Maturation and evolution of the vestibular system

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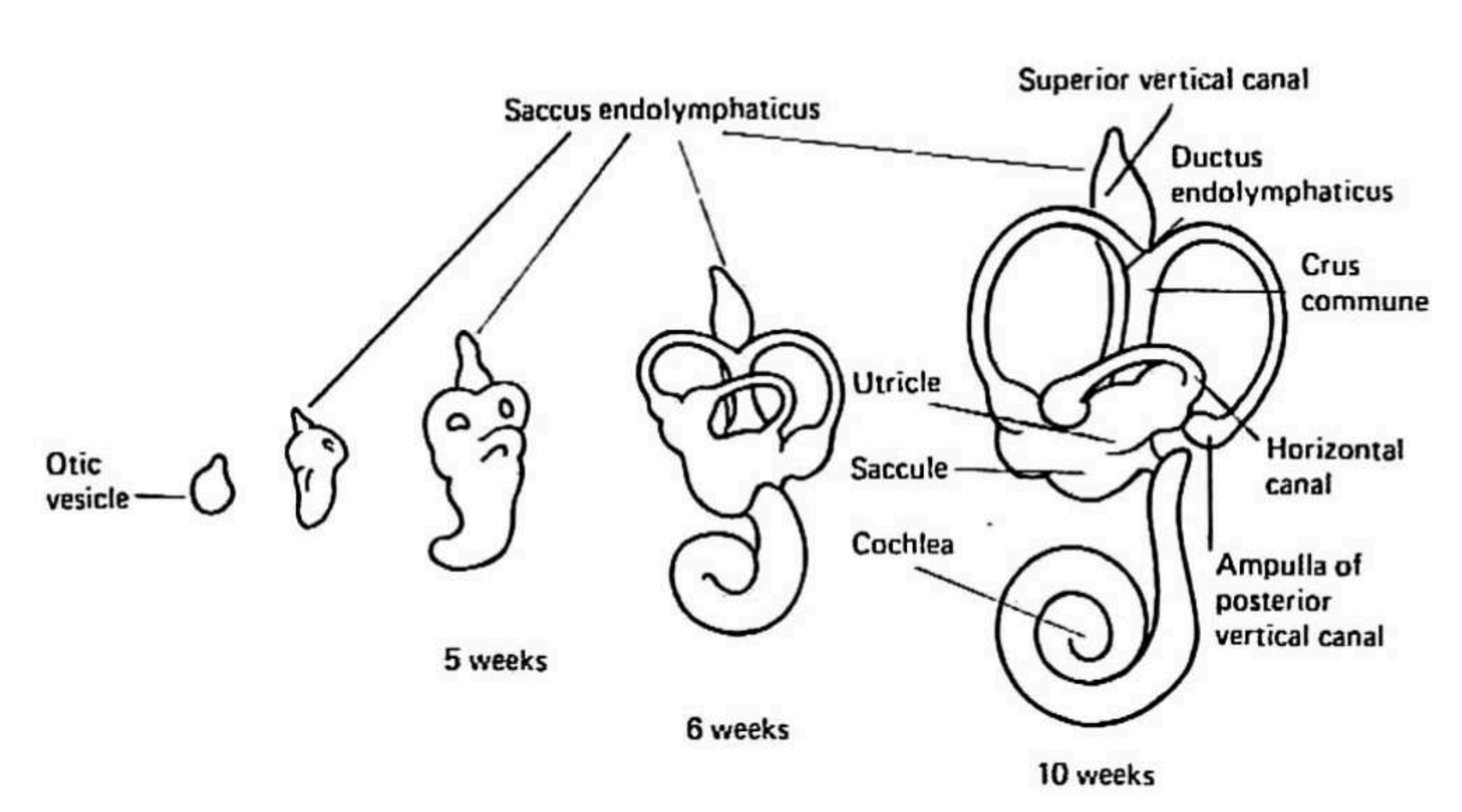
The vestibular system in humans is the first sensory system to develop .

Morphogenesis of the vestibular apparatus is complete by the 49th day in utero, and neural connections between the labyrinths and the oculomotor nuclei in the brainstem occur between the 12th and 24th weeks of gestation.

The vestibular nerve is the first cranial nerve to complete myelination and the system itself becomes functional in the 8th to 9th month of intrauterine life.



At birth the system is morphologically complete.

In the normal course of events, vestibular function is present at birth, but continues to mature so that it is most responsive between 6 and 12 months of age.

Subsequently, vestibular responses are gradually modulated by developing central inhibitory influences, cerebellar control, and central vestibular adaptation .

The normal, gradual reduction of vestibular responses carries on until adult values are achieved by 10 to 14 years of age

The newborn infant adapts to the influence of gravity through a series of steps over time, first acquiring head control and, as spinal muscles develop, learning first to sit and finally to stand and walk (Sidebotham, 1988).

Maturing vestibular function in children can be related firstly, to general motor development and secondly, the ability to stabilize vision during head movements.

In terms of motor development, the newborn infant when held ventrally with a hand under the abdomen, cannot hold his head up.
By six weeks of age the head is held in the plane of the body and by 12 weeks, above this level.
Head control allowing the baby to look around in a horizontal plane is achieved by 16 weeks of age, and by the 36th week he or she is able to sit unsupported for a few minutes.
By the age of one year the child is able to crawl on hands and knees and stand up holding on to furniture. At about 15 to 16 months of age the child is normally able to start walking, albeit with uneven steps

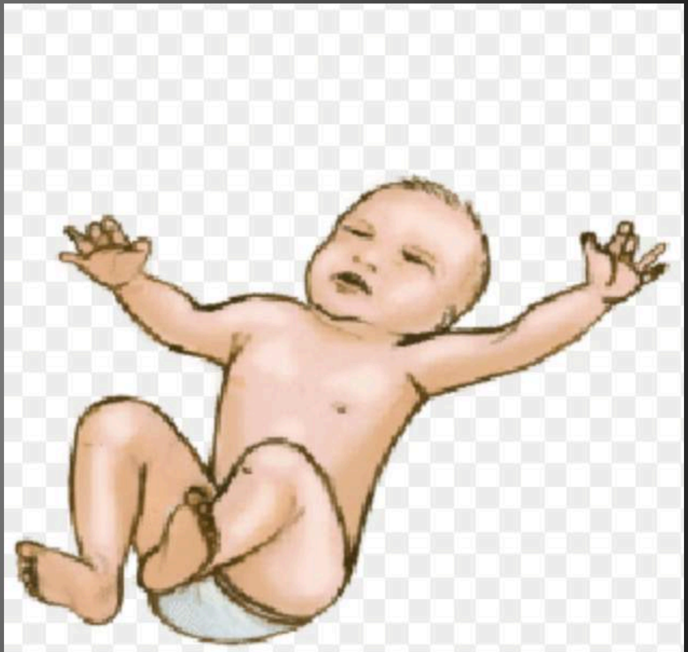
With maturation of physiologic processes and anatomical structures, certain developmental reflexes (often present at birth, disappearing as the child matures) can be elicited, aiding assessment of the developing nervous system.

These reflexes are primitive in nature and primarily reflect the integrity of the brainstem and spinal cord

The Moro reflex

It is an infantile reflex normally present in all infanta newborns up to 3 or 4 months of age .

It is elicited by holding the child supine and allowing his/her head to drop approximately 30gradi in relation to the trunk.
Extension and abduction of the arms with fanning out of the fingers followed by extension of the arms and tensing of the back muscles .



The tonic neck reflex is a primitive reflex found in newborn humans that normally vanishes around three months of age.

It is tested by turning the head to one side while the child is lying supine with the shoulders fixed.

The arm and leg towards the side that the head is turned to extend, while the arm and leg on the opposite side flex.

The head righting reflex

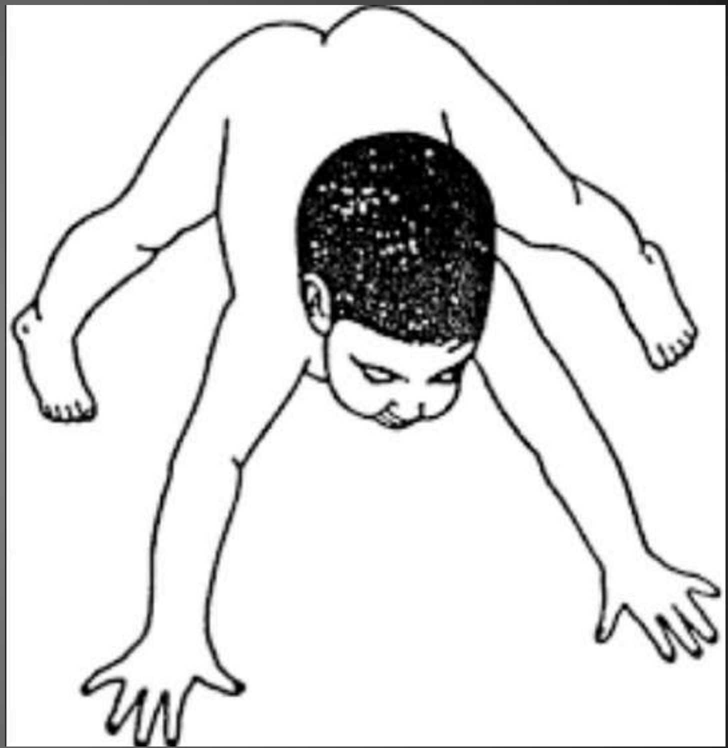
It develops by the age of four to six months. If the child's trunk is held 30° from the vertical, the infant will tilt the head so that it remains vertical.

At about five months the child will additionally move away his/her lower limbs from the side to which he/she has been tilted.

This reflex is elicited by rapidly changing the centre of gravity of the child, thus bringing about a vestibular response resulting in ‘head righting’.

It reflects functional integration of visual, vestibular and proprioceptive stimuli

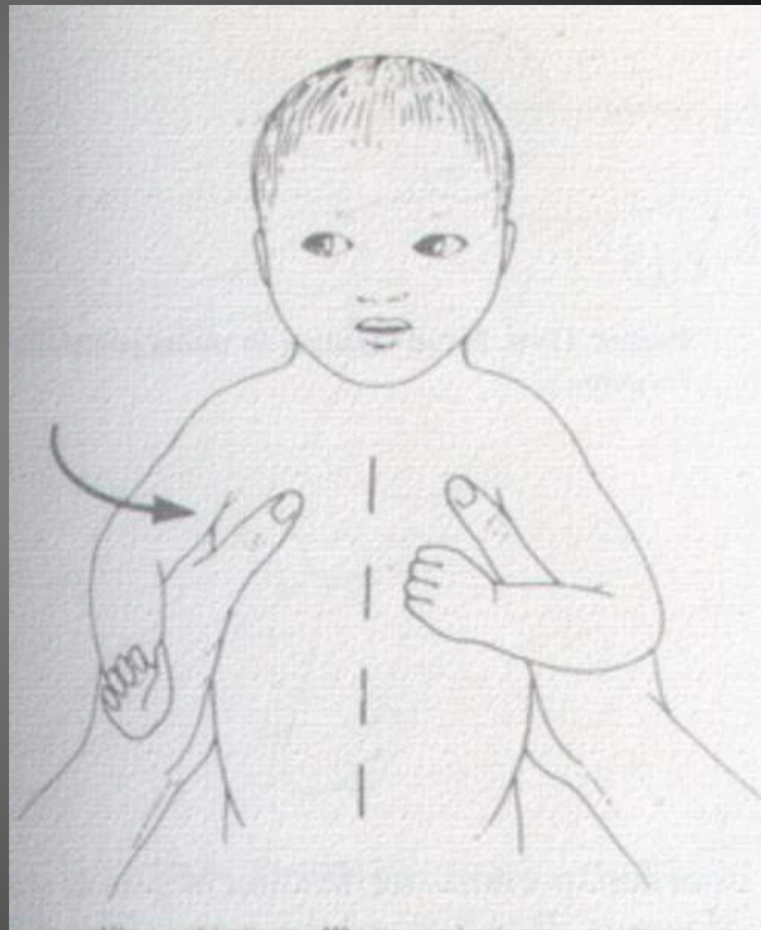
The ‘parachute reaction’ is elicited above the age of five months when a sudden downward movement of a vertically held child causes the lower limbs to extend and abduct. It is considered to represent visual-vestibular interaction (Blayney, 1997) with the otoliths presumably involved.



The ‘doll’s eye response’ is found normally in full-term babies within two weeks of birth.

When the baby (facing the examiner) is held at arm’s length and rotated in one direction around the examiner, a deviation of the eyes and head opposite to the direction of the rotation is produced, representing vestibular activity.

Due to an immature saccadic system at this stage the fast component of a normal nystagmic response is not seen. Later, however, nystagmus is apparent with the fast component in the direction of rotation



The vestibulo-ocular reflex in neonates aged from 24 to 120 h is poor, but normalizes by 2 months of age and then matures further in the first 2 years of life.

The balance control is still under maturation between 6 and 12 years, especially due to an improvement in using vestibular and visual inputs.

These late maturation processes coincide with the ultimate development of several visual functions like saccade latency or contrast or chromatic sensitivity which do not asymptote to adult level until about 12 years of age

No direct correlation could be demonstrated between the decrease in VOR gain and the increase in global balance control:

VOR is a fast buckle implying few synapses, while the postural control requires complex integrations.

All sensory inputs mature progressively during childhood, resulting in a better global postural control. Somesthetic sensation is the earliest function to mature, whereas vestibular and visual functions mature progressively until 12 years at least.

Vestibular maturation does not only imply VOR but also vestibulo-spinal pathways that are of major importance in the control of balance. The maturation of VOR gain to an adult normal level is probably due to the development of the cerebellar inhibition.

Maintenance of postural stability and balance when walking requires rapid processing of signals from the vestibular, visual, and proprioceptive–somatosensory systems.

Because balance is a function of multiple sensory systems, imbalance can occur when there is dysfunction in any one or several of the individual systems.

Neurophysiologic data demonstrate an age-related degeneration of the human vestibular periphery.

A decline in the vestibulo-ocular reflex in people older than 75 years compared with a younger group has been well-documented.

Comparisons of the initial linear vestibulo-ocular reflex demonstrated a prolonged latency and reduced occurrence of vestibular catch-up saccades in people older than 55 years of age compared with young adults ranging from 18 to 31 years old.

In a longitudinal assessment of older people, there was a significant correlation between decreases in VOR gain, optokinetic gain with decreases in Tinetti gait and balance scores over the long period of follow-up.

There is evidence that the age-related decline in visual-vestibular function is associated with a clinical decline in gait and balance.

The neuronal and sensory hair cells of the vestibular system are “fixed postmitotics” that are likely unable to regenerate in the mammalian model.

Hair cells have been classified into two types based on morphologic characteristics, which likely also have specific physiologic characteristics. Type I hair cells are globular or flask-shaped and surrounded by an afferent terminal. The type II hair cell is cylindrical and innervated by multiple afferent boutons. Movarec and Peterson postulated that the differential bundle mechanics and mechanotransduction currents of the type I versus the type II hair cells may be secondary to differential stereocilia number. In addition, there are likely functional specializations of the afferent fibers.

An age-related differential loss of hair cell type or of afferent fiber could affect vestibular physiology and thus, correspondingly balance function.

Significant cell and neuronal loss with increasing age has been documented in the saccule, utricle, and cristae ampullares of the vestibular periphery, as well as the primary afferent neurons, Scarpa’s ganglia, and its afferent nerves.

Earlier studies did not distinguish between type I and type II hair cell loss secondary to the inherent difficulty of preserving the vestibular neuroepithelium.

Richter reported decreasing density after the age of 50, with relative sparing of the utricle compared with the saccule and cristae ampullares.

Rosenhall compared densities of two age groups, one ranging from 17 to 40, and the second group consisting of adults older than 70 years old. There was a 24% decrease in hair cell density in the saccule, a 40% decrease in the cristae, and a 21% decrease in the utricle.

Using density measurements to extrapolate a total hair cell count, Rosenhall reported 7,800 total hair cells in fetal crista ampullaris and 4,700 in older adults of age ranging from 71 to 95 years old.

Merchant et al used the Abercrombie method50 to obtain density measurements in the vestibular endorgans using archival human temporal bones, reporting a gradual continual loss of vestibular hair cells in all endorgans with relative sparing of the utricle, and greater loss of type I than of type II vestibular hair cells with increasing age.

Regional estimates revealed that supporting cells and hair cells were packed more tightly in the periphery; furthermore, that although there was significant age-related hair cell loss in the periphery and the central zones, the intermediate zone appeared to be spared.

Of note, there was no significant effect of age on the dimensions of the crista ampullaris.

Animal studies have also demonstrated an age- related decline in horizontal crista hair cell density of 30%, with an associated mild loss in the VOR gain at 0.8 Hz in the senescent C57BL/6 mouse.

Given that the age-related VOR dysfunction is dependent on velocity of rotation, it is possible that this is secondary to a differential loss of either hair cell type, or of vestibular afferent type.

The clinical significance of the age-related decline in hair cell number remains unclear.

However, the loss of horizontal cristae hair cells in the late 70s and beyond 58 corresponds with the age at which the decline in the VOR has been noted.

The decrement in the VEMP amplitude may reflect the loss of vestibular hair cells in the saccular macula. In a study using the Abercrombie method, an 27% loss of hair cells was noted in the saccular macula after 80 years old.

With regard to the utricle, Rosenhall reported a 21% decrease in hair cell density of the utricle when comparing adults of age ranging from 71 to 95 years old compared with those younger than 40 years old.

degree of age-related sensory hair cell loss in the horizontal crista than that occurring in the utricle.

Of note, in contrast with Rosenhall, in our study there were only two individuals younger than 80 years old, a 42-year-old and a 67-year-old.

Thus, we cannot rule out a lesser degree of age-related hair cell loss in the utricle.

AGE-RELATED LOSS OF PRIMARY AFFERENT VESTIBULAR NEURONS AND NERVE FIBERS

Other potentially age-related alterations in morphometric measures that may affect the VOR response include a loss of neurons in the primary afferent Scarpa's ganglion.

demonstrate an age-related loss of Scarpa's ganglion neurons, with a gradual decline of 23% comparing the oldest group with infancy.

Previous studies have also demonstrated an age-related loss of vestibular afferents, with those older than 75 years having a 37% reduction compared with those age 35 years and younger.

Animal studies also demonstrate age-related vestibular afferent nerve fiber loss and alteration in function.

Kevetter and Leonard demonstrated in senescent gerbils (>36 months) that the calyx-bearing vestibular afferents

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