Chapter 7
Hearing Loss & Vestibular Dysfunction: A Common Comorbidity

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Early Development of the Vestibular System & Associated Milestones

The vestibular system is the first of the sensory systems to fully develop in utero.[1,2] Embryonic ectoderm develops into otic placodes, and as the otic placodes are surrounded by the embryonic mesoderm, they transition into otic pits.[1,2] Upon closure of the otic pits, otocysts are formed, which then develop into the membranous cochlea and vestibular labyrinth.[1,2] Beyond this, embryonic mesoderm then surrounds the vestibular labyrinth to form the bony labyrinth. At the completion of the 7th week in utero, the vestibular apparatus is formed.[1,2] The vestibular apparatus consists of three semicircular canals, which are responsible for detecting angular acceleration, as well as the utricle and saccule, which are responsible for detecting linear acceleration.[1,2]

Between the 12th and 24th weeks, neural connections between the labyrinth and oculomotor nuclei are finalized.[1,2] Additional connections between the cerebellum, reticular formation, and spinal cord also develop.[1] The vestibular nerve is the first of the cranial nerves to complete myelination with full function finalizing between the 8th and 9th month.[1]

At birth, the vestibular system is complete in structure.[1,2] It continues to mature in function over the next several weeks—demonstrating the greatest response to environmental stimuli between the 6th and 12th months of life.[1,2] Sensory inputs from multiple systems—including the visual system, somatosensory system, and peripheral vestibular system—converge within the vestibular nuclei and cerebellum.[1,2] Connections to the muscles of the eyes and neck, as well as the spinal cord, produce nearly immediate responses within the body.[1,2] The output from these afferent inputs result in the body's ability to control posture, locomotion, spatial orientation, and gaze stabilization.[1]

There are multiple developmental reflexes that are pertinent to the maturation of the vestibular system in the first 6 months of life.[2] Within the first 2 weeks of life, a doll's eye response can be elicited.[1,2] As the infant's head is rotated, movement of the eyes opposite of the rotation is observed.[1,2] This represents stimulation of the vestibular system. Beginning at 4 months of age, head righting begins to emerge.[1,2] As the infant is tipped horizontally when held, the infant lifts the head so that the head and eyes align vertically.[1,2] This represents integration of vestibular and visual input.[1,2] Head righting continues to mature over the next 2 months, and emergence of responses from the lower extremities are observed, as they lift opposite of the side that they have been tilted.[1,2] This indicates additional integration of the body's proprioceptive response.[1,2] Lastly, a parachute response can be produced by 6 months of age. When the infant is held in ventral suspension and is quickly tipped forward toward a support surface, extension of the arms and splaying of the fingers are observed.[3] This represents a protective response with resultant interaction between the visual and vestibular systems.[3]

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There are three vestibular-specific reflexes necessary for functional vestibular balance control. The vestibulo-ocular reflex (VOR) is responsible for gaze stabilization.[1,2] This is the communication between the visual and vestibular systems that results in the maintenance of clear vision of an object in front of one's self during head movements.[1,2] Although the VOR is present at birth, maturation of the centrally-mediated visual pathways is needed for full functionality.[2] This is typically present by 2 months of age, reaching full maturity between 6 and 12 months of age.[2] It is considered abnormal if a VOR has not developed by the age of 10 months.[2]

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The second of the vestibular-specific reflexes is the vestibulo-spinal reflex (VSR), which is responsible for body stabilization.[1,2] Afferent signals are received from three main sensory systems, which coordinate within the central vestibular system to maintain postural control.[1,2] The eyes provide visual input, while the vestibular input from the inner ears provides information regarding the body's linear and angular acceleration through space.[1,2] In addition, somatosensory receptors in various joints provide proprioceptive input to the central vestibular system.[1,2] The resulting output of the central vestibular system is the brain's ability to send signals to anti-gravity muscles activating equilibrium and protective responses to maintain balance control. [1,2]. These muscles counteract the downward pull of gravity, activating equilibrium and protective responses to maintain balance control with an upright posture and prevent a fall.

In addition to the VOR and VSR, the vestibulo-collic reflex (VCR) assists with both visual and body stabilization.[1,2] The VCR utilizes co-contraction of the cervical muscles in the neck to stabilize the head while the body is moving.[1,2] This is most notable during predictable movements, as is demonstrated while one is ambulating.[1,2] However, the VCR is also functional during movements that are unpredictable.[1,2]

The functionality of the vestibular system in a growing child is dependent on the integration of the physiologic performance of the above vestibular reflexes.[1,2] Balance control develops in a cephalo-caudal fashion, with head control maturing

Multiple studies have looked at the integration of the sensory systems by age utilizing both computerized dynamic posturography as well as foam posturography.

first followed by the ability to sit, stand, and walk independently.[2] Head control progresses throughout the first 4 months of life. This is demonstrated as the infant progresses from holding the head in line with the body, to holding the head above the plane of the body, and finally holding the head steady while rotating the neck to visualize the environment around him.[1,2]

The ability to sit independently is normally achieved by 6 months of age in the typically developing child. It is most definitely a building block for the attainment of more advanced gross motor skills, including standing and eventually walking. It is also of utmost importance in that it allows the infant to reach and play, which is necessary for the development of fine motor and cognitive skills.[4] In order to maintain balance while sitting, the infant must demonstrate the ability to integrate sensory input from all three systems (visual, vestibular, and somatosensory) for proper execution of protective and equilibrium responses when stimulated. The ability to maintain this upright posture is challenged by the:

- Surrounding environment.
- Infant's own biomechanics.
- Task the infant is trying to complete (i.e., play)[4].

The infant who has developed the skill of independent sitting is constantly weight shifting and utilizing degrees of freedom to maintain an upright posture.[4] Studies show that infants are most dependent on visual input for maintenance of postural control during this time.[4,2] In fact, a change in somatosensory input (sitting on compliant foam vs. even ground) in an infant who has already attained independent sitting—but who is not yet mobile—does not result in an increase in sway, unlike what is seen in standing adults.[4] This indicates that infants utilize not only visual input but perhaps also vestibular input prior to somatosensory input for balance control while sitting.[4]

As an infant transitions from learning to sit independently to learning to stand independently, the interpretation of somatosensory input proves to be very valuable. Even slight somatosensory input to the infant's hand on a support surface improves upright posture by decreasing postural sway, which is why infants rely on holding onto furniture prior to hands-free standing.[5] The ability to stand while having hand(s) on a support surface develops between 10 to 12 months of age.[5] Independent walking is attained in the typically-developing child between 12 to 15 months of age. It is during these months that the child's balance transitions from static to dynamic, which molds the functional balance control of the child.[5] Responses to sensory input build upon past experiences. This allows the infant to transition from being reactive to proactive with balance control while ambulating.[5]

Multiple studies have looked at the integration of the sensory systems by age utilizing both computerized dynamic posturography as well as foam posturography.[6-8] As stated earlier, the visual system is the primary sensory system utilized by infants, which continues through the toddler and preschool ages up to age 5.[5-8] Per posturography testing, it appears that the visual system is fully integrated for balance at age 5, as the child can adapt to changes in the visual surround at this age.[7] At 7 years of age, the child has fully integrated individual visual and somatosensory input; however, continues to have difficulty maintaining balance during conditions that create a sensory-conflict for the vestibular system. This occurs when vision is occluded (eyes closed) and somatosensory cues are inaccurate (surface is responsive to the child's sway), pushing the peripheral vestibular system to provide input to the brain for maintenance of upright stance.[7] By 9 years of age, the child can stabilize himself during these sensory-conflict conditions, which solely test the input of the peripheral vestibular system.[7] Changes in postural control during these conditions are not observed at age 12, indicating that integration of all sensory inputs to maintain stance may be fully mature as early as 9 years of age.[7]

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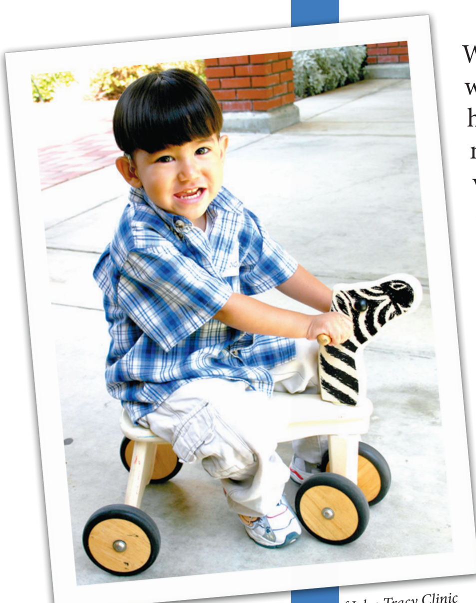
Vestibular Dysfunction in the Literature

Understanding the typical development of the vestibular system and balance constructs is critical for identifying vestibular impairment and the effect it can have on an individual. While the prevalence of vestibular disorders in children is thought to be low in the general population (from 0.5 to 5%[9-10]), it should be noted that children with balance and vestibular disorders frequently do not complain of dizziness or balance difficulties. This may be due to the inability to describe the sensation or perhaps not realizing the symptoms are not typical of everyone. Many children are able to accommodate for—and mask—their balance deficits much more rapidly and readily than adults[9]. The prevalence of vestibular dysfunction in children is likely much higher than reported in the literature. The challenges associated with recognizing vestibular and balance deficits in children is compounded by the fact that the impact of vestibular dysfunction—and the outward signs and behaviors observed—may vary in this population.

Vestibular Dysfunction & the Relationship to Hearing Loss



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While recent estimates of children with co-existing vestibular and hearing loss are high, they are not that surprising, since the vestibular and auditory portion of the inner ear are attached to each other, share the same chemical makeup, and house similar structures. Like the auditory system, the vestibular system is a membranous cavity filled with endolymph and suspended within the otic capsule by perilymph. The vestibular end organ has two types of hair cells: Type I and Type II. Similar to the auditory end organ, they become depolarized or hyperpolarized through the opening and closing of calcium and potassium transduction channels [11]. The damage from some etiologies is restricted to the auditory portion. Others (e.g., in utero infections) affect the vestibular portion as well.

Several etiologies of hearing loss are more likely to be accompanied by vestibular loss. In general, those that are related to cochlear malformation, infections, and syndromes seem to have a higher prevalence of vestibular dysfunction. Acquired hearing loss can also have effects on vestibular function. Particularly, bacterial meningitis, progressive hearing loss related to Enlarged Vestibular Aqueduct Syndrome, and some chemotherapeutic agents can alter vestibular function. Children with etiologies, such as CHARGE association and cochlear nerve aplasia, often have no vestibular function due the absence of vestibular structures. Some centers have set up standardized protocols to address the balance function of children with the most common forms of vestibular loss related to hearing. *Table 1* outlines a literature review of some common etiologies for vestibular dysfunction related to hearing loss.

Because the effects of vestibular loss on an individual are now being recognized, efforts are underway to identify children with vestibular dysfunction early so that they may receive intervention and vestibular rehabilitation as young as possible.

Impact of Vestibular Dysfunction on Children with Hearing Loss

Some children may compensate for vestibular dysfunction and show little to no effect on activities of daily living, while others may be greatly affected. This can be evident early on if critical gross motor milestones are not being met. In fact, it is well reported in the literature that infants and toddlers with co-existing hearing and vestibular impairment are delayed in reaching their developmental milestones. These children show

Table 1

Common Etiologies for Vestibular Dysfunction Related to Hearing Loss

Etiology	VNG/ Calorics Abnormal	Rotary Chair Abnormal	OVAR Abnormal	cVEMP Abnormal	Notes from the Literature	Prevalence
Enlarged Vestibular Aqueduct	X	X		X	Unilateral or bilateral	Roughly 22-63% of pediatric patients have vertigo symptoms. Patients also have reported motor delays/ imbalance. About 45-89% have abnormal vestibular test findings.
Meningitis (Bacterial)	X	X		X	Unilateral or bilateral	Ten percent of children with bacterial meningitis had vestibular dysfunction. Postural instability noted.
Cytomegalovirus (Congenital)	X		X	X		Of children who had hearing loss due to CMV, 92% were reported to have some degree of vestibular impairment. Half of these patients showed progression. Balance may be poorer and more difficult to rehab due to neurodevelopmental disabilities.
Usher Syndrome Type 1 & III	X				Postural control testing also abnormal	Usher Syndrome Type I patients have absent function of the peripheral vestibular system. Usher Syndrome Type II patients have normal vestibular system. Usher Syndrome Type III, approximately 50% have abnormal vestibular systems. Postural control is also altered in types all due to progressive vision loss and when combined with vestibular loss.
Connexin 26 & 30				X		Low prevalence reported (Innoue, 2013). Some studies use these patients as controls due to normal vestibular reflexes. Reports of normal motor milestones.
CHARGE Association	X	X		X	X	Children with CHARGE often have absent or dysmorphic semicircular canals and vestibules.

Key to specific vestibular tests:

- *VNG = **Videonystagmography.*** Central and peripheral findings.
- ***Caloric irrigations.*** Directly stimulate the individual horizontal semicircular canal.
- ***RC = Rotational Chair.*** Primarily tests horizontal semicircular canal.
- ***cVEMP = Cervical Vestibular Evoked Myogenic Potential.*** Pathway includes that of the saccule/division of the inferior vestibular nerve through the lower brainstem to motor neuron pathway measured from a muscle in the neck.
- ***oVEMP = Ocular Vestibular Evoked Myogenic Potential.*** Pathway includes that of the utricle/division of the superior vestibular nerve through the upper brainstem to motor neuron pathway measured from a muscle under the eyes.
- ***OVAR = Off Vertical Axis Rotation.*** A rotational test of otolith function.

significantly delayed acquisition of head control and independent walking when compared to deaf or hard of hearing (D/HH) children with normal vestibular function[12]. As a child ages, academic performance may also be affected. Reading difficulties often occur due to a faulty VOR. Indeed, studies show that children with vestibular hypofunction have poorer reading acuity scores than their peers with normal vestibular function[13]. Children may struggle to track words when reading a book or looking up at the board and back down to their notes. Both of those actions require a functioning VOR to maintain clear vision while the head is moving. A Brazilian study showed a statistical significance between academic underperformance and peripheral vestibular dysfunction[14]. Cognitive and memory problems have been cited in the adult literature as comorbidities of vestibular dysfunction, but this has not been explicitly addressed in the pediatric literature. So whether academic difficulty is tied to language deficits from the hearing loss, faulty VOR inputs, or issues with executive function, clinicians are taking notice of the role of vestibular function on academic success.

Children with vestibular dysfunction may exhibit difficulty keeping up with their peers in sports or physical activities. The ability to maintain upright balance while running and tracking a moving object (e.g., when trying to kick or hit a ball) is highly dependent on a working VOR.

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Safety is always a concern for these children, as they are at greater risk for frequent falls that may result in injury. Wolter and colleagues[15] linked vestibular loss and cochlear implant failure. Falling and subsequent trauma to the implant were associated with having preexisting horizontal canal dysfunction. Some less obvious indicators of vestibular loss in children may include parent report or observation of the child being “clumsy” or uncoordinated. Difficulty with learning to ride a bike or scooter is often a red flag for vestibular impairment. Clinicians often do not ask about these skills or fail to ask more probing questions that would indicate the presence of vestibular impairment. Other common indicators of vestibular impairment may include, but are not limited to, those listed in *Table 2*. Many children with vestibular loss compensate for general gross motor milestones on their own. Those who show developmental delays, underlying neurological disorders, or are D/HH are at the greatest disadvantage for full compensation[16].

Table 2
Indicators of Vestibular Impairment in Children Who Are D/HH

1	Delayed head control
2	Delay in sitting independently
3	Late onset of walking
4	Clumsy
5	Unsteady
6	Uncoordinated
7	Frequent falls
8	Difficulty walking on uneven surfaces (grass, mulch, gravel)
9	Blurry or double vision
10	Difficulty reading
11	Difficulty riding a bike, scooter, or using roller skates
12	Difficulty walking in low-light areas
13	Dizziness/vertigo

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One study of children with cochlear implants compared those with vestibular loss to those without and found that the children with vestibular loss did not recover their skills that utilized vestibular input naturally to the levels of their unaffected peers[17]. Estimates indicate that as many as 70% of children presenting with sensorineural hearing loss have some degree of impairment of their vestibular system, with 20-40% having severe bilateral vestibular loss[18]. Motor delays and reading difficulties can significantly impact overall academic achievement, social skills, and ultimate independence for the child. Therefore, early diagnosis and intervention focusing on vestibular rehabilitation is critical for these children.

Screening for Vestibular Dysfunction in Children

An innovative group of researchers from Belgium[19] are advocating for a cervical vestibular evoked myogenic potential (cVEMP) screening for all D/HH infants under 6 months of age. This noninvasive and quick electrophysiological test gives the clinician site specific information about the function of the vestibular system. It may help identify children with vestibular deficits earlier, getting them on the rehabilitation path sooner.

Many clinicians do not have access to vestibular diagnostic equipment. Several groups have been exploring simple screenings for detecting vestibular loss that pediatric audiologists can use with their D/HH patients. Tools that do not require specific lab equipment include formal questionnaires, parent interviews, and bedside screenings.

Formal questionnaires are a helpful tool, because they can be completed prior to the examination and do not require cooperation from the child. The Pediatric Vestibular Symptom Quotient (PVSQ) and the Pediatric Dizziness Handicap Inventory (pDHI) are intended for the caregiver/parent to complete[20-21]. Both of these validated questionnaires are useful when the primary symptom or concern is dizziness. In many cases of vestibular loss coupled with hearing loss, vertigo is not reported, and the effectiveness of these questionnaires declines. In fact, in the case of very young children or even older children with bilateral losses, the concern is primarily for motor development—and even less obvious to most practitioners, reading difficulty[13].

A recent study from Boystown National Research Hospital found that parent interview questions specific to motor development and concern for vestibular loss were key components to identifying children with vestibular loss who were also D/HH. Through a retrospective chart review, Janky and colleagues[22] looked at which factors were most predictive of those children who were at greatest risk for having vestibular dysfunction. They found that a combination of degree of hearing loss, family report of concerns for balance, and ages of sitting and walking independently identified the most children with bilateral vestibular losses. Specifically, using cutoff values of 66 dB HL pure tone average for hearing thresholds, 7.25 months for sitting age, 14.5 months for walking age, plus parental concern yielded the greatest chance of identifying children with bilateral vestibular loss.

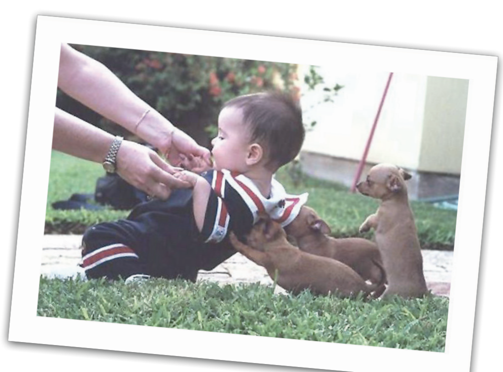

Photo courtesy of NCHAM

Once a child is suspected of having vestibular dysfunction, norm-referenced and age-specific diagnostic vestibular testing is indicated to further evaluate and identify the presence of vestibular dysfunction.

Another study by Oyewumi and colleagues[23] suggested that simply asking children approximately ages 5 and older to perform simple motor maneuvers may predict vestibular loss. The researchers looked at a specific motor proficiency test and compared children without vestibular concerns to those who had known vestibular losses. The most pronounced differences were seen in the tests that isolated the vestibular sense by removing vision and/or stable proprioception. The authors recommended performing one of the following balance tasks:

- Single leg stance eyes open
- Single leg stance eyes closed
- Tandem Romberg

They noted the most sensitive test was a single leg stance with eyes closed. Those who could not perform the task for at least 8 seconds with eyes open or 4 seconds with eyes closed were considered at-risk for having a vestibular disorder. In addition, they looked at the Tandem Romberg stance. This requires the child to stand with a narrow base of support, standing with one foot in front of the other. Maintaining balance less than 8 seconds with eyes closed was a red flag for vestibular dysfunction.

Finally, data from our own center shows balance function can be effectively evaluated through a series of bedside tests. These tests characterize more than just balance. They also assess VOR function. We worked with professionals at a local school for the deaf to evaluate the effectiveness of several bedside screening tests in identifying vestibular dysfunction. Children were administered a battery of tests, such as the head impulse test, dynamic visual acuity (DVA) screening, single leg stance, and standing on foam with eyes open and eyes closed. Approximately 39% of the children from the school referred on at least one test, with single leg stance, DVA screening, and the head impulse test being most predictive of vestibular dysfunction[24]. These easy and noninvasive bedside tests were found to be instrumental in determining which children who are D/HH should be referred for a full diagnostic vestibular evaluation.[35-51]

Vestibular Rehabilitation for Children with Sensorineural Hearing Loss

Once a child is suspected of having vestibular dysfunction, norm-referenced and age-specific diagnostic vestibular testing is indicated to further evaluate and identify the presence of vestibular dysfunction.[25-27] Vestibular testing can often validate the child's complaints or the parents' observations and concerns.[25-27] Examples of formal objective vestibular system testing include:

- Videonystagmography (VNG).
- Rotational testing.
- Video head impulse testing (vHIT).
- Vestibular evoked myogenic potential testing (VEMP).

Functional vestibular system testing includes:

- Diagnostic dynamic visual acuity (DVA).
- Tests of gross motor performance.
- Posturography (foam and computerized).[25]

The purpose of vestibular rehabilitation is to improve these objective measurements with respect to the child's function. Specifically, vestibular rehabilitation is indicated to improve balance, gaze stabilization, and gross motor skills.[25-27] Peripheral vestibular complaints or symptoms vary based on whether or not the dysfunction is unilateral or bilateral.[25-26] The child's ability to verbalize symptoms or demonstrate avoidance behaviors to provoking situations can give insight into the components of vestibular rehabilitation that will be appropriate for each child.[25] Vestibular rehabilitation is vital for children who present with balance deficits to reduce the impact on socialization with peers, cognitive skills, and reading in the school-aged child.[25-26]

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Components of Vestibular Rehabilitation

There are three components of vestibular rehabilitation well documented for use in the adult population that can be adapted for use in the pediatric population:

1. Habituation
2. Adaptation
3. Substitution

Habituation utilizes repeated exposure to positions and movements (body and head) that provoke dizziness and vertigo.[25] It is first necessary to formally identify the provoking positions and movements. This allows the physical therapist to streamline habituation exercises in a progressive manner comfortable for the child, thereby decreasing the child's dizziness or vertiginous symptoms and increasing tolerance to the provoking positions or movements. Habituation is vital for children with position-provoking dizziness or vertigo, as they often avoid age-appropriate play and recreational activities, limiting social interaction with peers.[25-26]

Adaptation of a dysfunctional and/or asymmetric VOR is another component of vestibular rehabilitation.[25] Specifically, adaptation of the VOR facilitates the vestibular system's ability to make long-term changes to the neuronal response with visual and peripheral vestibular input. The functionality of the VOR is measured with DVA testing, which identifies how well the child can visualize an object in front of them during head movements. DVA testing is warranted when there are complaints of oscillopsia (blurry vision when head is in motion) or when reading difficulties are noted in the school-aged child, as VOR training can improve both.[25] DVA testing evaluates gaze stabilization in horizontal and vertical planes by having the child move their head back and forth in the horizontal plane or up and down in the vertical plane while trying to identify the direction in which the letter E is facing. When gaze stabilization is dysfunctional due to VOR impairment, specific vestibular rehabilitation exercises are used to strengthen neural connections in the visual system. They are designed to overcome the lack of input to the VOR from the vestibular system when the head is in motion.

Physical therapy trains the child in a progressive fashion. Formal VOR x 1 training for adults requires the patient to rotate the head as fast as possible while maintaining focus on a stationary object in front of them.[25,27] The pediatric vestibular rehabilitation physical therapist must get creative with children in order to ensure they are properly performing the exercise and adapting the VOR. Utilization of flashcards and favorite books as the stationary object while prompting head movements by the child in the appropriate plane are ways to promote adaptation of the VOR.[25, 27] As the child improves their function with the VOR x 1 exercise, progressions are made to move the objects of focus, which requires a quicker response of the eyes during head movements.[25, 27]

Photo courtesy of Centers for Disease Control and Prevention

Further progression includes horizontal eye-head movements (i.e., gaze shifting) while walking. The use of technology (i.e., tablets with visual seek-and-find games) are often stimulating for children and can be used in multiple environments.[25, 27] These strategies and tools increase the likelihood of success for the child's home exercise program, as they make the routine of the daily exercise regimen a fun experience.

Substitution is the final component of vestibular rehabilitation. This involves training the visual and somatosensory systems to substitute for a lack of peripheral vestibular function.[25] Visual and somatosensory training can begin as early as infancy when balance limitations are identified in the child with vestibular deficits. For instance, for the infant who demonstrates delays with attaining independence with sitting, the pediatric vestibular rehabilitation physical therapist will promote visual focus on toys in various planes to train the visual system. As the infant progresses with balance, reaching across midline and shifting weight onto one hip in a side-sit posture will be promoted. This prompts head righting with visual-vestibular integration. Further progression includes use of a physio ball with movements in various positions while the infant is seated on the ball, visually focusing on a toy. This promotes training of the VSR with visual-postural coupling, as protective and equilibrium responses are elicited during these exercises.[28]

It is not uncommon for children with bilateral vestibular hypofunction to be delayed in independent standing and walking.

It is not uncommon for children with bilateral vestibular hypofunction to be delayed in independent standing and walking.[29-30] These children typically demonstrate resistance to letting go of the support surface to attain hands-free standing, as postural sway and the chance of falling increases dramatically. Therefore, the vestibular rehabilitation physical therapist progressively decreases the child's use of support on furniture and surrounding surfaces. As the child progresses to training with walking, small toys that can be held in the hands are utilized, so the child can feel the somatosensory input through their hands without relying on the support surface itself for somatosensory input. Once the child attains independent walking, training with horizontal and vertical head turns ensues, as gaze stabilization is often impacted in this population. Attainment of independence with walking is absolutely a vital skill for a D/HH child who may or may not already be at a disadvantage with communication skills. Vestibular rehabilitation allows the child to attain independence and safety with functional mobility in their environment, which helps to increase social interaction, play, and communication with peers.

Validity of Vestibular Rehabilitation

Vestibular rehabilitation programs and exercises for young children have been sparsely validated in the literature. However, it should be noted that pediatric vestibular disorders have become a widely recognized entity only over the past decade. There are a dozen or so studies published after the year 2000 that have attempted to quantify the improvement children who are D/HH show after receiving balance and vestibular therapies. Collectively, these papers looked at various motor control therapies, balance training, gaze stabilization exercises, and neuromuscular training. In these studies, training was often compared to placebo exercises. For example, one study compared gaze stabilization exercises to Brandt-Daroff exercises (a popular adult vestibular rehabilitation exercise) with children who were D/HH with complaints of vertigo[31]. The children who were given gaze stabilization exercises reported the largest decrease in their symptoms on a clinical test. Other studies suggest intense training of the child's balance, coordination, and hand-eye coordination could ameliorate balance concerns[32-33]. While vestibular rehabilitation exercises were reported to be effective in each of the studies, the largest limitation is that the studies only report data for children ages 3 and older[34], with most studies reporting

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results for children ages 6 and older. There is a gap in the literature regarding the effectiveness of vestibular rehabilitation for children less than 3 years of age.

While the importance of early intervention is known for so many other developmental fields, such as speech and language, auditory training, gross and fine motor training, we have yet to validate the effectiveness of early vestibular rehabilitation for the young child. As evidenced by delayed gross motor milestones and the compounding effect that delays pose, it is the opinion of these authors that it is merely a matter of time before the science catches up with the notion that children with vestibular loss can significantly benefit from early vestibular rehabilitation.

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