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Academy Clinical Consensus Statement

American Academy of Audiology Clinical Consensus Statement: Assessment of Vestibular Function in the Pediatric Population

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Abstract

Vestibular function testing is recommended in children who report dizziness and in children with imbalance or delays in gross motor milestones related to sensorineural hearing loss. This clinical consensus statement developed by the American Academy of Audiology serves as a guide for assessing vestibular function in the pediatric population and allows for expected variations in practice and available equipment. It focuses on the pediatric approach to test administration and interpretation, offers protocols and tips for testing, and provides additional information on individual tests of vestibular function. Basic, practical knowledge of vestibular testing is required to incorporate the guidance provided in this consensus statement. Children have activities of daily living that are different from those of adults, so the overall goal of assessment and intervention should be to arrive at the best recommendations to help children meet their vestibular goals without hindrance to educational, social, and developmental outcomes. As this area of pediatric vestibular testing develops, more normative data and test techniques will be included, and this guidance will continue to evolve.

Key Words: bedside, children, pediatrics, questionnaire, rotational chair, vestibular, vestibular evoked myogenic potential, videonystagmography

Abbreviations: ACS = air-conducted sound; CHL = conductive hearing loss; CI = cochlear implantation; cVEMP = cervical vestibular evoked myogenic potential; DVA = dynamic visual acuity; EMG = electromyogram; FL = force level; HIT = head impulse test; LVAS = large vestibular aqueduct syndrome; nHL = normalized hearing level; oVEMP = ocular vestibular evoked myogenic potential; SCM = sternocleidomastoid; SHA = sinusoidal harmonic acceleration; SNHL = sensorineural hearing loss; SPL = sound pressure level; VEMP = vestibular evoked myogenic potential; vHIT = video head impulse test; VNG = videonystagmography; VOR = vestibulo-ocular reflex

INTRODUCTION

In recent years, considerable attention has been given to disorders of the pediatric vestibular system. Perhaps, children with vestibular disorders have gone unnoticed in the past because they do not have the language to accurately describe symptoms of dizziness or imbalance. Children undergo an immense period of development for motor skills from birth through the teenage years and therefore require unique assessment and treatment in this area. Today, advances in the niche area of pediatric vestibular

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testing have allowed clinicians to obtain more data on young children than ever before. Empowered with new technology, techniques, and more readily accessible treatment options, audiologists can offer families more information about a child's emerging balance function and concerns for dizziness.

This clinical consensus statement is designed to serve as a guide to approaching vestibular testing in children and allows for expected variations in practice and available equipment. It also functions as a practical guide, offering protocols, tips, and tricks for testing children of all ages, specifically children whose developmental age is young. This document focuses on the pediatric approach to test administration and interpretation. See Table 1 for an overview of vestibular function tests available by age. Each of the following sections provides additional information on individual tests of vestibular function. Basic, practical knowledge of vestibular testing is required to incorporate the guidance below. As this niche develops, more normative data and test techniques will be included, and this guidance will continue to evolve.

BACKGROUND

The vestibular system is the first fully myelinated system that is completed in utero. Although it is intact at birth, the vestibular system continues to mature as the child masters control of their movement, ocular motor system, and postural stability. Vestibular testing and evaluation are warranted in two populations: (1) those who present with complaints of dizziness and (2) those with disequilibrium and/or delay in gross motor milestones. Dizziness in children represents a small patient population at about 5.3 percent (Davitt et al, 2020) of all children. Vestibular disorders in children can be either congenital or acquired and originate in the peripheral and/or central vestibular system. Specific vestibular tests are helpful in parsing out these distinctive causes.

Table 1. Overview of Vestibular Function Tests Available by Child Age

TEST	0–2 YEARS	3–7 YEARS	8+ YEARS
BEDSIDE	▪ Identification of nystagmus ▪ Head impulse test	▪ Identification of nystagmus ▪ Dynamic visual acuity screen ▪ Romberg test ▪ Tandem gait and walk ▪ mCTSIB ▪ Single-leg stance test	▪ Identification of nystagmus ▪ Dynamic visual acuity screen ▪ Romberg test ▪ Tandem gait and walk ▪ mCTSIB ▪ Single-leg stance test
QUESTIONNAIRES	Ages and Stages: Gross Motor (birth–5 years)	Ages and Stages: Gross Motor (birth–5 years) ▪ DHI-PC (5–12 years) ▪ PVIDQ (6–17 years) ▪ PVSQ (6–17 years)	▪ DHI-PC (5–12 years) ▪ PVIDQ (6–17 years) ▪ PVSQ (6–17 years)
CANAL	▪ Video head impulse test (remote camera system) ▪ Rotary chair test (electrodes, in-room camera, handheld goggles after 2 years)	▪ Video head impulse test ▪ Rotary chair test	▪ Video head impulse test ▪ Rotary chair test
OTOLITH	Cervical VEMP	▪ Cervical VEMP ▪ Ocular VEMP	▪ Cervical VEMP ▪ Ocular VEMP
VNG	▪ High-frequency headshake ▪ Skull vibration-induced nystagmus test	▪ High-frequency headshake ▪ Positional testing ▪ Skull vibration-induced nystagmus test ▪ Ocular motor test (after 5 years)	All components of VNG

DHI-PC: Dizziness Handicap Inventory for Patient Caregivers
mCTSIB: modified clinical test of sensory integration of balance
PVIDQ: Pediatric Visually Induced Dizziness Questionnaire
PVSQ: Pediatric Vestibular Symptom Questionnaire
VEMP: vestibular evoked myogenic potential
VNG: videonystagmography.

There is a higher prevalence of peripheral vestibular dysfunction in children with hearing loss. In many cases, but not all cases, the primary reported symptom is imbalance or deviation from age-appropriate motor development. It is estimated that nearly half of all children with hearing loss have some degree of vestibular impairment (Cushing et al, 2013). Children who have greater degrees of hearing loss (>66 dB) (Janky et al, 2018) or specific etiologies of hearing loss are at an increased risk. Notably, children with etiologies including structural anomalies (i.e., enlarged vestibular aqueducts, cochlear malformations), congenital cytomegalovirus, certain syndromic hearing loss (i.e., Usher syndrome type 1), meningitis, temporal bone fracture, and/or exposure to ototoxic medications experience vestibular loss more frequently (Santos et al, 2015; Martens et al, 2022).

Children with normal hearing both ears more often experience symptoms of dizziness, lightheadedness, and vertigo. The most common etiology in this group is pediatric migraine variants, which affect approximately 3 percent of all children younger than 18 years of age (Abu-Arafeh et al, 2010). Vestibular migraine of childhood represents 23.8 percent of children with vertigo, and recurrent vertigo of childhood (previously benign paroxysmal vertigo of childhood) represents 13.7 percent (Davitt et al, 2020). Probable vestibular migraine of childhood (Aguggia and Saracco, 2010) may or may not be accompanied by actual head pain but often has a migraine feature such as photophobia or phonophobia. It is hypothesized that perimeningeal vasodilatation and neurogenic inflammation cause pain and other neurological symptoms (Mohamed et al, 2015).

Children can experience, similar to adults, vestibular neuritis, labyrinthitis, postural orthostatic tachycardia syndrome, and persistent postural perceptual dizziness, among others. Etiologies that occur in children, but less frequently compared with adults, are benign paroxysmal positional vertigo, Meniere's disease, and superior canal dehiscence syndrome. In addition, teenagers, in particular, may have autonomic dysfunction, depression, anxiety, psychosomatic, amplified pain syndrome, and other mental health diagnoses as an underlying condition with dizziness.

SIGNIFICANCE OF VESTIBULAR TESTING

Vestibular testing serves to differentiate peripheral vestibular disorders from central vestibular disorders, determine the severity of a vestibular loss, and parse out any functional effects. Patterns of abnormality can vary by etiology, as well as by child, with abnormalities of the semicircular canals, otolith organs, and functional balance. Often, a normal vestibular test is still helpful in diagnosis by ruling out other issues. In children with suspected vestibular migraine, laboratory findings are varied, with the majority of children showing normal tests, followed by abnormal eye movements, abnormal ocular motor findings, and abnormal vestibular evoked myogenic potentials (VEMPs) (Rine et al, 2000; Langhagen et al, 2015).

Early intervention and appropriate differential diagnostics are important. The most common manifestation of congenital bilateral vestibular loss is a gross motor delay and, often, accompanying muscle hypotonia (Rine et al, 2004). For children who are experiencing delays related to congenital vestibular loss, intervention at an early age with qualified vestibular rehabilitation specialists is needed to aid developing milestones. Emerging studies are showing improvements in balance deficits with targeted vestibular rehabilitation in children (Eggers and Zee, 2003). In addition, it is helpful for parents to have a clear understanding of their child's diagnosis. In many cases, the role of audiological testing is part of the "rule-out" process. When medication is needed, a good working relationship with physicians, including neurologists, otolaryngologists, pediatricians, and psychiatrists, helps bridge the diagnostic gap for families.

BEDSIDE EXAMINATION

Test Names: Identification of nystagmus, head impulse test (HIT), dynamic visual acuity (DVA) test, tandem and Romberg test, modified clinical test of sensory integration of balance, and single-leg stance test.

Purposes: To evaluate basic vestibular and balance function in children, aiding clinical diagnosis and management in real time. The results of these bedside examinations can also guide further laboratory testing. Initially used for evaluating adult patients with dizziness and imbalance, these methods are valid and valuable, as clinical studies have shown (Mandalà et al, 2008; Huh and Kim, 2013; Tarnutzer and Straumann, 2018; Cohen, 2019; Tarnutzer and Dieterich, 2019). With minimal modification, these bedside examinations can be implemented in pediatric practice.

Population Intended: Pediatric patients with reported balance and/or vestibular symptoms. These bedside examination methods are also appropriate for young children who are unable to describe their problems and whose parents or caregivers have balance and/or vestibular concerns.

Expected Outcomes: Many of these bedside tests have no quantitative outcome; therefore, the outcome is mostly binary (e.g., normal vs. abnormal or present vs. absent).

Normative Data: See individual section for tests with quantitative measures.

Practice Guidance: These tests are relatively easy to perform and require no or minimal devices. Clinicians can perform the testing at the bedside, in the emergency

room, or for ambulatory services. For a detailed description of each test, see the individual section.

Test Interpretation and Reporting: Clinicians must have a good understanding of vestibular anatomy, physiology, and pathology to conduct these tests and interpret them accurately. Abnormal findings usually suggest possible vestibular pathologies; however, vestibular dysfunction cannot be ruled out based on a normal/negative finding of any individual test.

Infection Control Procedures: All testing procedures must follow universal precautions (e.g., prevention of bodily injury and transmission of infectious diseases). Decontamination, cleaning, disinfection, and sterilization of multiple-use equipment (e.g., goggles, electrode leads, seating) must be carried out at the completion of testing according to facility-specific infection control policies and procedures and according to manufacturer's instructions.

Reporting: Written interpretation of results, recommendations, and additional referrals should use language appropriate for caregivers, health care providers, educators, and other intervention providers.

IDENTIFICATION OF NYSTAGMUS

Nystagmus is involuntary rhythmic eye movement with fast and slow phases. The direction of nystagmus is named for the direction of the fast phase. Whereas horizontal (left- or right-beating) and vertical (up- or down-beating) nystagmus can be easily recognized, torsional nystagmus may be difficult to observe without goggles (Shawkat et al, 1996). It should be pointed out that abnormal eye movements are common in young children and may consist of ocular oscillation, opsoclonus, and flutter among others, which are not vestibular in origin (Halmagyi and Curthoys, 1988; Gottlob, 1997; Zhou et al, 2018).

Spontaneous Nystagmus

Because spontaneous nystagmus of vestibular origin can be suppressed by fixation, Frenzel goggles (Figure 1) are recommended. If Frenzel goggles are not available, then the light in the exam room should be dimmed for better observation. Spontaneous nystagmus often exists in cases of peripheral vestibular lesion or uncompensated vestibular loss and can be suppressed by visual fixation. In contrast, central lesions are indicated if not suppressed by fixation. Most of the time, spontaneous nystagmus is horizontal, and the direction of the nystagmus is opposite to the side of lesion (i.e., right-beating nystagmus indicating left vestibular lesion/loss, toward the more neurally active side); however, irritative nystagmus can occur where nystagmus beats toward the affected side. Spontaneous nystagmus in the vertical plane, especially down-beating, is uncommon,

Figure 1. Examples of Frenzel goggles/lenses.

and central vestibular pathology may be suspected, if present. Any nystagmus with direction and/or velocity changing also raises the concern of central involvement.

Evoked Nystagmus

Gaze-evoked nystagmus is commonly used for examining a patient with suspected vestibular impairment. Both horizontal gaze (looking to the left or right) and vertical gaze (looking up or down) can be performed. An attractive toy with flashing lights (Figure 2) can be very helpful to get the attention of a young child. A parent can hold the child's head during the exam. The toy should not be placed too far away from the center in any direction (i.e., less than 30°) to avoid eliciting end-gaze nystagmus (i.e., normally occurring nystagmus with eccentric gaze). Gaze-evoked nystagmus is often most evident or only seen with gaze in the direction of the fast phase (Alexander's law). With proper tools, sound- or pressure-evoked nystagmus can also be performed to rule out certain types of vestibular conditions.

Nonvestibular Nystagmus

It should be noted that not all observed nystagmus is vestibular in origin. For example, congenital nystagmus may be found in children without vestibular impairment. Although the pathophysiology of congenital nystagmus is not entirely clear, its characteristics (e.g.,

Figure 2. Examples of toys.

presence in infancy, being purely horizontal, diminishing with convergence, causing vision loss, etc.) make congenital nystagmus distinguishable from vestibular nystagmus.

ASSESSMENT OF VESTIBULO-OCULAR REFLEX

The vestibulo-ocular reflex (VOR) is present at birth. Although its function may not be fully matured, even infants have nystagmus in response to angular acceleration. The main role of the VOR is to maintain clear vision when the head is in motion. By observing the reflexive eye movement responding to head motion, apparent vestibular loss (i.e., loss in semicircular canal function) can be identified.

Head Impulse/Thrust

Introduced by Halmagyi and Curthoys in 1998, the HIT has been proven to be a reliable tool for identifying unilateral or bilateral loss of semicircular canal function (Janky and Rodriguez, 2018). Performing the HIT sounds easy, but mastering the technique requires proper training and practice, particularly in children. Starting with instruction to the patient to look at the clinician's eyes or nose, or a designated fixation point, the clinician then performs a brief, but quick, head thrust that turns the head no more than 15°. Impulses can be completed either away from or toward the midline. For infants or toddlers, toys or stickers can be used as a fixation point. Testing should be completed with an otherwise blank wall, free of visual distractions. If a child has intact VOR, their gaze will hold steady during the head impulse. A corrective/catch-up saccade at the end of head movement implies an impaired VOR/semicircular canal function (Singh et al, 2022). Several impulses should be completed. Children with impaired VOR should demonstrate a repeatable catch-up saccade. Although HIT can be done for all six semicircular canals, it is performed mostly for the horizontal semicircular canals without goggles. In contrast to caloric or rotary testing, the HIT evaluates high-frequency VOR function.

Postrotary Nystagmus

Rotating a child at a constant velocity on a swivel chair for about 30 seconds with eyes closed will elicit nystagmus when the VOR is intact. This postrotary nystagmus can be seen when the chair is stopped and the eyes are open. Lack of postrotary nystagmus to clockwise and counterclockwise rotations indicates bilateral vestibular loss (Christy et al, 2014). Nystagmus that decays before 15 seconds in room light and 29 seconds with Frenzel lenses is predictive of vestibular loss (Nandi and Luxon, 2008).

Dynamic Visual Acuity

Impaired VOR can also affect visual acuity during head movement. To perform DVA testing, a certain type of eye chart (Snellen, Sloan, or E) is needed. For testing at bedside or in a small exam room, a pocket Sloan letter chart can be used (Figure 3). First, the patient is told to read optotypes (letters or symbols) in the eye chart with their head still at a specific distance (e.g., 16 inches), establishing static visual acuity. Then, the examiner moves the patient's head horizontally at a frequency of 2 Hz while the patient views the eye chart to again obtain DVA. A drop of two lines or more from static visual acuity suggests an impaired VOR or bilateral vestibular loss. DVA testing is often used at bedside to screen for ototoxicity.

ASSESSMENT OF VESTIBULO-SPINAL REFLEX

The vestibulo-spinal reflex helps stabilize the body and maintain postural control. In a normally developing child, the maturation of postural control grows in a cephalocaudal fashion (i.e., first controlling the head, then the trunk) and finally postural stability with standing. Specifically, the earliest development starts about 6 weeks of age with head holding up, followed by head control/turning at 16 weeks of age. Sitting without help normally occurs by 9 months of age, standing about 12 months of age, and walking independently by 15 months of age (Apeksha et al, 2021; Zubler et al, 2022). Any vestibular loss during this process will have a negative impact on postural stability.

Romberg Test

This test can assess a child's ability to control balance while standing still. In standard Romberg, the patient is instructed to stand with feet together and hands on the sides/hips, eyes open and closed, for 30 seconds. Positive findings include excessive sway or fall, indicating acute unilateral vestibulopathy or severe bilateral vestibular impairment (Cohen, 2019). A failed Romberg test also may be a sign of cerebellar lesion. There are limitations to this test, such as its being insensitive for detecting chronic unilateral vestibular loss.

Tandem Gait/Stance and Walk

This test is sensitive to an acute vestibular loss. The patient is instructed to stand with one foot in front of the other with eyes open and closed then walk heel-to-toe along a straight line on the floor with stop and turn.

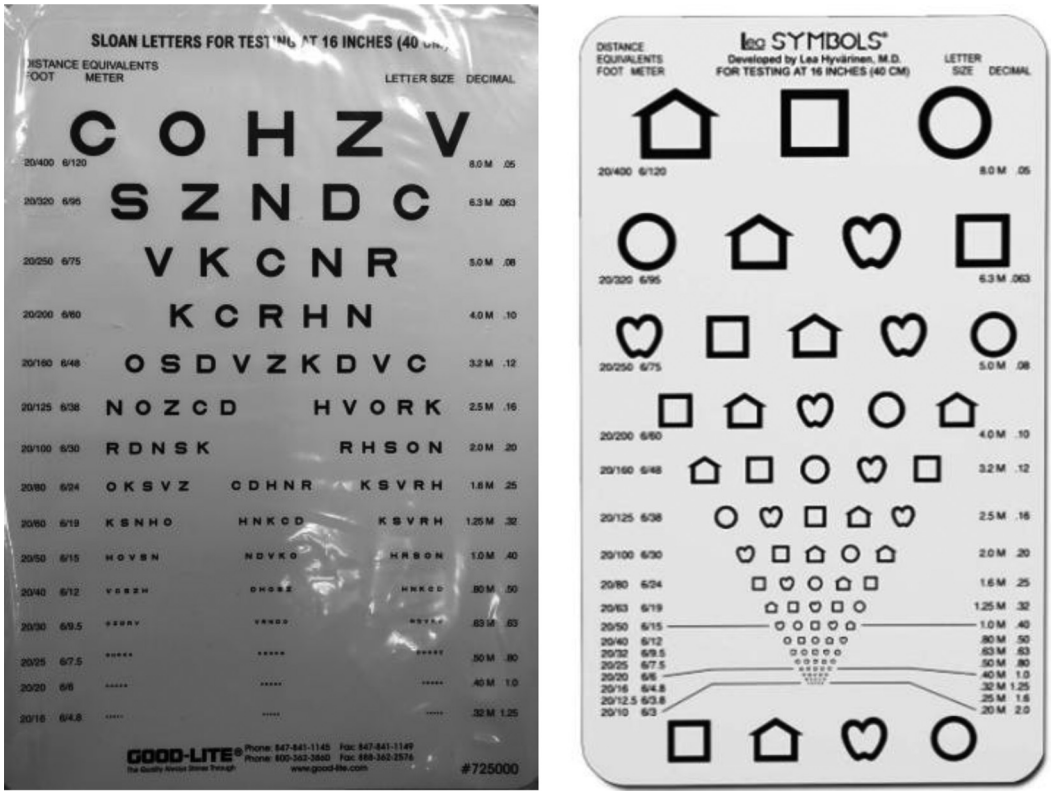

Figure 3. Example of pocket Sloan letter chart and LEA SYMBOLS card for children.

Children can put their hands on their hips, if helpful. Positive findings include excessive sway during walking or inability to maintain balance within a certain time frame (e.g., 10–30 seconds). For age-specific norms in tandem stance, Table 2 can serve as a reference. It should be noted that children with ataxia/gait problems or cerebellar lesions also can have difficulties with this test (Condon and Cremin, 2014; Soylemez et al, 2019). Young children can be provided practice trials.

SCREENING TESTS FOR BALANCE FUNCTION

Assessment of balance function is important for accurate diagnosis of vestibular impairment, identification of fall risk, and treatment planning. There are a variety of tests that can serve as screeners, and many have been used primarily by physical therapists (Sibley et al, 2015). Two of the most popular and commonly used tests, which are easy for audiologists to adopt in clinics, are described below.

Table 2. Age-Specific Norms for Tandem Stance

Age	Duration in Seconds (Eyes Open/Closed)
4–5 years	>7/4
6–7 years	>13/6
8–9 years	>51/12
10–11 years	>68/17
≥12 years	>120/18

Modified Clinical Test of Sensory Integration of Balance

To complete the modified clinical test of sensory integration of balance test, the patient first stands still on a hard surface with eyes open and closed (Romberg). Then the patient is asked to stand on a soft surface/foam with eyes open and closed (Richardson et al, 1992; Gagnon et al, 2006; Lekskulchai and Kadli, 2015; Kakebeeke et al, 2018) (Figure 4). If the patient cannot finish the task on the first try, an additional trial may be given. Normally, one can stand for 30 seconds in each condition without difficulty. This test is reliable for children aged 6 years and older.

Single-Leg Stance Test

During the single-leg stance test, the patient is instructed to stand on one leg (left or right, whichever is dominant) with arms on the sides/hips (Figure 5). Record the time that a patient can stand still with eyes open and closed. Excessive sways or falls are abnormal findings. In fact, failing to stand for 10 seconds would raise a flag for

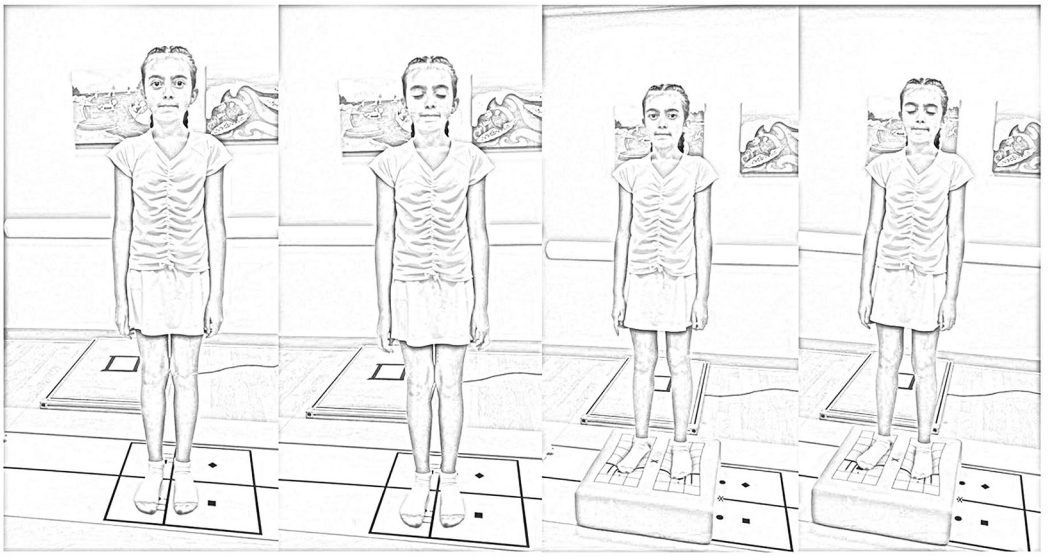

Figure 4. Clinical test of sensory interaction for balance.

vestibular impairment, and inability to maintain balance for 4 or 5 sconds has been found to be sensitive for vestibular loss (An et al, 2009; Condon and Cremin, 2014; Oyewumi et al, 2016; Soylemez et al, 2019; Janky et al, 2022). For age-specific norms, Table 3 can serve as a reference (Cushing et al, 2020).

Figure 5. Depiction of single-leg stance.

CERVICOGENIC SCREENING

Cervicogenic dizziness can be screened at the bedside by placing the child on a swivel chair; keeping the head still, the child is rotated side to side and assessed for the presence of dizziness. Deep palpation of the neck that triggers dizziness also can be a clinical indicator for cervicogenic dizziness.

SUMMARY

The evaluation of children with dizziness, vertigo, and/or balance problems is a challenging task. Contemporary vestibular laboratories normally implement sophisticated testing equipment; however, this computerized equipment is not readily available in most clinical settings. Therefore, audiologists who may encounter these children need to be familiar with the tests described in this clinical consensus statement.

VESTIBULAR EVOKED MYOGENIC POTENTIAL

Test Name: Vestibular evoked myogenic potential (VEMP). There are two kinds of VEMP responses used clinically: cervical VEMP (cVEMP) and ocular VEMP (oVEMP).

Purposes: cVEMPs are ipsilateral, inhibitory responses measured from the contracted sternocleidomastoid (SCM) muscle and represent function of the descending reflex pathway extending from the saccule and inferior portion of the vestibular nerve to the SCM muscle (Colebatch and Halmagyi, 1992; Colebatch et al, 1994), whereas oVEMPs are excitatory responses measured from

Table 3. Age-Specific Norms for Single-Leg Stance

Age	Duration in Seconds (Eyes Open/Closed)
30–36 months	1–2
4 years	5
5 years	10/<5
7 years	15/5
9 years	30/15
11 years	30 + /30

Modified with permission from Cushing et al (2020).

the inferior oblique muscle and represent function of the ascending, crossed reflex pathway extending from the utricle and superior portion of the vestibular nerve to the contralateral inferior oblique muscle (Todd et al, 2007; Todd, 2010). VEMP responses have gained particular interest in children because they do not elicit dizziness, can be completed in 15–30 minutes, and collectively provide information about otolith and vestibular nerve function.

Populations Intended: cVEMP can be completed across the life span from newborn through adulthood (Sheykholeslami et al, 2005), with cVEMP responses more likely to occur in full-term compared with preterm infants (Wang et al, 2013). oVEMP responses undergo maturation in early childhood and can be measured in 100 percent of children by age 4 years (Wang et al, 2013); therefore, oVEMP responses are routinely completed in children starting at age 4 years through adulthood. oVEMPs can be attempted in children younger than 4 years of age; however, it may be difficult to differentiate whether absent responses are related to maturation or pathology.

Expected Outcome: cVEMP outcome parameters are the p13/n23 latency, peak-to-peak amplitude, corrected amplitude (raw peak-to-peak amplitude/raw electromyogram [EMG]), and threshold. An example cVEMP waveform is shown in Figure 6, panel A; cVEMPs are measured in the ipsilateral channel. oVEMP outcome parameters are the n10/p16 latency, peak-to-peak amplitude, and threshold. An example oVEMP waveform is shown in Figure 6, panel B; oVEMPs are measured in the contralateral channel.

Normative Data: One of the biggest downfalls with VEMP testing in both children and adults is the lack of standardization (Rosengren et al, 2019). Although several normative datasets have been published, there is no uniformity in stimuli, electrode placement, or overall test settings. If using any of these datasets for reference values, note stimuli, electrode placement, and test setting used. Sample normative data in children are outlined in Table 4 and demonstrate the wide variability in reported age ranges and stimuli (Sheykholeslami et al, 2005; Kelsch et al, 2006; Erbek et al, 2007; Valente, 2007; Lee et al, 2008; Wang et al, 2008; Chou et al, 2012; Maes et al, 2014; Rodriguez et al, 2018; Kuhn et al, 2018; Brix et al, 2019). In summary, cVEMP latencies are shorter in infants and children than in adults (Sheykholeslami et al, 2005; Kelsch et al, 2006; Valente, 2007), which has been attributed to neck length (Chang et al, 2007; Wang et al, 2008). There is no difference in oVEMP parameters between children and adults (Chou et al, 2012; Kuhn et al, 2018). Most studies have used either 500 Hz or click stimuli; 500-Hz tone bursts yield later latencies and larger amplitudes compared with click stimuli (Valente, 2007). Both cVEMP and oVEMP responses have been recorded in nearly 100 percent of normal control ears, demonstrating their feasibility.

Practice Guidance (Method): For cVEMP, the most common electrode montage is to place the active (noninverting) electrode on the SCM belly (located midway between the mastoid and sternum, roughly at the level of the chin), the reference (inverting) electrode on the manubrium of the sternum, and a ground electrode on the forehead. Depending on the manufacturer, EMG monitoring electrodes may be placed just below each active electrode. Of note, some centers use the clavicle as a reference. To contract the SCM,

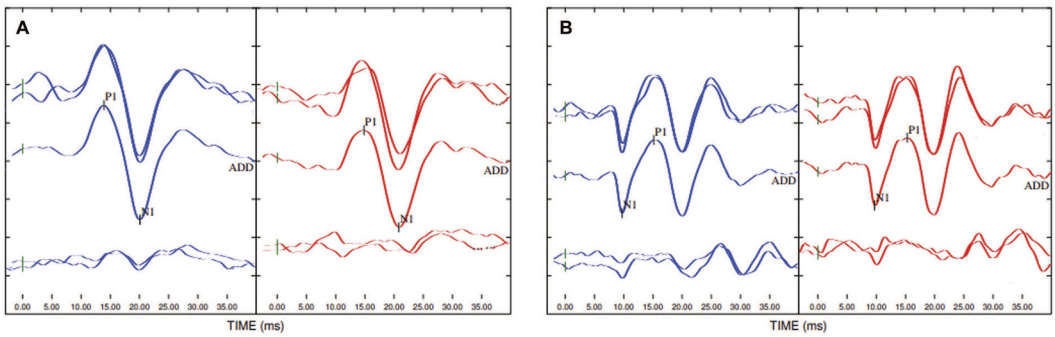

Figure 6. (A) Sample cervical vestibular evoked myogenic potential (cVEMP) waveforms: left cVEMP in blue and right cVEMP in red; cVEMPs are ipsilateral responses, thus measured in the ipsilateral channel (top waveform). Contralateral responses are shown in the bottom waveform. (B) Sample ocular vestibular evoked myogenic potential (oVEMP) waveforms: left oVEMP in blue and right oVEMP in red; oVEMP are contralateral responses, thus measured in the contralateral channel (top waveform). Ipsilateral responses are shown in the bottom waveform.

Table 4. Vestibular Evoked Myogenic Potential Normative Data

			Cervical Vestibular Evoked Myogenic Potential					
Author	Stimuli	n (age)	RR (%)	P13 (ms)	N23 (ms)	Amp (μV)	AR (%)	Threshold
Brix et al (2019)	500 Hz, 100-dB nHL	n = 30 (13–16 years)	85	15.52 (1.74)	25.66 (2.29)	1.65 (0.65)	15.25 (11)	—
Erbek et al (2007)	500 Hz, 100-dB nHL	n = 24 (4 weeks)	100	13.7 (1.1)	20.5 (1.6)	22.6 (18.4)	31.3 (23.1)	—
Kelsch et al (2006)	Click, 90-dB nHL	n = 30 (3–11 years)	100	11.3 (1.3)	17.6 (1.4)	122 (68)	17.7 (12.8)	—
Lee et al (2008)	Clicks, 95-dB nHL	n = 97 (12–77 years)	100	13.79 (2.35)	19.46 (2.55)	16.96 (7.26)	0.1 (10.8)	—
Maes et al (2014)	500 Hz, 95-dB nHL (130-dB SPL)	n = 48 (4–12 years)	100	13.19 (0.82)	20.78 (1.47)	208.38 (61.53)	1.76 (7.96)	72.17 (6.18)
Rodriguez et al (2018)	500 Hz, 120-dB SPL	n = 15 (4–12 years)	100	13.23 (0.87)	20.94 (1.77)	268.85 (210.12)	—	—
Sheykholeslami et al (2005)	500 Hz, 95-dB nHL	n = 24 (1–12 months)	100	—	—	—	—	—
Valente (2007)	Click, 95-dB nHL, 500 Hz, 120-dB SPL	n = 60 (3–6, 9–11 years)	100	—	—	—	—	—
			Ocular Vestibular Evoked Myogenic Potential					
			RR (%)	N10 (ms)	P16 (ms)	Amp (μv)	AR (%)	Threshold
Brix et al (2019)	70-dB nHL (B-81)	n = 31 (13–16 years)	100	10.61 (0.78)	16.58 (1.17)	23.26 (11.51)	16.1 (13.6)	—
Chou et al (2012)	500 Hz, 128-dB FL (V201 Shaker)	n = 15 (3–14 years)	100	8.0 (0.7)	12.2 (1.5)	16.1 (9.0)	12 (14)	—
Kuhn et al (2018)	500 Hz, 105-dB nHL	n = 22 (3.5–8.9 years)	100	10.9 (1.1)	15.0 (1.3)	15.3 (13.4)	18.9 (14)	92.4 (7.2)
Rodriguez et al (2018)	500 Hz, 120-dB SPL	n = 15 (4–12 years)	100	10.2 (0.72)	14.52 (1.82)	6.62 (2.51)	—	—
Wang et al (2013)	500 Hz, 95-dB nHL	n = 15 (4–13 years)	100	11.1 (0.9)	16.1 (1.0)	7.3 (3.0)	—	—

Amp = amplitude; AR = asymmetry ratio; FL = force level; nHL = normalized hearing level; RR = response rate; SPL = sound pressure level.

children aged 3 years and older lay in the supine position, elevated 30° (often propped on their forearms), and are instructed to lift their heads and turn away from the ear receiving the air-conducted stimulus. Toddlers can sit on a parent's lap and contract the SCM by turning the head, which can be reinforced with toys or a short video. Infants can either lay supine and turn the head or be held in a declined position, facing the parent/caregiver, during acoustic stimulation. cVEMP amplitudes increase as SCM contraction increases up to 400 microvolts (μV), where cVEMP amplitudes either asymptote or decline (McCaslin et al, 2014). Thus, EMG monitoring is recommended to ensure that a minimum amount of EMG is obtained (>50 μV) and that EMG does not exceed 400 μV. Children often have a difficult time sustaining SCM contraction; therefore, frequent breaks may be needed. If a child cannot meet minimum EMG requirements, cVEMP can be attempted with EMG monitoring turned off. VEMP testing is not favorable for some children; therefore, care is taken to complete testing as quickly and efficiently as possible to minimize the burden on children. For this reason, a second, or team, tester is often used for pediatric vestibular testing.

For oVEMP, the most common electrode montage is to place the active (noninverting) electrode mediolaterally below the eye, over the contralateral inferior oblique muscle with a reference (inverting) electrode on the inner canthus and a ground electrode on the sternoclavicular notch (Sandhu et al, 2013; Govender et al, 2016). Previously, active electrodes were centered under the pupil, with reference electrodes placed directly below the active electrode or on the chin; however, this is not current practice. Children can lie in the supine position or be seated upright and are instructed to gaze upward at a visual target. oVEMP amplitudes increase with increasing upward gaze (Govender et al, 2009); therefore, the gaze angle during testing is standardized by placing a visual target at 30° above eye level. To help maintain a constant upward gaze, fun stickers or short video recordings can be placed at 30° upward gaze (which are helpful with young children). For children who cannot sustain upward gaze, oVEMP can be completed with the eyes closed (Huang et al, 2012); however, it should be noted that response rates are lower and oVEMP amplitudes are smaller and less reliable (Huang et al, 2012; Fuemmeler et al, 2020).

STIMULI AND RECORDING PARAMETERS

Air-conducted, 500-Hz tone bursts presented at a rate of 5.1 Hz are commonly used to elicit both cVEMP and oVEMP responses; however, click and tone burst stimuli ranging from 500–1000 Hz can be used to elicit responses. VEMP responses are deemed morphologically acceptable if they meet latency criteria (p13/n23 for cVEMP and n10/p16 for oVEMP) and are larger in amplitude than surrounding noise. Two trials are completed to ensure replicability. Responses are considered absent if not replicated over at least two trials. Artifact rejection is turned off. EMG signals are amplified 5,000× and band-pass-filtered from 5–500 Hz. Because VEMP protocols are not standardized, there is variability among laboratories in terms of stimuli and recording parameters. Example stimulus settings are 125 dB sound pressure level (SPL); Blackman-gated; 2 ms rise/fall time, 0 ms plateau, condensation polarity. For an overview of VEMP testing, see the review article by Rosengren et al (2019).

To minimize the amount of acoustic energy reaching the cochlea, care should be taken to limit the overall number of sweeps, stimulus duration, and stimulus intensity, particularly with children whose ear canals are smaller, which results in higher peak-equivalent SPL in the ear (Thomas et al, 2017; Rodriguez et al, 2018). In children, the number of sweeps can be limited to 75 per trial, stimulus duration to 2 ms, and stimulus intensity to 120 dB SPL. Limiting the stimulus duration to 2 ms also reduces potential contributions from the acoustic reflex (Smith et al, 2019) and reduces artifact from obscuring portions of the response (Rosengren et al, 2019).

TESTING CONSIDERATIONS

Tympanometry

Air-conducted VEMP responses can be abolished with 9 dB of conductive hearing loss (CHL) (Bath et al, 1999). Thus, completing tympanometry prior to VEMP testing is recommended to rule out the presence of middle ear disorder (i.e., perforation, effusion, negative pressure, etc.). If CHL is present, or tympanometry is abnormal, bone conduction stimulation can be used. If using air conduction stimuli, tympanometry can be used to measure the ear canal volume, which in turn can be used to determine the air conduction stimulus level. Children with ear canal volumes <0.8 mL have significantly higher peak-equivalent SPL compared with adults (Thomas et al, 2017; Rodriguez et al, 2018). Thus, if ear canal volumes are >0.8 milliliters (mL), 125-dB SPL (97-dB normalized hearing level [nHL]) stimuli can be used; however, if ear canal volumes are ≤0.8 mL, 120-dB SPL (92-dB nHL) should be used to ensure safe levels (Portnuff et al, 2017; Rodriguez et al, 2018).

Bone Conduction

VEMPs can be elicited in response to bone conduction stimulation. Whereas evoked potential units display

stimulus levels in dB nHL, bone conduction stimuli are typically reported in dB force level (FL), which is measured using an artificial mastoid. The following are types of bone conduction stimulation and their approximate dB FL, which can vary by equipment: B-71 (132-dB FL), B-81 (138-dB FL), tendon reflex hammer (145-dB FL), and mini-shaker device (149-dB FL), among others (Greenwalt et al, 2021; Patterson et al, 2021). Bone conduction stimulation is typically delivered at the midline when using a tendon reflex hammer or mini-shaker. When doing cVEMP testing, bilateral SCM contraction can be achieved by having patients lift their head straight up, nose toward the ceiling. In this instance, left and right cVEMP waveforms can be recorded simultaneously if using a two-channel device. Interpretation of waveforms is contingent on patient setup. For example, if the system is set for right stimulation, yet bone conduction stimulation is delivered at the midline and there is bilateral SCM contraction, channel 1 is the left ear response and channel 2 is the right ear response. Although most commercial evoked potential units are equipped with a B-71 or B-81 device, VEMP testing is less reliable (Greenwalt et al, 2021) and is not believed to be an adequate stimulus for use in adults (Iwasaki et al, 2007); however, B-71 is reliable in children (Greenwalt et al, 2021). It is the authors' experience that when using B-71, optimal responses are achieved by placing the bone oscillator on the mastoid of the stimulated ear and having the child turn their head away from the ear receiving stimulation. In this instance, interpretation is like using air-conducted sound (ACS). Although the contralateral ear is receiving stimulation, the SCM is not contracted; thus, an adequate response is not being recorded. Bone conduction is the stimulation method of choice in children where otitis media is prevalent.

Reliability

cVEMP and oVEMP responses are reliable in children (Fuemmeler et al, 2020; Greenwalt et al, 2021). Bone conduction VEMPs can be reliably completed using a B-71 bone oscillator (Radioear Corporation, New Eagle, PA, USA), 4810 mini-shaker (Brüel and Kjær, Denmark), or PCB Piezotronics impulse hammer (model 086C01, sensitivity of 11.2 mV/N; PCB Piezotronics, a subsidiary of Amphenol Corporation, Depew, NY, USA) (Rodriguez et al, 2020; Greenwalt et al, 2021). Although other bone conduction options (i.e., B-81, etc.) may be considered, reliability has not been specifically assessed in children.

cVEMP Amplitude Normalization

Amplitude of the cVEMP response is contingent on degree of SCM muscle tension; larger contractions of the SCM muscle result in larger cVEMP amplitudes (Bogle et al, 2013; McCaslin et al, 2014). Although this relationship is neither completely linear nor proportionate, amplitude normalization can be helpful for controlling for differences in muscle contraction (Bogle et al, 2013; McCaslin et al, 2014). One common way of doing this is to measure EMG in the prestimulus window and then dividing the raw amplitude by the EMG level, which yields a corrected amplitude. Amplitude normalization can be helpful in young children, who often have a difficult time with sustained head-holding/SCM contraction.

INTERPRETATION

VEMP parameters are latency, amplitude, and threshold. The parameters used to interpret VEMP vary based on the population. However, most etiologies use presence/absence of VEMP responses as the primary outcome parameter. VEMP interpretation by etiology is outlined in Table 5. This is not an all-inclusive list and is limited to populations composed primarily of children. Short summary descriptions of each etiology and the VEMP parameter used for interpretation are provided below.

Cochlear Implantation

Several studies have examined VEMP changes following cochlear implantation (CI). A large percentage (>50 percent) of individuals have absent VEMP responses before implantation (Jin et al, 2006; Licameli et al, 2009; Wagner et al, 2010; Katsiari et al, 2013; Imai et al, 2019; Li et al, 2020). In total, as many as 50–100 percent of children have VEMP abnormalities postimplantation (Jin et al, 2006; Licameli et al, 2009; Wagner et al, 2010; Cushing et al, 2013; Katsiari et al, 2013; Devroede et al, 2016; Imai et al, 2019). Although the majority of studies have focused on cVEMP, oVEMPs follow similar trends (Imai et al, 2019; Li and Gong, 2020). It should be noted that CI can result in air–bone gaps (Chole et al, 2014; Mattingly et al, 2016). Although air–bone gaps do not affect children's use of their CI, the air–bone gaps can affect VEMP responses (Merchant et al, 2020). Higher VEMP response rates have been reported in children using bone conduction compared with air conduction, suggesting that the degree of cVEMP abnormalities may be inflated if air conduction stimuli are used (Merchant et al, 2020). In a cohort of 50 patients (100 ears) postimplantation, only three ears showed a decline in VEMP following implantation—all of which had congenital cytomegalovirus infection (Dhondt et al, 2022). Thus, pre- and post-CI VEMP testing should incorporate bone conduction stimuli. In addition, VEMP response rates can increase when completed with the implant on rather than off (Jin et al, 2006; Li et al, 2020). Finally, children with CIs who have vestibular loss are more likely to evidence

Table 5. VEMP Interpretation by Etiology

Group	Author	n (age)	cVEMP	oVEMP
CI	Cushing et al (2013)	n = 153 children (3–20 years)	135 children completed cVEMP; 72/135 (53%) had abnormal cVEMP (32/72 (44%) bilateral; 40/72 (56%) unilateral	Not completed
	Devroede et al (2016)	n = 24 children (1–13 years)	Postunilateral CI, 19/24 (79%) had present cVEMP; postcontralateral CI, 15/24 (62%) had present cVEMP	Not completed
	Dhondt et al (2022)	n = 50 (<17 years)	Pre-CI, 82/100 (82%) had present cVEMP; post-CI, 1 had cVEMP return, while 3/82 had reduced cVEMP (1 ipsilateral, 2 contralateral)	Not completed
	Imai et al (2019)	n = 12 (7–82 years)	Pre-CI, 9/12 (75%) had present cVEMP; of those, 5/9 had reduced cVEMP post-CI	Pre-CI, 11/12 (92%) had present oVEMP; of those, 10/11 had reduced oVEMP post-CI
	Jin et al (2006)	n = 12 children (2–7 years)	Pre-CI, 6/12 (50%) had present cVEMP; of those, 1/6 had reduced cVEMP and 5/6 had absent cVEMP post-CI	Not completed
	Katsiari et al (2013)	n = 20 (10–77 years)	Pre-CI, 10/20 (50%) had present VEMP, bilaterally; of those, 6/10 had absent cVEMP post-CI	Not completed
	Li and Gong (2020)	n = 35 (3–18 years)	Pre-CI, 64/70 (91.4%) had present cVEMP, bilaterally; post-CI (1 month), 72% had present cVEMP	Pre-CI, 57/70 (81.4%) had present VEMP, bilaterally; post-CI (1 month), 34.6% had present VEMP
	Licameli et al (2009)	n = 42 post-CI (5–22 years)	Post-CI, 15 completed cVEMP; 3/15 (20%) had present cVEMP	Not completed
		n = 19 pre-/post-CI (2–23 years)	Pre-CI, 17/19 (89%) had present cVEMP; of those, 3.17 had no change and 14/17 had reduced VEMP post-CI	
	Merchant et al (2020)	n = 27 ears with CI (7–31 years)	Response rates increased from 41% (11/27) with ACS to 67% (18/27) with BCV	Response rates increased from 15% (4/27) with ACS to 52% (14/27) with BCV
	Wagner et al (2010)	n = 20 (40 ears) (11–58 years)	Pre-CI, 22/40 (55%) had present cVEMP; of those, 5 (23%) had absent cVEMP post-CI	Not completed
	Wolter et al (2015)	n = 187 children (22 with CI failure, 165 without failure)	A higher proportion of abnormal cVEMP in children with CI failure (81%) compared with those without CI failure (46%)	Not completed
SNHL	Birdane et al (2016)	n = 33 Unilateral SNHL (5–18 years)	ACS click: absent in 3/33 (9%)	Not completed
	Chen and Young (2016)	n = 16 Bilateral sudden SNHL (5–79 years)	Abnormal responses: 100% (12/12)	Abnormal responses: 100% (4/4)
	Shinjo et al (2007)	n = 20 Severe hearing loss (31–97 months)	ACS clicks: Present bilaterally in 10/20 (50%), asymmetrical in 6/20 (30%), and absent in 4/20 (20%)	Not completed

Continued

Table 5.— Continued

Group	Author	n (age)	cVEMP	oVEMP
	Singh et al (2012)	n = 15 children (4–12 years)	2/15 had bilaterally absent responses; children with SNHL had significantly smaller amplitudes compared with controls	Not completed
	Verbecque et al (2017)	n = 828 children Systematic review	Abnormal responses in 46.7%–100% of children with SNHL; abnormal responses more likely with greater severity of SNHL	63.5% of children with SNHL had normal oVEMP
LVAS	Liu et al (2021)	n = 44 Bilateral LVAS, 10 controls (<14 years)	500-Hz ACS: No difference in latency or threshold; LVAS had significantly larger amplitudes 500-Hz BCV: no difference in amplitude or threshold; LVAS had longer P1 latency and shorter P1-N1 interval	500-Hz ACS: no difference in latency, threshold, or amplitude 500-Hz BCV: no difference in amplitude; LVAS had longer P1 and N1 latency and higher threshold
	Manzari (2008)	n = 15 (21–68 years)	Normal responses in all patients (stimulus not described)	Not completed
	Sheykholeslami et al (2004)	n = 3 (31, 9, and 6 years)	500-Hz ACS: In two patients, ears with LVAS had lower thresholds and higher amplitudes compared with normal ears; in one patient with mixed hearing loss from tympanoplasty, VEMP responses present despite air–bone gap	Not completed
	Taylor et al (2012)	n = 1 (42 years)	250-, 500-, 1000-, and 2000-Hz ACS: amplitudes and thresholds in normal range for all frequencies	250-, 500-, 1000-, and 2000-Hz ACS: large amplitudes and low thresholds in the right ear at 250, 500, and 1000 Hz and large amplitudes in the left ear at 1000 Hz
	Taylor et al (2020)	n = 1	Not completed	Click ACS: enlarged amplitude
	Zalewski et al (2015)	n = 9 (4.6–17.3 years)	500-Hz ACS: one ear did not elicit a VEMP response; no significant difference in cVEMP amplitude between ears with and without LVAS	Not completed
	Zhang et al (2020)	n = 29 (23 children [3–12 years], 6 adults [15–33 years])	500-Hz ACS: absent in 6/46 child ears (13%) and 3/12 adult ears (25%); compared with control, LVAS adults had significantly smaller cVEMP amplitudes; there were no differences for LVAS children	500-Hz ACS: absent in 3/46 child ears (6.5%) and 2/12 adult ears (16.7%); compared with control, LVAS adults had significantly higher amplitudes; there were no differences for LVAS children
	Zhou et al (2008)	n = 54 (82 ears) (2–16 years)	500-Hz ACS: cVEMP completed in 14; VEMP thresholds were significantly lower in ears with EVA	Not completed
	Zhou and Gopen (2011)	n = 25 (37 ears) (3–20 years)	500-Hz ACS: thresholds were abnormally low in 34/37 (92%) of LVAS ears; VEMP were absent in three patients with vestibular complaints; no differences in latencies	Not completed

Continued

Table 5.— Continued

Group	Author	n (age)	cVEMP	oVEMP
	Zhou et al (2017)	n = 18 (7–27 years)	500-Hz ACS: lower thresholds, shorter latencies, and larger amplitudes	500-Hz ACS: lower thresholds and larger amplitudes
MD	Wang et al (2018)	n = 15	12/15 (80%) had normal cVEMP	13/15 (86.7%) ears had normal oVEMP
CHL	Monobe and Murofushi (2004)	n = 1 (3 years)	Bilateral OME present; BCV VEMP were used to diagnose vestibular neuritis; absent VEMP on right side and present on left with right caloric weakness and spontaneous left beat nystagmus	Not completed
	Yıldız et al (2019)	n = 40 (4–16 years)	Prolonged latency and reduced amplitude in ears with OME; latencies shortened and amplitudes increased following treatment	Not completed
	Zhou et al (2012)	n = 120 with ABG (3–76 years)	Responses used to differentiate types of air–bone gaps (middle vs. inner ear); middle ear pathologies resulted in absent VEMP; inner ear anomalies (SCDS and LVAS) had abnormal low VEMP thresholds	Not completed
ANSD	Akdogan et al (2008)	n = 3 (4–5 years)	500-Hz ACS: absent in two thirds (66.7%)	Not completed
	El-Badry et al (2018)	n = 54 28 prelingual onset, 16 postlingual onset (3.7–10.2 years)	500-Hz ACS: absent in 3/38 (8%) of the prelingual onset group and absent in 11/16 (69%) in the postlingual onset group	Not completed
	Emami and Farahani (2015)	n = 13 (15 ears)	500-Hz ACS: 4/15 (27%) ears had absent responses	Not completed
	Laurent et al (2022)	n = 9 Unilateral ANSD (0–95 months)	500-Hz BCV: abnormal responses in 4/9 (44.4%)	Not completed
	Sinha et al (2013)	n = 11 (15–28 years)	500-Hz ACS: absent responses in 20/22 ears (90.9%)	500-Hz ACS: absent responses in 22/22 ears (100%)
BPVC	Chang and Young (2007)	n = 20 (5–15 years)	500-Hz ACS: 10/20 (50%) children had abnormal responses: six children had absent responses and five had delayed responses (one child had both absent and delayed)	Not completed
	Lin et al (2010)	n = 15 (4–14 years)	500-Hz ACS: 11/15 (73%) children had delayed responses	500-Hz ACS: normal responses in 15/15 (100%)
	Zhang et al (2012)	n = 56 (3–12 years)	500-Hz ACS: 18/56 (32.1%) had abnormal responses: 16 had amplitude and 2 had latency abnormalities	Not completed
SCDS	Wenzel (2015)	n = 1 (11 years)	Not completed	Enlarged amplitude for affected ear

ACS = air-conducted sound; ANSD = auditory neuropathy spectrum disorder; BCV = bone-conducted vibration; BPVC = benign paroxysmal vertigo of childhood; CHL = conductive hearing loss; CI = cochlear implant; cVEMP = cervical vestibular evoked myogenic potential; EVA = enlarged vestibular aqueduct; LVAS = large vestibular aqueduct syndrome; MD = Meniere's disease; OME = otitis media with effusion; oVEMP = ocular vestibular evoked myogenic potential; SCDS = superior canal dehiscence syndrome; SNHL = sensorineural hearing loss; VEMP = vestibular evoked myogenic potential.

CI failure (Wolter et al, 2015). The primary outcome parameter is presence or absence of VEMP responses before and after implantation, with the recommendation to use bone conduction stimuli.

Sensorineural Hearing Loss

Vestibular loss is associated with sensorineural hearing loss (SNHL); however, not all children with SNHL will have vestibular loss (Shinjo et al, 2007; Singh et al, 2007; Birdane et al, 2016; Verbecque et al, 2017). The large percentage of children with absent VEMP responses prior to receiving a CI highlights the relationship between vestibular loss and hearing loss severity. Vestibular loss is more likely to occur as hearing loss severity increases, with specific etiologies and with sudden SNHL (Cushing et al, 2013; Chen and Young, 2016; Verbecque et al, 2017). The primary outcome parameter is presence or absence of VEMP responses. Due to the high association between hearing loss and vestibular loss (O'Reilly et al, 2010; Li et al, 2016) and because cVEMP responses can be completed in newborns, cVEMPs are beginning to be used to screen for vestibular loss in children with hearing loss (Martens et al, 2020). Bone conduction cVEMPs are used due to the high incidence of middle ear disease.

Large Vestibular Aqueduct Syndrome

Large vestibular aqueduct syndrome (LVAS) occurs when the vestibular aqueduct is greater than 1.5 millimeters (mm), which often leads to congenital hearing loss (Valvassori and Clemis, 1978). LVAS has been considered one type of third-window disorder (Merchant and Rosowski, 2008). VEMP findings in LVAS vary considerably. Whereas many reports note reduced thresholds and increased amplitudes (Sheykholeslami et al, 2004; Zhou et al, 2008; Zhou and Gopen, 2011; Zhou et al, 2017; Taylor et al, 2020; Liu et al, 2021), normal thresholds, normal amplitudes, and reduced amplitudes in LVAS have also been reported (Manzari, 2008; Taylor et al, 2012; Zalewski et al, 2015; Zhang et al, 2020; Liu et al, 2021). Longer bone conduction and shorter air conduction latencies have also been noted (Zhou et al, 2017; Liu et al, 2021). Outcomes with LVAS consist of analyzing oVEMP amplitude, cVEMP threshold, and latency differences.

Meniere's Disease

Meniere's disease is rare in children; pediatric Meniere's disease is estimated to include 2.3 percent of all Meniere's disease cases (Wang et al, 2018). Although rare, Meniere's disease is third to vestibular migraine and recurrent vertigo of childhood for causes of dizziness in children (Wang et al, 2018). Thus, there are few publications in pediatric Meniere's disease. Of those, most children with pediatric Meniere's disease have present cVEMP and oVEMP responses in the reference range (Wang et al, 2018). The primary outcome parameter is presence or absence of VEMP responses.

CHL

The presence of CHL reduces the amount of acoustic energy reaching the vestibular system when using air conduction stimuli. In adults with CHL, cVEMP responses are diminished with CHL of 9 dB, yet remain in some ears with as much as 24 dB of CHL (Bath et al, 1999). In children with otitis media, cVEMP responses have been recorded with reduced amplitude and delayed latencies that normalize 3 months following medical treatment (Yıldız et al, 2019). In a case of CHL, use of bone conduction stimuli has been helpful for diagnosing underlying vestibular loss (Monobe and Murofushi, 2004; Zhou et al, 2012). The primary outcome parameter is presence or absence of VEMP responses, with the recommendation to use bone conduction.

Auditory Neuropathy Spectrum Disorder

Many children with auditory neuropathy spectrum disorder demonstrate abnormal VEMP responses (Akdogan et al, 2008; Sinha et al, 2013; Emami and Farahani, 2015; El-Badry et al, 2018; Laurent et al, 2022). Children with auditory neuropathy spectrum disorder and abnormal VEMP responses are more likely to have auditory neuropathy spectrum disorder onset postlingually (El Badry et al, 2018), more severe hearing loss (El Badry et al, 2018), and worse speech discrimination (El Badry et al, 2018) and evidence vestibular involvement on the magnetic resonance imaging (e.g., vestibular dysplasia) (Laurent et al, 2022); however, these associations have not been uniform across studies. The primary outcome parameter is presence or absence of VEMP responses.

Superior Canal Dehiscence Syndrome

In children, the prevalence of dehiscence is estimated to be 1.7 percent in the superior canal and 1.2 percent in the posterior canal (Saxby et al, 2015). Few studies have been published on VEMP outcomes in children with superior canal dehiscence syndrome. One published case study demonstrated abnormally large oVEMP amplitudes (Wenzel et al, 2015). In adults, high-amplitude oVEMPs, low-threshold cVEMPs, and altered tuning are typically used to diagnose superior canal dehiscence syndrome (Welgampola et al, 2008; Janky et al, 2013; Manzari et al, 2013; Zuniga et al, 2013). Thus, the primary outcome parameters would be oVEMP amplitude, cVEMP threshold, and presence or absence of VEMP responses for high-frequency stimuli (e.g., 4000 Hz).

Recurrent Vertigo of Childhood

Recurrent vertigo of childhood (previously benign paroxysmal vertigo of childhood) is common in children and considered a variant of migraine. Absent and/or delayed cVEMP responses and normal oVEMP responses have been reported (Chang et al, 2007; Lin et al, 2010; Zhang et al, 2012). Due to normal oVEMP responses and abnormal cVEMP responses, the lower brainstem is thought to be affected (Chang and Young, 2007; Lin et al, 2010). The primary outcome parameters are cVEMP and oVEMP amplitude and latency.

SUMMARY

Air- or bone-conducted stimulation can be used for VEMP testing. If using air-conducted stimuli, tympanometry is recommended prior to VEMP testing to assess middle ear status. If tympanometry is normal, VEMP using air-conducted stimuli can be used but should not exceed 120-dB SPL (92-dB nHL) if ear canal volumes are <0.8 mL. If tympanometry is abnormal, VEMP using bone-conducted stimuli is recommended (e.g., B-71). Bone-conducted stimulation is recommended in children before and after implantation and for newborn screening due to the high rate of otitis media. Most etiologies use presence/absence of VEMP responses as the primary outcome parameter; however, abnormal latencies can be seen in benign paroxysmal vertigo of childhood (using ACS) and LVAS (using either ACS or bone-conducted vibration), and abnormally high oVEMP amplitudes, low cVEMP thresholds, and high-frequency responses can be noted in superior canal dehiscence syndrome and LVAS. cVEMP can be completed in newborns, whereas oVEMPs are initiated around age 3–4 years.

VIDEO HEAD IMPULSE TEST

Test Name: Video head impulse test (vHIT).

Purpose: The purpose of vHIT is to evaluate the VOR associated with each of the six semicircular canals. The VOR allows for stable gaze and clear vision while the head is in motion. During vHIT, children wear tightly fitting goggles, and the clinician administers high-acceleration head impulses in the plane of each semicircular canal (horizontal, superior, and posterior) of each ear. Stimulation of the semicircular canal via a head thrust in the plane of that canal drives the neural response to the cranial nerves that innervate the eye muscles, turning the eyes equal and opposite to the movement of the head. This allows the patient to maintain stable gaze on a focal point. Ear-specific and canal-specific information may be obtained.

Populations Intended: Children aged 4 years and older. Of note, approved outside of the United States and for research purposes inside the United States a remote camera system is available. This remote camera stands alone and measures the pupil without goggles while facing the child. Normative data are available for children as young as 3 months of age (Wiener-Vacher and Wiener, 2017).

Expected Outcomes: The main outcome parameter is gain, which is calculated by dividing eye velocity (measured by a camera within the goggles) by head velocity (measured by a gyroscope within the goggles).

Normal Results: In children with normal vestibular functions, head impulses in the plane of each semicircular canal result in an equal and opposite eye movement, generating gain values near 1.0. Normal gain values for healthy children and adults are listed in Table 6. For quick reference, 0.80–1.2 is considered normal gain for lateral canal vHIT. Gain cutoff values for left anterior/right posterior semicircular canal plane and right anterior/left posterior semicircular canal plane in children are lower, however, on the order of 0.60–1.2 (McGarvie et al, 2015; Bachmann et al, 2018). Normal neural input from the canals drives the VOR, allowing the patient to maintain focus on a visual focal point on the wall. The computer recordings of the patient's eye movement and the patient's head movement are viewed as either superimposed (Figure 7, panel A) or 180° out of phase (Figure 7, panel B).

Abnormal Results: In children with significant vestibular dysfunction, there is not enough vestibular input to drive the VOR when the head is turned toward the affected side. Thus, head impulses in the plane of the abnormal canal result in eyes that briefly move with the head, resulting in low gain values and requiring the patient to make a compensatory (catch-up) saccade back to the visual target. Catch-up saccades may be seen on the recording either during the head movement or following the head movement as a spike in the eye movement tracing.

a. Overt saccades are corrective eye movements that occur at least 100 msec after the head movement has ended (Figure 8).
b. Covert saccades are corrective eye movements that occur during the head movement. They may be seen beginning around 70 msec after the start of the head impulse and occur at any point in time while the head is in motion (Figure 8).

For analysis purposes, determination of the presence of pathological catch-up saccades includes a consistent spike in the response tracing occurring on more than 50 percent of impulses and having a magnitude greater than half the size of the head movement (Barin, 2013). Random or

Table 6. Vestibulo-Ocular Reflex Gain for Each Semicircular Canal for Children and Adults

Age Group	Semicircular Canal Tested					
	Left Lateral	Right Lateral	Left Anterior	Right Anterior	Left Posterior	Right Posterior
Children aged 4–12 years (McGarvie et al, 2015)	0.96 (0.09) (0.79–1.14)	1.04 (0.09) (0.87–1.23)	0.80 (0.11) (0.58–1.02)	0.90 (0.19) (0.53–1.27)	0.91 (0.14) (0.65–1.18)	0.83 (0.09) (0.65–1.01)
Adults (McGarvie et al, 2015)	0.91 (0.06) (0.79–1.04)	1.03 (0.06) (0.91–1.14)	0.93 (0.07) (0.78–1.07)	0.95 (0.18) (0.60–1.30)	0.95 (0.09) (0.77–1.12)	0.89 (0.08) (0.73–1.05)
Adults (Barin, 2013)	0.92 (0.06) (lower cutoff = 0.80)	1.00 (0.07) (lower cutoff = 0.86)	0.96 (0.12) (lower cutoff = 0.71)	0.95 (0.12) (lower cutoff = 0.70)	0.92 (0.17) (lower cutoff = 0.58)	0.98 (0.15) (lower cutoff = 0.68)

Data are mean (standard deviation) (5th–95th confidence intervals); from Bachmann et al (2018) and Curthoys et al (2016).

extraneous eye movements recorded on only a few tracings are not considered pathological (Figure 9). Low gain and catch-up saccades are indicative of peripheral vestibular dysfunction in the semicircular canal on the side and in the direction of head thrust. For example, if there is low gain and catch-up saccades observed with left horizontal head thrusts, this is indicative of left horizontal semicircular canal dysfunction, as seen in Figure 8.

Practice Guidance Method (GN Otometrics 2015):

a. The child should be seated in a chair 1 m from a visual target (1- × 1-inch sticker or video on a cell phone; see tips for testing below) on the wall at eye level (Figure 10).
b. The vHIT goggles should be placed on the patient's face and firmly secured with the attached elastic band, provided by the manufacturer, around the back of the head to prevent goggle slippage and subsequent inaccurate gain data.
c. The goggle cord should be secured to the patient's clothing with a clip to limit cord movement that may cause movement of the goggles.
d. To obtain optimal pupil recordings, the loose skin above the eyelid of the recorded eye should be pulled up and secured with the goggles. Pulling down on the cheek below the recorded eye may also widen the eye by pulling the lower eyelid down.
e. Prior to the start of testing, calibration of the goggles should be performed according to manufacturer's instructions.
f. If calibration cannot be achieved by the patient, "default" calibration should be used.
g. After calibration is accepted by the system, calibration should be manually verified by slowly rotating the patient's head to the left and right while the patient maintains focus on the sticker or focal point, confirming that eye and head movement recordings are superimposed, or 180° out of phase, depending on the equipment used.
h. Following calibration, the patient should be instructed to maintain focus on the visual target or sticker.
i. Horizontal/lateral canal testing: The patient's head should be rotated by the examiner using small (no larger than 15°), rapid (150–300° per second) head impulses to the left and right in the plane of the lateral semicircular canals.
j. Left anterior and right posterior canal testing: Test setup varies based on equipment manufacturer (i.e., head straight or head rotated 35–45° to the right). The examiner then places one hand under the patient's chin and one hand on top of the patient's head with the index finger pointing toward the visual target or sticker. The patient's head should be thrust forward for testing of the left anterior canal and backward for testing of the right posterior canal using rapid (100–250° per second) downward and upward head impulses.

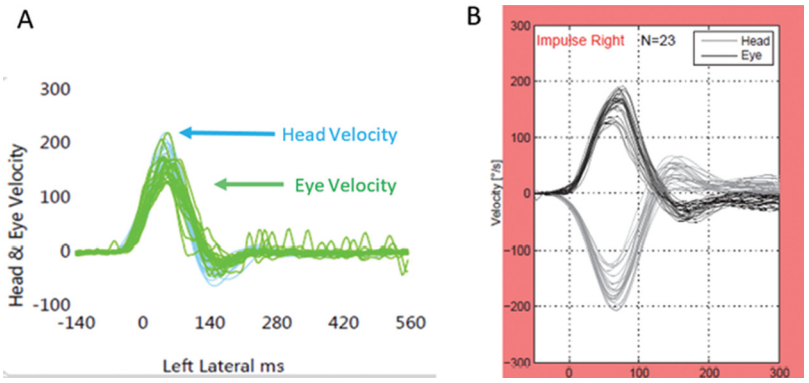

Figure 7. Normal VHIT recordings that display eye velocity superimposed on head velocity (A) and eye velocity opposite to, or out of phase with, head velocity (B).

k. Right anterior and left posterior canal testing: Test setup varies based on equipment manufacturer (i.e., head straight or head rotated 35–45° to the left). The examiner then places one hand under the patient's chin and one hand on top of the patient's head with the index finger pointing toward the visual target or sticker. The patient's head should be thrust forward for testing of the right anterior canal and backward for testing of the left posterior canal using rapid (100–250° per second) downward and upward head impulses.
l. Twenty acceptable impulses are recommended for each canal, if possible.
m. Results must be inspected for clean data prior to analysis. Messy tracings and poor-quality head impulses and eye recordings must be eliminated from the record before an accurate analysis of the data may be made. One of the most common artifacts seen during anterior canal testing in children is eyelid artifact (Mantokoudis et al, 2015). An example of eyelid artifact is seen in Figure 11. A "V" shape in the response indicates that the top of the pupil was obscured by the eyelid. This is especially problematic in children because their pupil size is very large compared to that of an adult (Birren et al, 1950; Jacobson, 2002). As the crosshairs on the equipment are centered on the pupil, any change in pupil shape (caused by the eyelid covering the top portion of the pupil) will result in the crosshairs moving down on the pupil to find a new center. This is what causes the "V" in the eye response. To eliminate this, try pulling up on the eyelid or down on the cheek to create a wider recording area. Consider also starting with the head tilted backward slightly before thrusting anteriorly. In addition, it is important to perform vHIT in a well-lit room or area of the room because the naturally larger pupil diameter in children makes pupil tracking difficult in a dimly lit environment. Use of a portable bright light, such as that from an otoscope, is helpful for constricting the pupil, allowing for easier pupil tracking and cleaner tracings. See Mantokoudis et al (2015) for a list of other common vHIT artifacts (Mantokoudis et al, 2015).

General Rules for Interpretation: Results of each test should be evaluated for both average gain and the presence of consistent saccades occurring during the head movement (covert) or after the head movement (overt).

a. It stands to reason that low gain will likely be accompanied by a catch-up saccade, as low gain is an

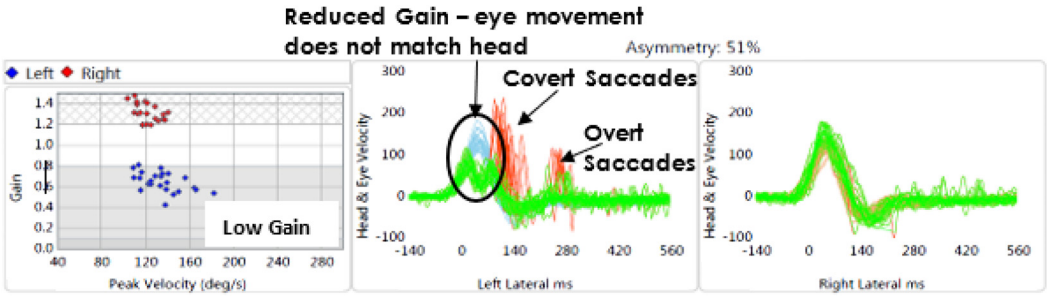

Figure 8. Example of lateral, video head impulse test showing vestibular dysfunction in the left lateral canal and healthy function in the right lateral canal. Note the reduced gain in blue (left ear, lateral canal) on the gain graph in the left panel of the figure, and the green tracing circled on the video head impulse test recording (center panel). Covert saccades are seen as red spikes during the head movement (light blue tracing), whereas overt saccades are seen as red spikes after the head movement has ended.

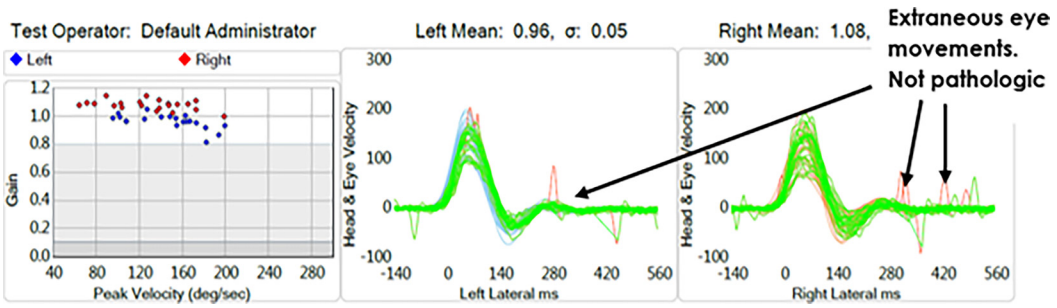

Figure 9. Example of normal video head impulse test tracings with some random or extraneous eye movements seen after the head movement (arrows). These eye movements are not consistent and are too small to be considered pathological catch-up saccades. See text for definition of saccade.

indication that the eye has moved with the head to some degree and did not stay on target, requiring the eyes to make a saccade back to the target.

b. As described earlier, determination of the presence of a saccade includes a consistent spike in the response tracing occurring on more than 50 percent of impulses and having a magnitude greater than half the size of the head movement (Barin, 2013).

Tips for Testing: Pediatric modifications for vHIT testing are necessary to reduce goggle slippage and body movement, as well as to increase attention and focus on the target.

a. Reducing body movement during head impulses.
   (i) The child may be seated with legs crossed on the chair.
   (ii) The child may be seated with feet placed on a step stool.
   (iii) The child may be seated on the caregiver's lap.

b. Reducing goggle slippage on a child's fine, slippery hair.
   (i) A disposable bouffant cap (like that used for hair covering in food service) may be placed on the patient's head prior to placing the goggles on the patient. This is also helpful for infection control because the cloth strap cannot be adequately wiped down.
   (ii) A piece of disposable foam or sponge (i.e., packing foam from a hearing aid box) may be placed inside the elastic headband on the back of the child's head. This adds bulk to the head to make the elastic band fit tighter and also serves to add friction so that the elastic band cannot slip on the child's hair. The foam or sponge is disposed of following the test.
   (iii) For children with long hair, putting the hair in a low ponytail on the head is effective for preventing the elastic band from slipping down the child's head. Ensure that the ponytail sits below the elastic strap of the goggles.

c. Increasing attention and focus on the focal point.
   (i) Ages 4–10 years:
      1. A cell phone with the child's favorite video or show playing on it may be used as a focal point.

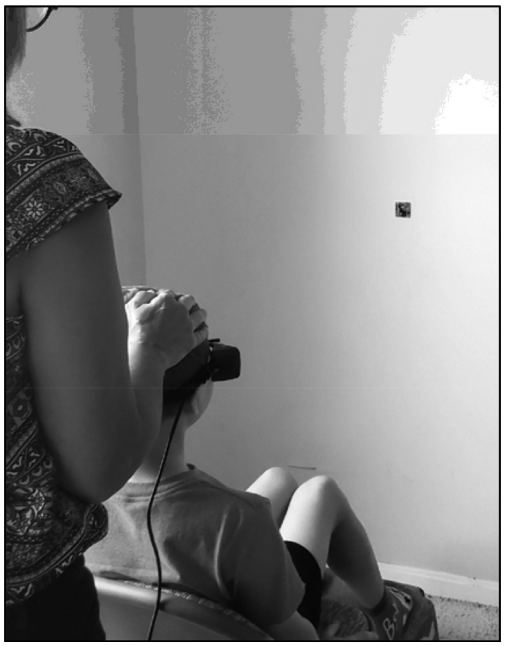

Figure 10. Video head impulse test setup for a pediatric patient. The child is seated in a chair 1 m from a visual target (1- × 1-inch sticker) on the wall, and a footstool is used to stabilize the feet.

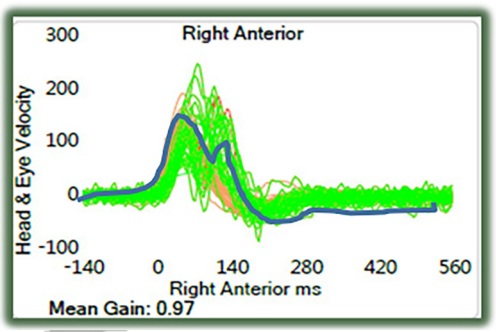

Figure 11. Example of recordings with eyelid artifact seen as the "V" in the tracings. See text for full explanation.

2. Colorful stickers may be used as the focal point.
3. To ensure that the child is looking at the visual target during head impulses, questions about the video or sticker should be asked to the child (e.g., How many sprinkles are on the cupcake? How many tires are on the fire truck? What colors are on that flag?). When using a sticker as the focal point, the sticker should be replaced with a new sticker if the child is losing interest.

(ii) Ages 11–21 years: A colorful sticker, or the sticker provided by the manufacturer may be used.

Note that it is not recommended to use a cell phone with a video due to unpublished data that showed that older children do not focus as well with a video as the focal point, perhaps because of an increased level of relaxation and overall reduced alertness watching a show.

d. Congenital nystagmus: There may be continuous beats or what looks like rhythmic catch-up saccades overlying the tracing in vHIT. This is more evident in the horizontal canals and less so in the vertical canals.

VIDEONYSTAGMOGRAPHY

Test Name: Videonystagmography (VNG) refers to video recording of eye movements. VNG is broken down into multiple subtests including high-frequency headshake, positional testing, Dix–Hallpike, skull vibration-induced nystagmus test, ocular motor testing, and caloric testing. Although VNG is the most readily available assessment in vestibular testing centers, it is often not used in children younger than 5–7 years of age due to limitations discussed below (i.e., goggle fit, invasive nature of the test, length of the test, etc.).

Purpose: VNG is helpful for differentiating central versus peripheral vestibular system involvement and side of lesion.

Populations Intended: Although children as young as 6 months can complete some subtests and most manufacturers claim their goggles fit children aged 3 years and older, VNG is typically not used in the pediatric population until 5–7 years of age (Figure 12).

Expected Outcome and Methods: Like adults, children are asked to refrain from using any vestibular suppressant medications (i.e., dimenhydrinate, meclizine, etc.) prior to testing. There are several subsets of the VNG test battery. Each subtest is designed to target either the central and/or peripheral vestibular system physiologically. Outcomes vary based on each subtest, which are described below.

High-Frequency Headshake (Katsarkas et al, 2000)

a. Purpose: Used to assess asymmetrical vestibular system firing.
b. Population: Children aged over 10 months.
c. Expected outcome: In normal subjects, no nystagmus should be observed in response to horizontal headshake. If there is asymmetric vestibular function, an initial burst of nystagmus (typically horizontal and beating toward intact ear), which decays over approximately 30 seconds, will be recorded. For central involvement, nystagmus can occur with a latent onset and/or may be persistent (beyond 30 seconds). In addition, cross-coupling, or vertical nystagmus seen after horizontal headshake, can suggest central pathology.
d. Method: The patient is seated with vision denied and head tilted 20° downward. The tester moves the patient's head horizontally at about 2 Hz with displacement of approximately 30° horizontally. The headshaking continues for 15–20 seconds. Once the headshaking is stopped, the eyes are observed for nystagmus for up to 60 seconds.
e. Normative data: None specific to children. Most laboratories consider three consecutive beats of nystagmus pathological.
f. Considerations:

Figure 12. Options for videonystagmography goggles on a 4-year-old's face.

(i) Patients with complete bilateral vestibular loss will not have nystagmus after headshaking; however, post-headshake nystagmus can occur in cases of asymmetric bilateral loss.
(ii) Post-headshake testing can also be completed while recording in rotary chair or with electrodes.
(iii) Telling the child, "Let's be silly and shake our head and say 'no! no! no!' 10 times!"

Positional Testing

a. Purpose: To determine whether certain positions elicit nystagmus, thus indicating abnormal or asymmetrical firing in the vestibular system.
b. Population: 4 years of age and older. This test is easily tolerated by children, though is often not localizing on its own.
c. Expected outcome: Nystagmus may be observed in one or several positions. To classify positional nystagmus as clinically significant, nystagmus should be present in at least half of the positions or be greater than 6° per second in any one position.
d. Method: The patient is placed with vision denied in a combination of the following positions: sitting neutral, supine head center, supine head right, supine head left, side lying right, side lying left, head hanging, and a precaloric position (inclined 30°). Eyes are observed for nystagmus for approximately 30 seconds. If nystagmus is present, a fixation light is turned on to determine if central suppression is present.
e. Normative data (Levens, 1988; Zhou et al, 2018):
(i) 15–22 percent of healthy children have positional nystagmus.
(ii) Most clinics use persistent nystagmus greater than 4–6° per second that appears in greater than 50 percent of the tested positions to be clinically significant; however, other adult studies suggest that observing three or more beats of nystagmus in a 10-second window to be clinically significant (Roberts et al, 2016). Of note, these guidelines were based on adult data. Different cutoff criteria could exist for children but have not been studied or established.
f. Considerations:
(i) May not be beneficial when bilateral vestibular loss is identified and/or there is no complaint of positional dizziness.
(ii) For children, consider tasking appropriately with songs, games, colors, etc.
(iii) In the authors' collective experience, nystagmus without fixation is a nonlocalizing finding when all other peripheral tests yield normal results. This finding has been documented in peripheral, as well as central, etiologies (i.e., migraine) (Zhou et al, 2018).

Dix–Hallpike Test/Roll Test (Hornibrook, 2011)

a. Purpose: To assess for benign paroxysmal positional vertigo.
b. Population: For patients complaining of positional vertigo. Benign paroxysmal positional vertigo is not a common entity in pediatrics (Balatsouras et al, 2007).
c. Expected outcome: In patients without benign paroxysmal positional vertigo, no nystagmus will be observed in each position. If nystagmus is observed, it should present with an initial burst that gradually fatigues and reverses upon sitting. The direction/type of nystagmus should be noted to determine which semicircular canal is affected. For a practical guideline for diagnosis and treatment, see Bhattacharyya et al (2017). If nystagmus is noted, the Dix–Hallpike should be repeated. Nystagmus should fatigue more quickly on repeat. The roll maneuver can also be performed if horizontal canal benign paroxysmal positional vertigo is suspected. The roll test will be positive when horizontal nystagmus is observed in each head position. Geotropic nystagmus is horizontal nystagmus beating toward the earth (i.e., right beating with head right and left beating with head left) and is consistent with canalithiasis. The side with more intense nystagmus is the affected side. Ageotropic nystagmus is consistent with cupulolithiasis. The side with less intense nystagmus is the affected side.
d. Method:
Dix–Hallpike: The patient starts in a seated position with their head turned 45° toward the test ear. The patient is then placed in a supine position with their head extended about 20° below the horizontal plane. The eyes are observed for 30 seconds. The patient is then brought back to the sitting position with the head remaining turned and the eyes are again observed for nystagmus for 30 seconds.

Roll test: The patient will lie supine on the bed and the head will be supported into 30° of flexion to align the lateral semicircular canal in the horizontal plane. Then, the head is quickly rotated 90° to one side. The eyes are observed for nystagmus for 60 seconds. The head is then returned to the straight face-up supine position. After any nystagmus subsides, the same is repeated to the other side. In a positive test, the patient will experience vertigo during this test. In the case of horizontal semicircular canal benign paroxysmal positional vertigo, the nystagmus will be predominantly horizontal.
e. Considerations: Testing should be avoided and/or extreme care taken with patients who have cervical or vascular issues, such as vertebrobasilar insufficiency or craniovertebral junction abnormalities (e.g., patients with Down syndrome). Assess the patients' ability to rotate their head safely prior to performing the maneuver.

Skull Vibration-Induced Nystagmus Test

a. Purpose: To assess asymmetrical firing in the peripheral vestibular system.
b. Population: All children.
c. Expected outcome: Skull vibration-induced nystagmus starts and stops immediately with stimulation,

is continuous, reproducible, and beats in the same direction irrespective of which mastoid process is stimulated. A positive test is most widely seen in patients with asymmetric vestibular function (Sinno et al, 2020). The nystagmus typically beats toward the healthy ear. Positive cases have also been noted in those with third-window lesions. In the literature, third-window pathologies may show nystagmus beating toward the affected side (Dumas et al, 2007).

d. Method: Patient is seated upright with fixation removed. Apply 10 seconds of low-frequency vibration at 100 Hz to the mastoid process on each side. Eye movements are recorded before, during, and after vibration application.
e. Normative data (Dumas et al. 2007; Sinno et al, 2020; Dumas et al, 2021): The first effects of vibration (motion and reflexes) were described by Von Bekesy (1935) and the vibratory-induced nystagmus test was introduced in 1973 by Lücke (Lücke, 1973). The primary response expected is nystagmus in the direction of the healthy end organ during 100-Hz skull vibration. As noted above, nystagmus can beat toward the affected ear in cases of third-window pathologies. The typical method of stimulation is vibration between 60 Hz and 100 Hz. The most recent study (Sinno et al, 2020) that assessed children aged 5–17 years applied 100-Hz stimulation to each mastoid and the vertex. Nystagmus was considered pathological when horizontal/rotary nystagmus was observed (>10 beats and slow-phase velocity >2° per second) beating toward the same direction and reproducible in at least two locations. If there was preexisting nystagmus, the evoked nystagmus had to enhance by at least 50 percent. Most protocols call for recording without stimulation for 5 seconds, then applying vibration for 10 seconds. This study recorded for 20 seconds because of the high number of eye blinks in children. The study also looked at 120 healthy controls compared to 60 children with hearing loss and concomitant bilateral or unilateral vestibular loss. The skull vibration-induced nystagmus test yielded clinically significant findings in the controls only 2.5 percent of the time. The skull vibration-induced nystagmus test showed a sensitivity of 86 percent and specificity of 96 percent. The positive predictive value was 75 percent, and negative predictive value was 98 percent. It also statistically correlated well with patients with a caloric weakness. The skull vibration-induced nystagmus test was not useful in bilateral weaknesses. Thus, it is a useful and noninvasive tool when evaluating for vestibular asymmetry.
f. Considerations:
   (i) Observe preexisting nystagmus prior to the application of vibration.
   (ii) Show the children the vibrator and let them touch it. "This is going to tickle our ears, and we are going to sing 'Happy Birthday.' When we are done, we are going to tickle the other ear and sing!"

Ocular Motor Test

a. Purpose: To assess the central vestibular ocular motor system.
b. Population: Minimum age of 4 years, although best completed in ages 9 years and up.
c. Expected outcome: A series of ocular motor tests is completed to assess central vestibulo-ocular pathway function. An abnormality in one of the tests may indicate central vestibulo-ocular abnormalities or other ophthalmologic issues.
d. Method:
   Smooth pursuit test: The pursuit system enables one to generate a conjugate eye movement that can hold the foveae on a slow-moving target. Testing is often completed at different frequencies. Patients are instructed to watch a visual target that moves smoothly side to side. Gain (eye velocity divided by target velocity) and symmetry (a comparison of right versus left gain) are recorded.

   Optokinetic test: This test looks at a reflexive fast-tracking eye movement. For optimal results, stimuli for this test should fill at least 80 percent of the visual field. Often, this test can be completed in the rotary chair while the head is immobile. Patients are instructed to gaze at a moving visual target (similar to watching a train move across their visual field), and a reflexive eye movement (similar to nystagmus) is generated. The slow component eye movement is generated in the direction of the moving target, and the fast phase is generated in the opposite direction. Gain and symmetry are calculated.

   Random saccade test: The central nervous system can generate a fast conjugate eye movement that orients both eyes in the same direction and brings the visual target onto the foveae. This maintains visibility of targets that are moving quickly in the visual field. Patients are instructed to watch for a visual target that will randomly appear. Latency (the time from target onset to the initiation of eye movement), velocity (speed of eye movement), and accuracy are calculated.

   Gaze test: Patients are instructed to watch a stationary visual target that is oriented in center, right, left, up, or down gaze. Testing is then repeated with target removed. In all conditions, the eyes are observed for nystagmus and other abnormal eye movements in each eye position.

e. Normative data: Although the data remain sparse, the following normative data have been reported. These data show differences in pediatric population compared with adults as children continue to develop their brainstem, cerebellum, and parietal, temporal, and frontal cortices. Children also exhibit increased artifact in their responses, especially under the age of 7 years. This is thought to be related to reduced attention (Doettl et al, 2015; Doettl et al, 2018; Self et al, 2020).

Smooth pursuit test: Children have lower gains and more varied asymmetry at all test frequencies (Doettl et al, 2015). In fact, there appears to be an age trend, with the youngest participants (aged 4 years) demonstrating the lowest gains.

Optokinetic test: Abnormal findings on this test are considered indicative of central pathology if dysfunctional. Often, optokinetic nystagmus must be at least 80 percent of the target velocity (i.e., nystagmus must be at least 16° per second using a 20° per second target and 32° per second when using a 40° per second target). Asymmetry is also assessed. In pediatrics, it has been reported (Doettl et al, 2015) that the average asymmetry is 14 percent at 20° per second and 19 percent at 40° per second.

Random saccade test: Longer saccadic latencies have been reported in children (Doettl and McCaslin, 2018): up to 309 ms (48 SD) for children younger than 8 years of age and up to 276 ms (22 SD) for children aged 9–10 years.

f. Considerations:

(i) Infants and toddlers: Not recommended to record formally due to time, goggle fit, and attention limitations.
1. General observational assessment of each test can be produced with visual targets at the bedside (puppet, stickers, finger, light wand, etc.). For example, children can watch a cell phone, and tester moves it to see if there is gaze-evoked nystagmus or presence of smooth pursuit. Place the child on their parent's lap facing out. Have the child's parents hold their head forward so that only the eyes are following the target and not the head.
2. Questions to be answered: Does the child have smooth eye movements? Is the child able to move their eyes quickly and accurately for saccade testing? Is nystagmus present when gazing right, left, up, down? Do the eyes work together?

(ii) Ages 4–8 years: Consider skipping if time and attention are limited; assessment can take place using pediatric goggles.

Modifications:
1. Use a cartoon character as the visual target (software dependent).
2. Shorten the recording time.
3. Hold the child's head for stability.
4. Consider using default calibration, although if the child has difficulty calibrating, then they may have increased difficulty completing recorded ocular motor assessments.
5. Complete in rotary chair so the child can have full field vision with limited distraction.
6. Artifact is common in young children (Doettl et al, 2015).

(iii) Ages 9–teenage: Assessment can take place using appropriately fitting goggles. Calibration can be completed for those who are typically developing. Age-appropriate normative data are used. Children older than 9 years of age can usually complete the entire ocular motor battery.

Bithermal Alternating Caloric Irrigation

a. Purpose: To assess function of each vestibular end organ independently of each other; most commonly used test to identify presence of vestibular weakness and side involved. Warm and cool air or water irrigations are performed on each ear.
b. Population: Most widely tolerated on cooperative children developmentally 5 years of age and older with normal middle ear status.
c. Expected outcome: Nystagmus should be elicited with stimulation of each ear with the peak slow-phase velocity >5° per second and total velocity of all four irrigations >20° per second. Monothermal caloric irrigation screening is also acceptable assuming all other tests suggest a normal exam.
d. Normative data: It is important for each center to establish their own norms. Studies have shown that caloric responses in the pediatric population tend to be more robust (Janky et al, 2018). The magnitude of caloric response decreases with age (Langhagen et al, 2015; Felipe and Cavazos, 2021). In general, most laboratories continue to use a cutoff of 20–30 percent for asymmetry and directional preponderance. The cutoff for a monthermal irrigation test is considerably more stringent and has been reported as 10–15 percent asymmetry (Lightfoot et al, 2009; Adams et al, 2016), with each irrigation requiring a magnitude of 8–15° per second.
e. Method:
(i) Position: Patient's head is positioned at a 30° angle.
(ii) Temperature: Warm and cool water or air irrigations should be performed for each ear. (Air caloric temperatures: warm 48°C and cool 24°C; water caloric: warm 44°C and cool 30°C.) Younger children may be less tolerant for warm air/water stimulation. Stimulation must be consistent between ears.
(iii) Caloric calculation: To calculate asymmetry, the peak slow-phase velocity is used (degrees per second). The peak response for right warm (RW) irrigation, right cool (RC) irrigation, left warm (LW) irrigation, and left cool (LC) irrigation is used to calculate unilateral weakness (UW) and directional preponderance (DP). Whereas unilateral weakness represents the response asymmetry between the ears, the directional preponderance represents response asymmetry of nystagmus

beats in one direction compared with the other direction.

$$100\times(RW + RC) - (LW + LC)/(RW + RC + LW + LC) = \%UW$$

$$100\times(RW + LC) - (LW + RC)/(RW + LC + LW + RC) = \%DP$$

If horizontal spontaneous nystagmus is observed in the precaloric position, it should be added into the calculation.

(iv) Acronym: COWS (cold opposite, warm same) is used to remember the expected response. For example, left cold irrigations will yield right-beating nystagmus, whereas left warm irrigation will yield left-beating nystagmus.

(v) Irrigation recording time: 60 seconds for air/40 seconds for water; consider reducing this time for younger children but ensure that stimulation time is consistent between ears.

(vi) Flow rate: water: 250 mL/minute.

(vii) Time in between: 5-minute interval between each irrigation is necessary to ensure complete decay of nystagmus response from previous irrigation.

(viii) Tasking: Mental tasking is performed to avoid suppression of nystagmus. Consider the use of age-appropriate tasking (i.e., nursery rhymes, songs, easy trivia questions, colors, ice cream flavors, pizza toppings, cartoons, etc.).

(ix) Suppression fixation: When peak nystagmus response is obtained, the child is asked to fixate on a target. The slow-phase velocity is computed for the nystagmus just prior to fixation and after fixation. The fixation index is computed as the ratio of the eye velocity while fixating divided by the eye velocity prior to fixation. A fixation index of at least 50 percent should be obtained to determine that central mechanisms are intact.

(x) Hyperactive responses: Some children may show robust responses. Based on Cincinnati Children's Hospital Medical Center unpublished normative data, a slow-phase velocity greater than 50° per second with air stimulation is considered a central vestibular finding. In the literature, responses have been established to be hyperactive when greater than 40–80° per second (Gonçalves et al, 2008) or if the total of all four caloric irrigations is greater than 140° per second. The right ear and/or left ear can be considered hyperactive if the total for that ear is greater than 110 (Jacobson et al, 2020).

(xi) Pressure-equalizing tubes/tympanic membrane perforation: Water irrigation is contraindicated in patients without an intact tympanic membrane. Air caloric irrigation should be used. Asymmetry cannot be accurately assessed in patients without intact tympanic membranes. When using warm caloric irrigations in patients with tympanic membrane perforations or pressure-equalizing tubes, you may get a paradoxical response. The warm air actually produces a cooling effect on the wet middle ear mucosa; thus, the nystagmus will be in the opposite direction than expected. A hyperactive response may be observed with this population, and based on the comfort level of the patient, the irrigation time may need to be shortened.

f. Considerations and modifications:

(i) Although children should have a recordable caloric response by 10 months of age, calorics are typically not well-tolerated by young children. Factors influencing this include loudness of stimulation, sensitivity to temperature, being tested in the dark, and the sensation of dizziness. Consider lowering the warm temperature, performing monothermal irrigations (Melagrana et al, 2002), or shortening the test time to improve compliance (Janky et al, 2018). When these changes are made, test results will primarily provide information about whether each labyrinth has residual function. Comparison to normative data and interpretation of asymmetry is not appropriate when changes are made to stimulus parameters.

(ii) Water calorics are contraindicated, and only air caloric irrigations should be used in patients who are immunocompromised or whose tympanic membranes are not intact (e.g., perforation or pressure-equalizing tube).

(iii) May not perform if other vestibular tests confirm bilateral hypofunction, or consider using ice water caloric (not always available).

(iv) Monothermal screening may be applied if the following criteria are met (Lightfoot et al, 2009):
1. Warm monothermal caloric asymmetry <15 percent.
2. Responses from each ear are >8° per second.
3. Any spontaneous nystagmus present is >4° per second.

(v) Downfall of caloric irrigations: The variability in the strength of the caloric response from individual to individual can be due to external ear canal size and efficiency of thermal energy transfer across the middle ear.

(vi) The effects of medication on vestibular testing for children are not widely known. For the most part, adult standards are considered. In young children, it is not always necessary to worry about adult test barriers, such as caffeine, alcohol, or makeup before a test. For common medications and their length of activity in the body, readers are directed to Hoyme and Nelson (2018); these medications represent the most well-researched medications that may suppress the central nervous system (Hoyme and Nelson, 2018).

PEDIATRIC ROTATIONAL CHAIR

Test Name: Rotational chair. There are three rotational chair tests used clinically with pediatric patients: sinusoidal harmonic acceleration (SHA), step velocity, and VOR suppression.

Purpose: The purpose of rotational chair testing is to assess peripheral and central VOR function, as well as the central vestibular system's ability to suppress the VOR.

Populations Intended: Children aged 10 months through adulthood can complete SHA and step velocity. Children aged 7 years through adulthood can complete VOR suppression.

Expected Outcomes:

Gain: Ratio of slow-phase eye velocity to chair/head velocity.

Phase: Timing relationship between chair/head velocity and eye movement.

Gain symmetry: Ratio of the rightward and leftward slow-phase eye velocities.

Time constant: Time, in seconds, for the VOR response to decay to 37 percent of the peak value.

VOR suppression percentage: Percentage of VOR gain reduction with fixation.

Normative Data: Equipment software has normative data for patients aged 5 years through adulthood available as the basis for analyses. It is recommended that each testing center collect and establish normative data with their equipment and patient population (Eviatar and Eviatar, 1979; Valente, 2007; O'Reilly et al, 2011; Valente, 2011; Maes et al, 2014; Chan et al., 2016; O'Reilly et al, 2020). The lack of normative data in young children provides future multicenter research opportunities.

Practice Guidance:
Sinusoidal Harmonic Acceleration

a. Purpose: To assess the VOR by rotating the child in a pendular (back-and-forth) pattern at various frequencies while vision is denied.
b. Populations intended: 10 months of age through adulthood.
   VOR responses are present across all frequencies by 10 months of age. Although infants younger than 10 months of age can be tested, any abnormalities found should be confirmed after 10 months of age to rule out maturational factors before a definitive statement regarding VOR function can be made (Eviatar and Eviatar, 1979; Staller et al, 1986; Valente, 2007; O'Reilly et al, 2011; Janky et al, 2018; Jacobson et al, 2020).
c. Expected outcome: Gain, phase, and gain symmetry.
d. Normative data: Several studies have attempted to establish pediatric normative data for SHA testing. Although these studies have yielded conflicting results in relation to patient age and gain, one consistent finding is higher gain in children compared with adults. Therefore, high gain should not be considered an abnormal finding when assessing children (Casselbrant et al, 2010; Charpiot et al, 2010; Valente, 2011; Maes et al, 2014; Chan et al, 2016; Janky et al, 2018; Jacobson et al, 2020; O'Reilly et al, 2020).
e. Method: Due to nonlinearities of the vestibular system, assessment at a minimum of three frequencies is recommended. These frequencies should include a high, a mid, and a low frequency (i.e., 0.01, 0.04, and 0.16 Hz) (Staller et al, 1986; Jacobson et al, 1993; Valente, 2007; Casselbrant et al, 2010; Myers, 2011; O'Reilly et al, 2011; Valente, 2011; Chan et al, 2016; Janky et al, 2018). If SHA results at these frequencies are normal reference range, testing can be stopped. If SHA results at any of these frequencies are abnormal, testing should be repeated to ensure consistency before completing additional testing at adjacent frequencies. In addition, tympanometry should be performed prior to testing as middle ear dysfunction can impact results.
f. Considerations: The order of testing frequencies can be varied for patient comfort and to increase compliance for completion of test battery. Starting with a higher testing frequency (e.g., 0.16 Hz) should be considered over a low testing frequency (e.g., 0.01 Hz) because lower frequencies are more likely to provoke symptoms of motion sickness (Myers, 2011; Maes et al, 2014; O'Reilly et al, 2020). Particular consideration should be made for patients with known motion intolerance, generalized anxiety disorders, or nervousness in testing environment.
g. Interpretation and reporting (Jacobson et al, 1993; Valente, 2007; Myers, 2011; O'Reilly et al, 2020):
   (i) Gain:
      1. High gain: Not considered an abnormal finding for children.
      2. Low gain: Peripheral vestibular pathology (unilateral or bilateral).
      3. Factors that affect gain: Fatigue, stress/anxiety, level of alertness, difficulty mental tasking (Eviatar and Eviatar, 1979; Jacobson et al, 1993; Valente, 2007; Casselbrant et al, 2010; Myers, 2011; Maes et al, 2014; Janky et al, 2018; O'Reilly et al, 2020).
   (ii) Phase:
      1. Phase lead: Primarily indicates peripheral vestibular pathology (unilateral or bilateral) but can indicate a central vestibular disorder.
      2. Phase lag: Central vestibular disorders.
      3. Factors that affect phase: Head movement/slippage during testing can affect phase. It is important to ensure secure head movement during testing.
   (iii) Gain symmetry:
      1. Asymmetry indicates a bias in the vestibular system and can be present in unilateral and/or asymmetrical bilateral peripheral vestibular pathology, particularly if the pathology is in an uncompensated state.

2. Studies have documented greater variability for gain symmetry in children compared with adults. However, it is still considered a reliable measurement.

Step Velocity

a. Purpose: To evaluate the peripheral vestibular system (cupula mechanical response) and central vestibular system (velocity storage and adaptation).
b. Populations intended: 10 months of age through adulthood.

   VOR responses are present across all frequencies by 10 months of age. Although infants younger than 10 months of age can be tested, any abnormalities found should be confirmed after 10 months of age to rule out maturational factors before a definitive statement regarding VOR function can be made (Eviatar and Eviatar, 1979; Staller et al, 1986; Valente, 2007; O'Reilly et al, 2011; Janky et al, 2018; Jacobson et al, 2020).
c. Expected outcome: Gain, time constant, and time constant symmetry.
d. Normative data: Current research suggests that step velocity testing results in children should fall within established adult normative data (Casselbrant et al, 2010).
e. Method: Assessment at one rotational velocity is recommended. Equipment software may default to 100° per second, which is a suitable velocity for the pediatric population. The rotational chair accelerates to the set velocity, maintains the velocity for 30–45 seconds, and decelerates to a stop. Acceleration and deceleration phases are completed in the clockwise and counterclockwise directions. Any abnormalities found should be repeated to ensure consistency. As with SHA testing, tympanometry should be performed prior to testing as middle ear dysfunction can affect results.
f. Interpretation and reporting:
   (i) Gain:
      1. High gain: Like SHA testing, high gain is not considered an abnormal finding in children (Valente, 2007; Charpiot et al, 2010; Maes et al, 2014; Chan et al, 2016; Janky et al, 2018; Jacobson et al, 2020; O'Reilly et al, 2020).
      2. Low gain: Peripheral vestibular pathology (unilateral or bilateral) or central vestibular pathology.
   (ii) Time constant (Valente, 2007; Myers, 2011; Jacobson et al, 2020):
      1. Reduced time constants (<10 seconds): Peripheral vestibular pathology (unilateral or bilateral) or central vestibular pathology; correlate with phase lead in SHA testing.
      2. Long time constants (>26 seconds): Central vestibular pathology, migraine, or motion intolerance.
   (iii) Time constant symmetry (Valente, 2007; Myers, 2011; Jacobson et al, 2020): Asymmetry of time constant (>30 percent) is consistent with unilateral peripheral pathology.

Vestibulo-Ocular Suppression

a. Purpose: To assess the central vestibular pathway's ability to suppress the VOR.
b. Populations intended: 7 years old through adulthood (Jacobson et al, 2020; O'Reilly et al, 2020).
   Testing can be performed with children who demonstrate an understanding of the test instructions and ability to maintain visual focus on the target.
c. Expected outcome: Percentage of VOR gain reduction with fixation.
d. Normative data: Expected VOR suppression in adults is greater than 70 percent across frequencies (Jacobson et al, 1993). Like SHA testing, there is a lack of established pediatric normative data. Greater variations in VOR gain reduction are possible given the well-documented high VOR gains in the pediatric population.
e. Method: Assessment at two frequencies, a high and a low frequency (i.e., 0.16 Hz and 0.04 Hz) is recommended (Jacobson et al, 1993; Myers, 2011; O'Reilly et al, 2020). Select frequencies previously completed with SHA testing; however, frequencies below 0.04 Hz should not be assessed (Melagrana et al, 2002). Any abnormalities found should be repeated to ensure consistency.
f. Interpretation and reporting:
   (i) VOR gain suppression percentage:
      1. Low suppression: Indicative of central vestibular pathology (Myers, 2011; O'Reilly et al, 2011, 2020; Jacobson et al, 2020).

         Cross-check for other abnormal central vestibular test findings.

Pediatric Considerations and Modifications:

a. Calibration: Standard calibration should be completed if the patient is at an age/developmental level to participate in the task. Default calibration is often used with infants and young children when standard calibration cannot be adequately performed.
b. Seating and head position:
   (i) Children should be in a seated position, properly buckled in the rotational chair. Infants and young children under 40 pounds can use a car seat designed for use with the rotational chair. Children who do not tolerate sitting in the car seat can sit in the lap of a caregiver. Children over 40 pounds can be seated on a booster seat or standard seat of the rotary chair depending on their height.
   (ii) The child's head should be positioned to ensure that the horizontal canal is in the lateral plane and secured in a way to avoid excessive movement during testing (Myers, 2011; Valente, 2011; Janky et al, 2018; O'Reilly et al, 2020). This can be achieved by holding the child's head throughout testing when seated on a caregiver's lap or using

Velcro straps that are similarly used in testing adult patients when seated in the rotational chair, car seat, or booster seat.

(iii) Young children can hold a toy for comfort during testing; however, light-up toys are prohibited. Additionally, shoes that light up should be removed prior to testing and caregivers with watches that light up should remove their watch if holding their child during testing.

c. Recording method: Various recording methods are available for rotational chair testing. The recording method used will be dependent on child's age, size, developmental level, and overall compliance (Janky et al, 2018; Jacobson et al, 2020; O'Reilly et al, 2020).

(i) Currently, there are no commercially available binocular goggles sized for infants and young children to allow for video data collection, and the pediatric-sized goggles available are designed to fit school-aged children.

(ii) Testing with electronystagmography electrodes using a bitemporal montage and/or infrared camera is recommended for infants and young toddlers until goggle options are an appropriate physical fit on the head/face. The downside of using an infrared camera is that it only allows subjective observation of the VOR response. Given the lack of gain, phase, and symmetry data, only the presence/absence of a VOR response can be reported. The infrared camera cannot be used for VOR suppression testing.

(iii) Monocular goggles fit children about 2 years of age. If children are sitting with a caregiver, consider instructing the caregiver to assist with goggle retention during testing. When children are resistant to goggle placement, goggles may be held to the patient's face to allow for video data collection; however, this may not be feasible for step velocity testing given the speed of rotation.

(iv) Adult binocular goggles can be used if a binocular recording is preferred and both eyes can be centered between the goggles and software; however, there is the potential for gapping between the child's face and goggles. Other modifications to the testing environment may be needed to ensure a vision-denied state if testing is not conducted in an enclosed rotational chair.

d. Tasking:

(i) Tasking should focus on keeping the child mentally distracted, aware, alert, and motivated to keep their eyes open, while minimizing excessive eye blinking/shifting, fear, and crying throughout testing. Include a caregiver as a familiar voice for the child's comfort and compliance for testing. The child's language and developmental level should be taken into consideration when determining appropriate tasking speed and difficulty. If suppression of the VOR is suspected, increasing the difficulty of tasking is recommended (Eviatar, 1979; Jacobson, 1993; Valente, 2007; Casselbrant, 2010; Myers, 2011; Maes, 2014; Janky, 2018; O'Reilly, 2020).

(ii) Examples of tasking by age include the following:

1. Infants: Singing favorite songs/nursery rhymes, reciting stories, and other age-appropriate acoustic rituals.
2. Preschool: Asking simple questions about their daily routine, family/friends, and favorite activities can be incorporated once child has the speech and language skills to answer "wh" questions.
3. 5–9 years old: Asking questions about their home/school routine, family/friends/pets, and favorite activities (i.e., sports, movies/TV/video games, books).
4. 10 years of age and older: Asking questions about their family/friends/pets and favorite activities (i.e., sports/dance/martial arts), reciting plots of movies/books, steps in recipes, listing school schedule, and/or describing their room/house.

e. Testing environment: To fully deny vision, a rotational chair with light-free enclosure is recommended. To minimize patient fear/anxiety in the testing environment, visual access can be allowed as needed between cycles throughout testing.

Examples: Opening pediatric monocular goggle cover, opening rotational chair enclosure door, using light-emitting toys between tests.

f. Congenital nystagmus: Work is being completed on congenital nystagmus and how it affects the results of vestibular testing. Whereas magnitude and direction of the nystagmus can be accounted for during caloric testing, potential adaptations for rotary chair testing or vHIT are more complex. The eye movements in this group typically tend to be horizontal pendular or jerk nystagmus. Children with nystagmus may swing their head with oscillations or even present with a head tilt to account for their null point. These head positions may cause a phase issue during rotary chair testing. Ensure proper security of the head in the chair. The nystagmus itself may also pose a problem with gain and symmetry in rotary chair.

Supplies: Standard goggles, pediatric goggles, infrared camera, electronystagmography electrodes/leads, car seat, booster seat, intercom, wireless video camera, illuminated toys for midline focus, quiet toys without lights for patient distraction/comfort.

PEDIATRIC VESTIBULAR QUESTIONNAIRES

Test Name: Questionnaires available for the pediatric population differ from their adult counterparts to be age-appropriate and because in some instances the data are collected by a caregiver or tester. Although there are a variety of questionnaires that can be used with children, four interview-style questionnaires are detailed below including the Vanderbilt Pediatric Dizziness Handicap Inventory for Patient Caregivers (DHI-PC) (McCaslin et al, 2015), the Ages and Stages Questionnaire (ASQ)

(Squires and Bricker, 2009), the Pediatric Vestibular Symptom Questionnaire (PVSQ) (Pavlou et al, 2016), and the Pediatric Visually Induced Dizziness Questionnaire (PVID) (Pavlou et al, 2016). Additional questionnaires, such as the Fear of Falling Avoidance Behavior Questionnaire, are also available. It should be noted that some scales can be useful when obtaining the case history; for example, children can be asked to rank the degree of their dizziness (0–10; 0 = no dizziness, whereas 10 = unable to move because of dizziness). The FACES pain scale or FLACC (Face, Legs, Activity, Cry, and Consolability) scale can be used for younger children to gauge the degree of their dizziness.

Purpose: To gain a better understanding of any symptoms the child is experiencing and determine whether the child needs a diagnostic vestibular evaluation. In addition, questionnaires can help the clinician better understand the impact of vestibular impairment/symptoms on the child and help guide treatment/management. Questionnaires may also be used to track progress toward therapy goals using the pre-/post-test paradigm. No specialized equipment is needed, and the questionnaire can be completed prior to the test visit or at a separate appointment.

Expected Outcome and Methods: See below for each questionnaire.

Ages and Stages Questionnaire—Gross Motor Section Only

a. Purpose: To evaluate age-appropriate gross motor milestones.
b. Population: Birth to 60 months of age.
c. Expected outcome: The score for each milestone associated with the child's age is added and used to determine whether the child is above, close to, or below the cutoff score. The recommendation is to seek services if below target and monitor closely if close to the cutoff.
d. Method: The caregiver answers six questions about the child's progress toward age-appropriate gross motor milestones, indicating "yes" (10 points), "sometimes" (5 points), or "not yet" (0 points). The points are totaled for the gross motor section and a cutoff score is given based on the child's age.
e. Normative data: Once the questionnaire is completed, the score is plotted on the score sheet. If the score falls in the darkest shaded section, this suggests that the child is below the cutoff score and is not yet meeting age-appropriate gross motor targets; therefore, the child should be referred for services (e.g., physical therapy). If the score falls in the light shaded section, this suggests that the child is close to the cutoff score and should be monitored. If the score falls in the white section, this suggests that the child is above the cutoff and no intervention is needed.
f. Considerations: This is a helpful screener that can be quickly given at a hearing aid check or other audiological appointment. Although this test seems most sensitive for vestibular losses that are bilateral or uncompensated, its overall clinical usefulness for evaluating gross motor milestones in children with vestibular loss has not been studied. This test can be given more than once as a child grows and has different motor expectations.

Vanderbilt Pediatric Dizziness Handicap Inventory for Patient Caregivers

a. Purpose: This is a validated dizziness disability/handicap outcome measure for use with the pediatric population. This questionnaire gives information on the functional impact of the child's dizziness on their life and quantifies the psychosocial impact.
b. Population: Children aged 5–12 years of age.
c. Expected Outcome: Children who are affected the most by dizziness will have a higher score.
d. Method: The caregiver will answer "yes" (4 points), "sometimes" (2 points), or "no" (0 points) to 21 questions about their child's dizziness. The total score is out of 84.
e. Normative data: A DHI-PC total score of 0–16 indicates no participation and activity limitation; a score of 16–26 indicates mild participation and activity limitation; a score of 26–43 indicates moderate participation and activity limitation; a score of >43 indicates severe participation and activity limitation.
f. Considerations: Can be used as a pre-/post-test treatment measure. Proxy bias should be considered when evaluating the scoring.

Pediatric Vestibular Symptom Questionnaire

a. Purpose: To screen children for vestibular symptoms.
b. Population: Children aged 6–17 years.
c. Expected outcome: Children with higher scores have greater symptom severity.
d. Method: Children answer 10 questions about how often they feel dizziness or unsteadiness. They rate the severity of their vestibular symptoms in the past month using a Likert scale: 0 (never), 1 (almost never), 2 (sometimes), and 3 (most of the time). Of note, this scale is not reflected in the published questionnaire; however, the 0–3 scale should be used when scoring. Children are asked to respond with the help of a parent or caregiver as needed.
e. Normative data: Scores ≥0.68 out of 3 can differentiate a child with a vestibular disorder or concussion from a healthy child (95 percent sensitivity and 85 percent specificity) and indicate the need for a diagnostic vestibular evaluation.
f. Considerations: The questionnaire is valuable in differentiating healthy children from children with vestibular symptoms but does not differentiate children with vestibular dysfunction from children with concussion.

Pediatric Visually Induced Dizziness Questionnaire

a. Purpose: To quantify the presence and severity of visually induced dizziness.
b. Population: Children aged 6–17 years.
c. Expected outcome: Children with higher scores have greater symptom severity.

d. Method: Children answer 11 questions about how often they feel dizziness or unsteadiness in different places and situations. They rate the severity of their vestibular symptoms in the past month using a Likert scale: 0 (never), 1 (almost never), 2 (sometimes), and 3 (most of the time). Children are asked to respond with the help of a parent or caregiver as needed.
e. Normative data: Scores ≥0.45 out of 3 can differentiate a child with visually induced dizziness from a healthy child (83 percent sensitivity and 75 percent specificity) that may be helpful for guiding treatment. The patient group consisted of children with migraine, concussion, and vestibular dysfunction. Although not statistically significant, children with vestibular dysfunction had the highest scores, followed by concussion and migraine.
f. Considerations: The questionnaire is valuable in differentiating healthy children from children with visually induced symptoms but does not differentiate children with migraine, concussion, and vestibular dysfunction from one another.

CONCLUSIONS

Vestibular function testing is recommended in children with reports of dizziness and in children with imbalance or delays in gross motor milestones. This clinical consensus statement serves as a guide for choosing the appropriate vestibular function tests when working with young children. Table 1 provides a brief overview of the vestibular function tests available by age of the child. Whether or not vestibular function tests yield positive findings, children may need additional evaluation by other practitioners. Physical therapists and occupational therapists are the most common complement to the diagnostic assessment; however, children may also need assessment by psychology for underlying psychological comorbidities (i.e., anxiety), otolaryngology, developmental optometry, cardiology, or neurology. Although finding individuals in each of these disciplines can be challenging, they all provide a unique contribution to the assessment and rehabilitation of children with dizziness. Thus, having knowledge of these disciplines is necessary when working with pediatric vestibular patients. Children have activities of daily living that are different from those of adults, so the overall goal of assessment and intervention should be to arrive at the best recommendations to help the child return to their lives without hinderance to educational, social, and developmental outcomes.

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