
- Cognitive problems

VESTIBULAR SYSTEM

- While the clinical features and consequences of a vestibular dysfunction in adults are frequently discussed, vestibular failure in childhood has less often been described.

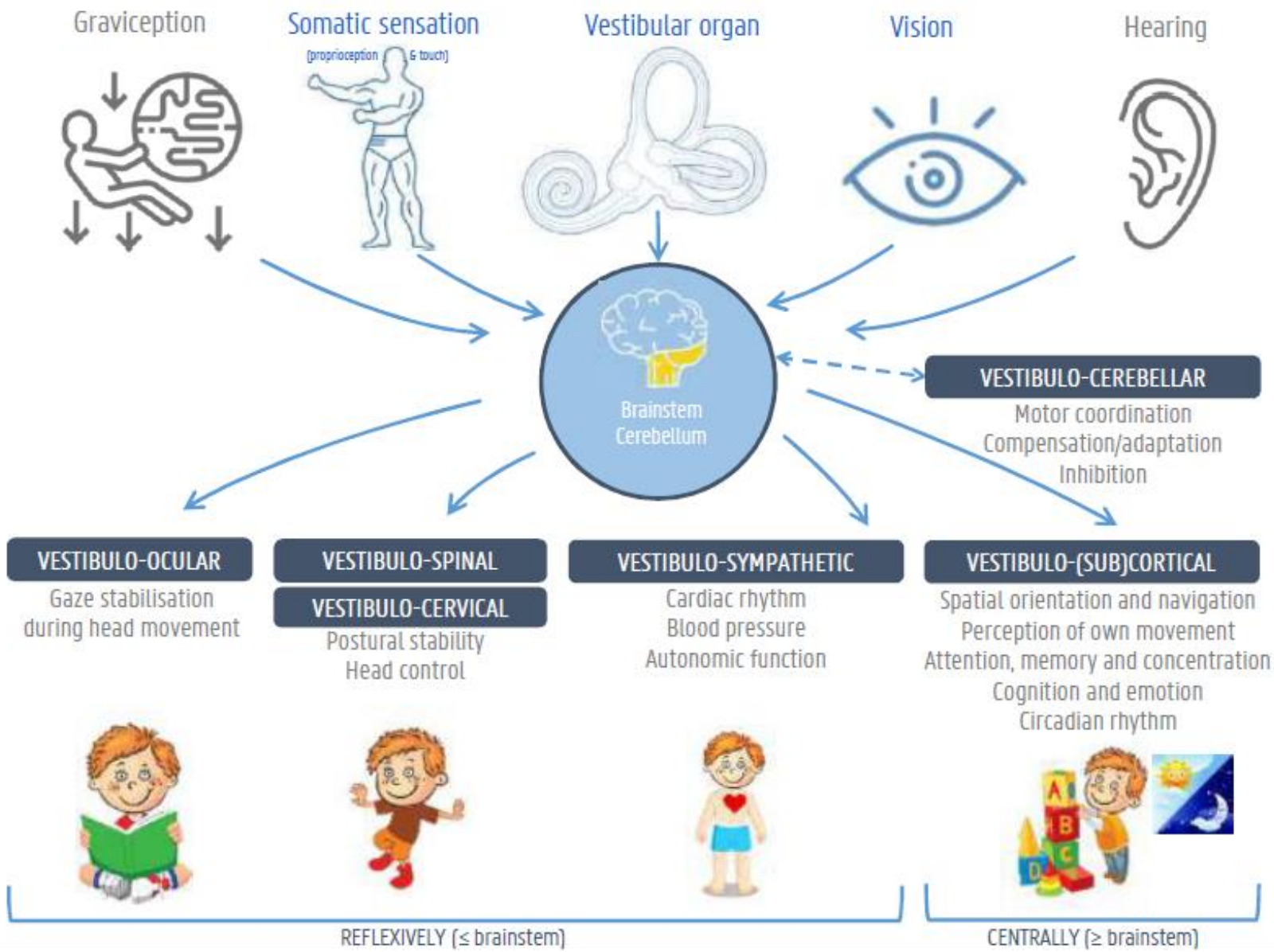
- Children are often not able to communicate their complaints properly and a vestibular dysfunction often has a different clinical course compared to that in adults.



VESTIBULAR SYSTEM

- vestibular examination in this population can be quite difficult, as these tests require cooperation, alertness and test conditions that may be frightening for children (e.g., some vestibular assessments have to be performed in the darkness in order to eliminate visual suppression of vestibular responses).

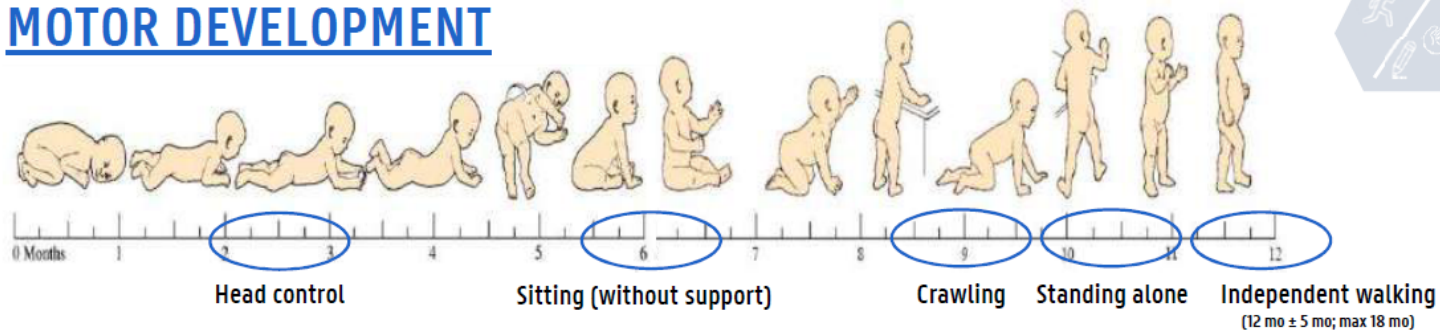
THE BALANCE SYSTEM



VESTIBULAR SYSTEM

- When a vestibular dysfunction occurs at birth or in early stages of life, one might expect that this may have an enormous impact on a child's development.
- It is known that a severe congenital or early acquired vestibular deficit in children results in delayed psychomotor milestones.

MOTOR DEVELOPMENT



- **YOUNG** age (before independent walking ≈ congenital)
  - Delay and/or difficulties with postural control and achieving the gross motor milestones
  - Wide-legged step pattern

- **OLDER** age (after independent walking ≈ acquired)
  - Difficulties with balance tasks, hand & ball skills, especially without visual and proprioceptive input

More severe impact:
complete bilateral vestibular loss before independent walking

Complete bilateral vestibular loss ≈ severe neurological problem

Kaga 1999; Rine et al. 2000; Cushing et al. 2008; Wiener-Vacher et al. 2008, 2012; Shall 2009; Hartman et al. 2011; Jafari & Asad 2011; Livingstone and McPhillips 2011; De Kegel et al., 2012; Inoue et al. 2013; Maes, et al. 2014; Wolter et al. 2016

VESTIBULAR SYSTEM

- Several studies have investigated the relationship with and the involvement of the vestibular system in the motor and cognitive development of school-aged children and shown that children with known difficulties in motor and/or cognitive functions have more difficulties in vestibular performances in comparison with their unaffected peers.

SCHOOL PERFORMANCE

- Decreased attention & concentration span

- Reading, writing and learning disorders
  - Disturbed gaze stabilization ((lip)reading, writing)
  - Disturbed postural control (fine motor control)
  - Disturbed spatial orientation & reasoning capacities (drawing, building, puzzling, calculating)

Dyscalculia and vestibular function

P.F. Smith *

Dept. Pharmacology, University of Otago, Dunedin, New Zealand

Background: A few studies in humans suggest that changes in stimulation of the balance organs of the inner ear (the 'vestibular system') can disrupt numerical cognition, resulting in 'dyscalculia', the inability to manipulate numbers. Many studies have also demonstrated that patients with vestibular dysfunction exhibit deficits in spatial memory.

Objectives: It is suggested that there may be a connection between spatial memory deficits resulting from vestibular dysfunction and the occurrence of dyscalculia, given the evidence that numerosity is coupled to the processing of spatial information (e.g., the 'spatial numerical association of response codes ('SNARC') effect').

Results and Conclusion: The evidence supporting this hypothesis is summarised and potential experiments to test it are proposed.

Evidence that vestibular hypofunction affects reading acuity in children

Jennifer Braswell [a,*], Rose Marie Rine [b,1]

Objective: Despite reported gaze stability deficits in children with hearing impairment and concurrent vestibular hypofunction, the reading difficulties reported in this population have not been linked to the gaze instability. The purpose of this study was to develop a modified version of the MNREAD chart that enabled responses orally or using sign language.

Methods: Seventy-two typically developing children and 14 children with sensorineural hearing loss with and without vestibular hypofunction participated. We examined: (1) reliability and age related changes in reading acuity scores, (2) the effect of vestibular hypofunction on reading acuity scores, and (3) the relationship between these scores and a test of dynamic visual acuity.

Results: The test was reliable (ICC (3,2) > 0.86). Reading acuity scores were significantly worse in children with vestibular hypofunction ($p \leq 0.002$). Furthermore, reading acuity scores correlated with dynamic not static visual acuity scores ($r = 0.55$, $p < 0.001$).

Conclusions: These results imply that the gaze instability due to vestibular hypofunction affects reading ability in young children.

- Overlap with dyslexia, dysgraphia, dyscalculia?
- In hearing-impaired children: often associated with impaired language development

Lovásco 1988; Braswell & Rine, 2006; Rine et al. 2013; Sauc et al. 2013; Wiener-Vacher et al. 2013; Janky & Givens, 2015; Janky et al. 2015; Cerny et al. 2015

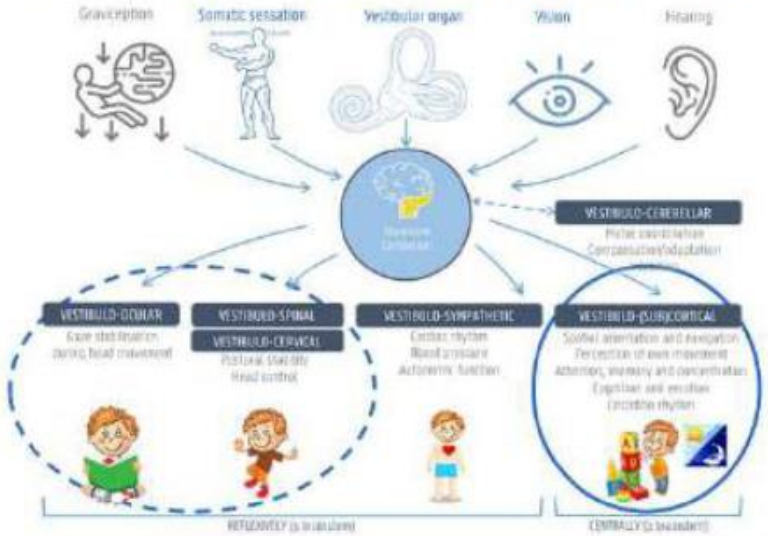
VESTIBULAR SYSTEM

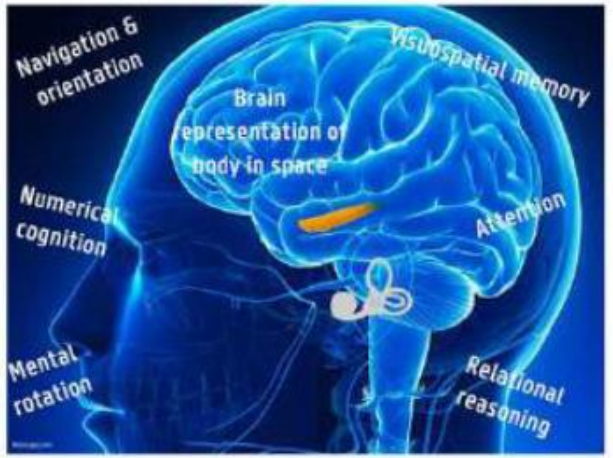
COGNITIVE DEVELOPMENT

- Problems with multi tasking, loss of concentration/attention, disorientation (disturbed visuospatial capacities), memory loss

- **DIRECT** WAY => central vestibular projections (HIPPOCAMPUS)

- **INDIRECT** WAY => less cognitive reserve





More severe impact:
complete bilateral vestibular loss before independent walking

Levinson, 1988; Bense et al, 2001; Brandt et al., 2005; Smith et al., 2005, 2010, 2017; Hanes et al., 2006; Franco & Panhoca 2008; zu Eulenburg 2012; Wiener-Vacher et al., 2012, 2013; Rine et al. 2013; Hitier et al. 2014; Bigelow et al. 2015; Bigelow & Agrawal, 2015; Dieterich & Brandt et al., 2015; Göttlich et al., 2016; Kremmyda et al., 2016

VESTIBULAR SYSTEM

PSYCHOSOCIAL DEVELOPMENT

- Anxiety, concentration/attention problems, avoidance behavior, depression, exhaustion, panic reactions, incomprehension of symptoms

- DIRECT WAY => central vestibular projections => LIMBIC SYSTEM

- INDIRECT WAY => multi tasking

BEHAVIORAL PROBLEM

Dependent on cognitive & emotional capacities

"autism spectrum disorder" (ASD)	"attention deficit hyperactivity disorder" (ADHD)
FEAR	AGRESSION

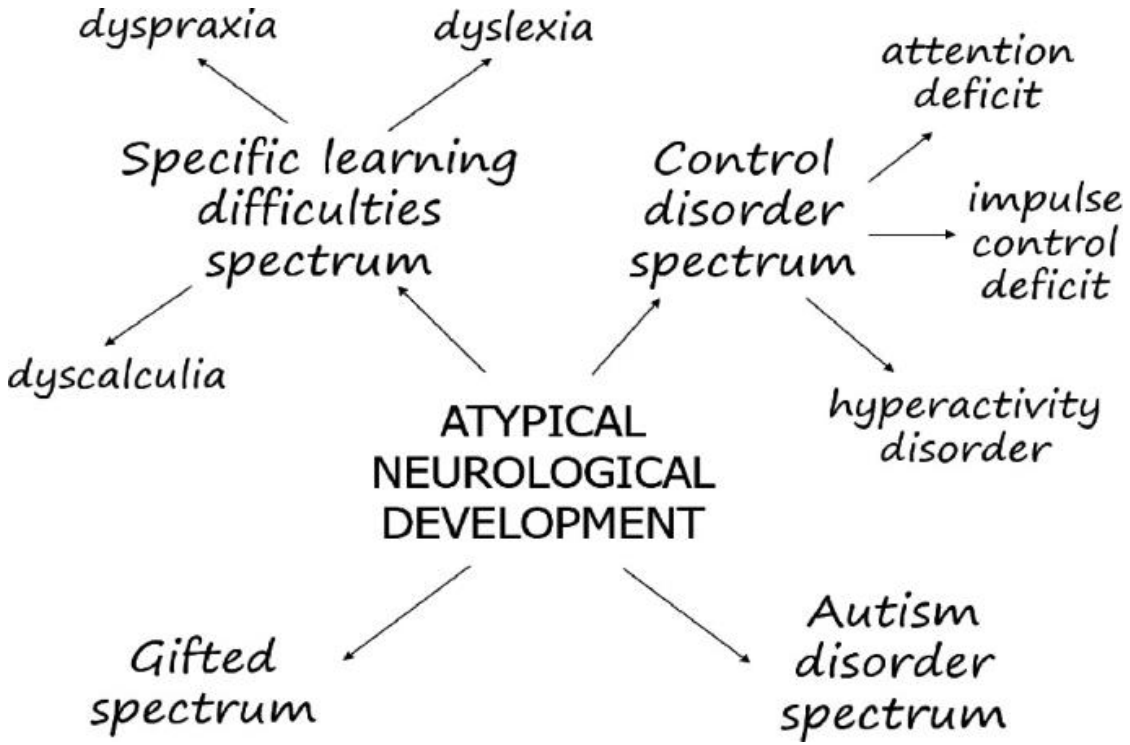
NEURODEVELOPMENTAL DISORDERS (NDDS)

NEURODEVELOPMENTAL DISORDERS (NDDS)

- Neurodevelopmental disorders (NDDs) encompass a group of complex conditions with onset during the early developmental period. Such disorders are frequently associated with a number of neuropsychiatric features.

The most prevalent ones:

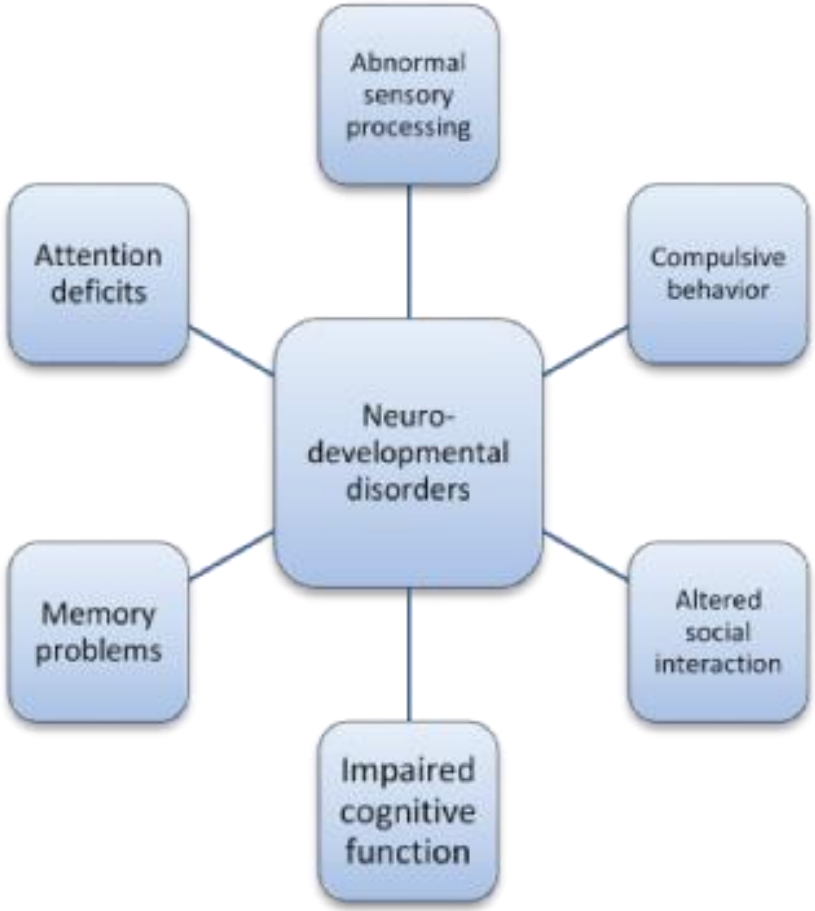
- autism spectrum disorder
- attention-deficit/hyperactivity disorder
- intellectual disability
- communication and
- specific learning disorders
- motor disorders



NEURODEVELOPMENTAL DISORDERS (NDDS)

Children with neurodevelopmental disorders can experience difficulties with:

- language and speech
- motor skills
- behavior
- memory
- learning
- or other neurological functions



VESTIBULAR FUNCTION & NDDS

- Vestibular dysfunction is associated with a range of problems, which may affect motor, cognitive, and behavioral development and which tend to overlap with symptoms found in neurodevelopmental disorders (NDD).

- In children with neurological or neurodevelopmental conditions, vestibular disorders may co-exist with the primary condition and further contribute to disability and restriction in functional independence and participation.

VESTIBULAR FUNCTION & NDDS

- Whether these balance problems are accompanied with a (peripheral and/or central) vestibular dysfunction which may contribute to the phenotype or behavioral features of these NDDs?

- Awareness of vestibular disorders existence may favor an early diagnosis and better treatment outcomes in children with NDDs .

- In recent years it has become accepted that identifying and treating vestibular dysfunction early in childhood is important for optimizing development.

IMPORTANCE OF EARLY DETECTION & REFERRAL

EARLY DETECTION & DIAGNOSIS

- Information and counseling for parents
  - Vestibular problem may explain (part of) the developmental problems (NOT clumsy, behavioural problem, neurological problem, …)
  - Provocation and avoidance of specific (dangerous) situations
  - Optimalisation of intact sensory input systems
- Early and appropriate rehabilitation

LATE DETECTION & DIAGNOSIS

- Unnecessary doctor visits
- Anxiety in parents
- Inadequate therapy
- Frustration in children
- No optimal development


CONCLUSION

RISK POPULATIONS

Standard, extensive vestibular assessment in at risk populations

Inner ear malformations (CHARGE, Pendred, aplasia n.VIII, ...)	TORCH infections (!cCMV!) Meningitis	Prematurity
Sensorineural hearing loss	Cochlear implantation	Vestibular symptoms (vertigo, delayed motor development, ...)

RED FLAGS

Delay / stagnation / deterioration in the motor development

Difficulties walking on unstable surfaces

Afraid in the dark

Frequent falling

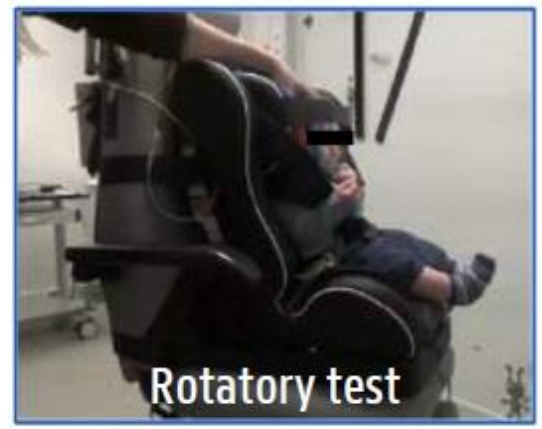
Difficulties with detecting gravity (bottom and back sliding)

ADJUSTMENTS FOR CHILDREN

Laryngoscope. 2019 Feb;129(2):490-493. doi: 10.1002/lary.27255. Epub 2018 Nov 5.

Vestibular assessment in the pediatric population

Dhondt C[1], Dhooge I[1,2], Maes L[3,2].



vHIT, video Head Impulse Test; cVEMP, cervical Vestibular Evoked Myogenic Potentials; oVEMP, ocular Vestibular Evoked Myogenic Potentials

THERAPY

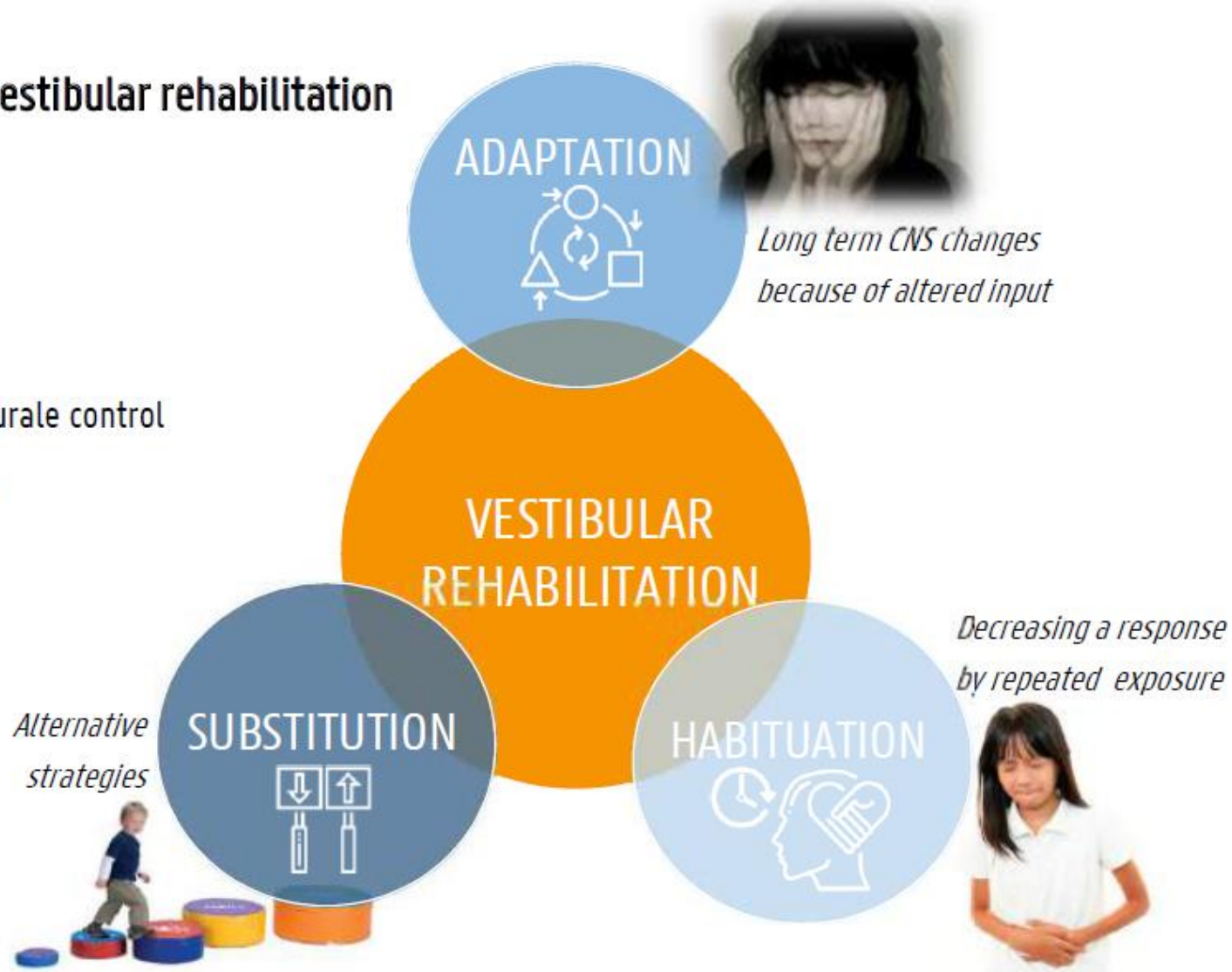
Early development => Stimulation of motor development

=> Increase postural control & muscle tonus, based on neural plasticity

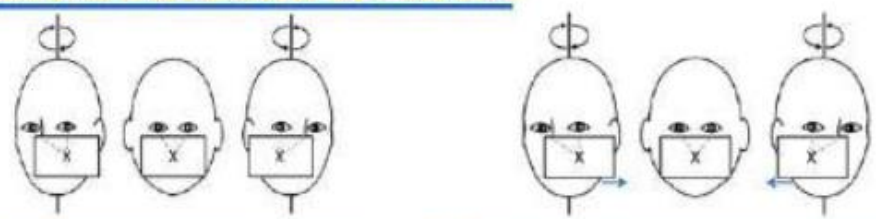
THERAPY

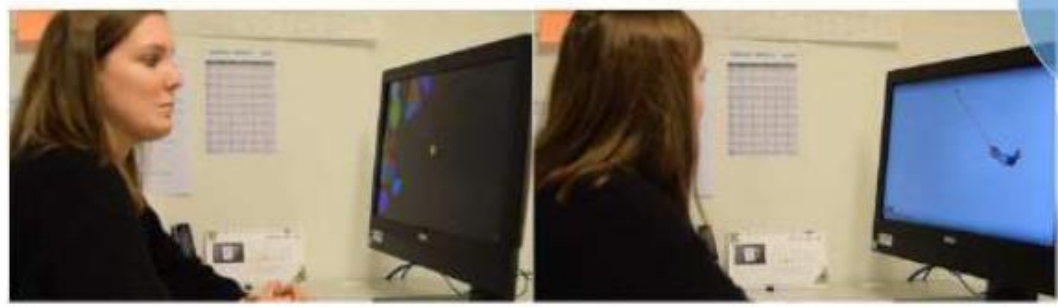
Later development => Vestibular rehabilitation

- Improve balance and posturale control
- Improve gaze stabilisation
- Reduce symptoms



GAZE STABILISATION

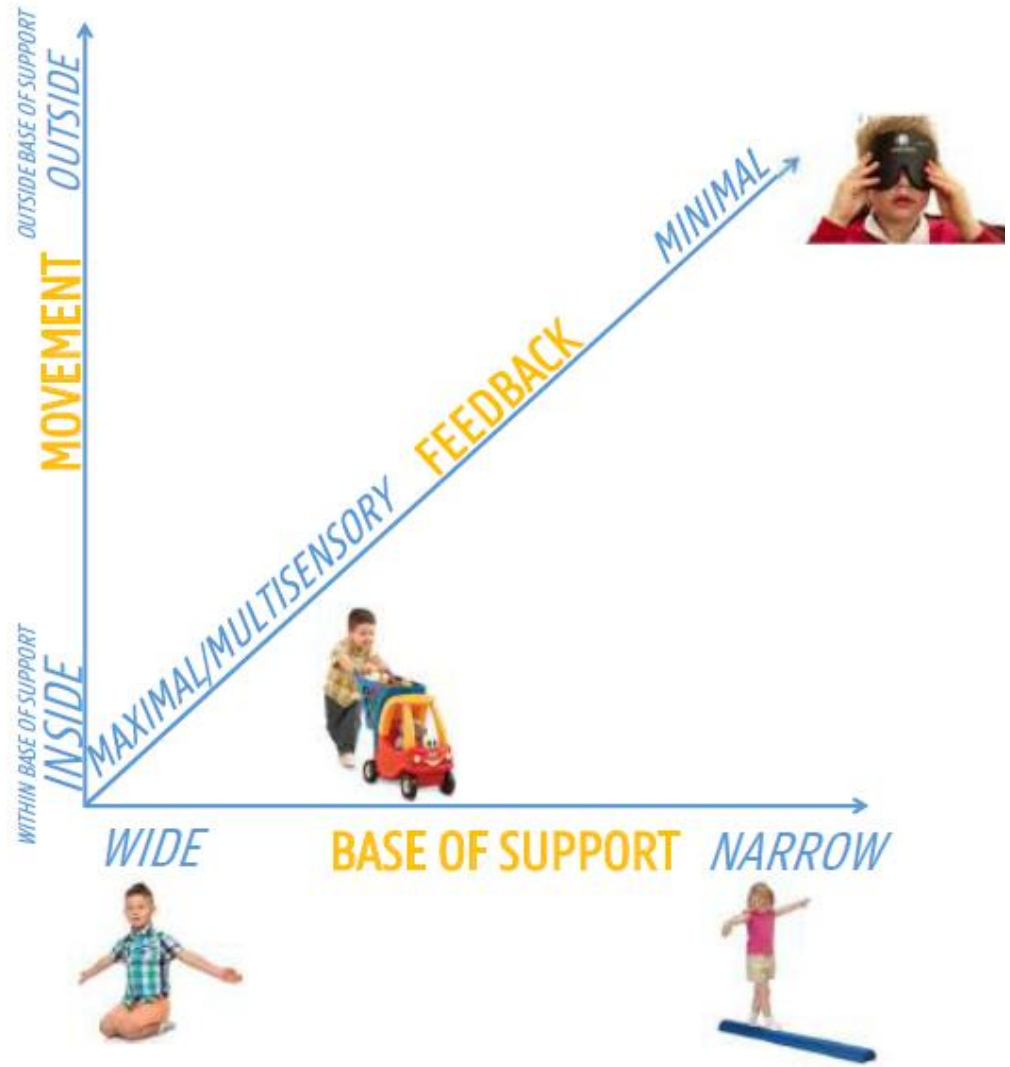




ADAPTATION

SUBSTITUTION

POSTURAL CONTROL



ADEQUATE VESTIBULAR FUNCTION IS IMPORTANT FOR DAILY FUNCTIONING

THANK YOU FOR YOUR ATTENTION!