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ASSESSMENT: VESTIBULAR TESTING TECHNIQUES IN ADULTS AND CHILDREN

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Overview. Neurologists are frequently called upon to evaluate patients with vertigo and dizziness and, in some cases, to make sense of abnormal vestibular tests. Consequently, it is useful to have some familiarity with the methods used to test vestibular function.

The vestibulo-ocular reflex (VOR) is a reflex that acts at short latency to generate eye movements that compensate for head rotations in order to preserve clear vision during locomotion. The VOR is the most accessible gauge of vestibular function. Evaluating the VOR requires application of a vestibular stimulus and measurement of the resulting eye movements.

This report reviews the advantages and limitations of the methods of stimulating the vestibular system: caloric irrigation, rotational chair testing, and auto-rotational testing. Vestibular testing in children is given additional consideration because of the paucity of recent reviews on the topic. This report will not address eye movement recording techniques, the neurophysiology of the VOR, which is reviewed elsewhere,[1,2] or interpretation of nystagmus.

Literature review. This evidence-based assessment was developed from a review of published articles obtained through the MEDLINE database of the National Library of Medicine. Relevant publications were rated by the strength of evidence according to a scheme approved by the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology (see Appendix 2).

Bedside vestibular assessment. Not every dizzy patient needs quantitative vestibular testing. Clinical examination can provide some qualitative information about vestibular function (table 1). Patients with dizziness should be examined for nystagmus in the supine and lateral head positions as well as following the Dix–Hallpike maneuver. Spontaneous and gaze-evoked nystagmus may help localize the lesion in a patient with a suspected vestibular disorder.[2,3] Peripheral vestibular nystagmus is often suppressed by visual fixation, but may be seen during funduscopic examination in the dark. Frenzel goggles have 10+ diopter lenses that prevent fixation, allowing vestibular nystagmus to be seen. Skew deviation and a head tilt suggest a unilateral disturbance in the otolith-ocular pathways. Shortly after unilateral (otolith) vestibular loss, patients often perceive vertical as being tilted 10 to 30 degrees toward the lesioned side.[4,5] In time, this distortion diminishes, but in some cases it may be present even after vestibular compensation has taken place.

Although it is not the purpose of this article to thoroughly review the clinical vestibular examination, recently there have been useful new developments worthy of mention. For detection of unilateral vestibular deficits, the head thrust sign, head-shaking nystagmus, and vibration-induced nystagmus can be helpful. The head thrust sign entails horizontal (yaw-plane) high-acceleration head thrusts, while the patient maintains gaze on the examiner. During this maneuver, one looks for a "catch up" saccade when the head is rapidly turned toward the lesioned side.[6] Head-shaking nystagmus can also demonstrate vestibular aysmmetry.[7] The head is vigorously turned back and forth horizontally with eyes closed for about 30 seconds, to "charge" the brainstem's velocity storage mechanism.[1] Upon stopping and opening the eyes (preferably using Frenzel lenses), nystagmus usually beats away from the lesioned side; such nystagmus is absent in normal subjects. Tapping the head[8] or application of a 60-Hz vibration stimulus to the mastoid bone can also evoke horizontal nystagmus beating away from the side of the vestibular loss.[9]

Dynamic visual acuity testing is indicated for those patients suspected of having bilateral vestibular loss[10]; abnormalities usually correlate with oscillopsia. Worsening of visual acuity by at least three lines on a visual acuity chart (e.g., Snellen chart or Rosenbaum card) during head turning from side to side at 1 Hz or more is abnormal. Further

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Table 1 *Components of clinical vestibular examination and subtests of standard electronystagmography (ENG) or infrared video-oculography (IRV)*

ENG/IRV subtest	Description of the test
Smooth pursuit tracking	Eye movement tracking of a moving target
Optokinetic nystagmus	Eye movement response to an optokinetic stimulus
Spontaneous nystagmus	Observe for fixation stability and spontaneous nystagmus, if any
Saccade testing	Observe the velocity, accuracy and latency of rapid eye movements from one target site to another
Gaze-evoked nystagmus	Observe for nystagmus and gaze holding during eccentric gaze
Static positional nystagmus	Observe for nystagmus during or after head position changes
Dix-Hallpike maneuver	Observe for nystagmus after rapid positioning from the sitting to head hanging right or left position
Bithermic caloric testing	Warm and cool irrigations applied to each ear for comparison of vestibular responses
Clinical tests of vestibular loss	
Head thurst sign	Look for a catch-up saccade with quick head turns toward the side of unilateral vestibular loss
Head-shaking nystagmus	Observe for nystagmus away from the side of unilateral vestibular loss after head shaking
Vibration-induced nystagmus	Observe for nystagmus away from the side of unilateral vestibular loss when mastoid vibration is applied
Subjective visual vertical	Patient directs bar or line to what he or she perceives to be straight vertical; in acute otolith dysfunction, the bar or line deviates to the side of unilateral vestibular (otolith) loss
Dynamic visual acuity	Look for a three-line decrease in visual acuity during rapid head turning indicative of bilateral peripheral vestibular loss

information on these bedside vestibular tests is reviewed elsewhere.[11] Hyperventilation has been used to accentuate downbeating nystagmus in patients with cerebellar lesions[12] and was found to evoke nystagmus toward the side of vestibular schwannomas in some patients.[13]

The sophistication of the clinical examination of the vestibular patient is rapidly evolving, but there is still a need to quantify vestibular function for validation, prognostication, and treatment planning. Furthermore, in some instances a suspected vestibular abnormality not evident by clinical evaluation can be determined by quantitative testing.[14] At present, there are no studies directly comparing the sensitivity and specificity of clinical vestibular examination to that of caloric or rotational chair vestibular testing.

Quantitative vestibular testing. *Eye movement recordings.* To test the VOR reliably, it is important to determine that other types of eye movements are normal for two reasons. First, proper interpretation of the VOR responses depends on intact eye movements. Second, abnormalities of eye movements can themselves be useful in localizing neurologic abnormalities. The most commonly employed method of recording eye movements is electro-oculography (EOG). This technique measures the change in corneoretinal potential using electrodes placed around the inner and outer canthi of the eyes. EOG permits recordings of the direction, amplitude, and velocity of eye movements; this should not be confused with EOG as used in the ophthalmologic literature—to determine retinal function. Infrared video nystagmography is an alternative method of determining eye movements that utilizes infrared cameras positioned to detect movement of the eyes in darkness.[15,16] Horizontal eye movements are the most important and easiest to record because vertical eye movements are prone to blinking and eyelid movement artifacts. However, vertical eye movements should be recorded to help determine vertical nystagmus and blinking that may affect horizontal channel recordings. Torsional eye movements are not recorded with EOG, but can be seen on infrared video recordings. Magnetic search coil is the most reliable eye movement recording technique, but it requires the patient to wear a specialized contact lens during testing and is available for clinical use only in a few institutions.

Methods of vestibular stimulation. Measurement of the VOR is generally limited to responses from the horizontal semicircular canals because they are easily and reliably determined. The function of the vertical semicircular canals and the utricle and saccule are not tested by commercially available vestibular testing equipment.

Two methods of stimulating the vestibular apparatus are used during testing: *caloric irrigation* (air or water irrigation of the external ear canals) or *rotation* of the head. Caloric irrigation produces a convection current of endolymph when the canal is oriented vertically because endolymph sinks when cooled and rises when warmed. Thus cool irrigation causes nystagmus away from the ear and warm irrigation causes nystagmus toward the ear. Caloric irrigation is inherently limited by the effectiveness of heat transfer between the external and inner ear. A small or occluded external ear canal reduces the intensity of the caloric stimulus to the inner ear. Consequently, a reduced response may result from inadequate irrigation rather than vestibular hypofunction.

Rotational testing can be performed using active (volitional) or passive, low frequency or high frequency, and head only or whole body (en bloc) rotations. There are two main advantages of rotational testing over caloric testing. First, rotational testing does not depend on the effectiveness of thermal energy transfer across the middle ear and through the temporal bone. Second, rotational testing allows precise application of multiple frequencies of rotational stimuli, whereas caloric testing is equivalent to a single, very low frequency (0.003 Hz) vestibular stimulus.[17] One of the main disadvantages of rotational testing is that rotation affects both ears simultaneously, making it less helpful in detecting unilateral lesions.

The stimuli during rotational testing are usually impulses or sinusoidal rotations. Impulse rotations demand a rapid acceleration (usually about 100°/s/s) to a constant speed and, after the nystagmus fades away, a sudden stop during which

the nystagmus is again recorded. Sinusoidal rotations are performed by rotating the patient's head or body from side to side so that head movement recordings appear as a series of sine waves. The frequency of the rotations refers to the number of turns per second and is expressed in Hertz. VOR testing is done in darkness or with the eyes closed to avoid the influences of vision on the VOR. The VOR can also be suppressed by fatigue or inattentiveness.[18] Consequently, mental alerting tasks (e.g., mental arithmetic) are used to maximize VOR responses.

By convention, measurement of the VOR in rotational testing is expressed in terms of the gain (slow-component eye velocity : head velocity) and the phase shift, which is an offset in the timing of eye movement relative to head motion. A gain of 1.0 and a phase shift of 180° indicate perfect VOR function, meaning that the eyes move synchronously with head movement but in the opposite direction. The VOR is at its best during head oscillations or rotations of 1 to 6 Hz as encountered in natural locomotion,[19,20] but is less efficient at the extremely low frequencies of head movement. The VOR may also show asymmetry, which is present in some cases of unilateral vestibular hypofunction.[21,22]

Caloric irrigation. Electronystagmography using caloric irrigation of the external ears was the topic of a previous report of the Therapeutics and Technology Assessment Subcommittee[23] and will only receive brief comment in this report. Electronystagmography (ENG) and infrared video-nystagmography (IRV) differ in the method by which eye movements are recorded, but are otherwise similar. Both techniques include caloric irrigation, testing for spontaneous and positional nystagmus, smooth pursuit tracking, saccadic eye movements, and optokinetic nystagmus (table 1).

Bithermal caloric testing is the most commonly used method to evoke vestibular nystagmus. Warm and cool water (or air) irrigations are applied to each ear and the maximum velocity of the slow component of nystagmus from each ear is determined. These data can then be used in a standard formula described by Jonkees[18,24]:

100 x [(LC + LW) - (RC + RW)/(LC + LW + RC + RW)] = % caloric paresis;

100 x [(LC + RW) - (RC + LW)/(LC + LW + RC + RW)] = % directional preponderance

where RC, RW, LC, and LW indicate the peak slow-component velocity of nystagmus from right cool, right warm, left cool, and left warm irrigations.

Caloric paresis refers to the relative decrease in the responses of one side compared with the other. Because this technique directly compares the vestibular function on the right and left sides, caloric testing is highly reliable in detecting unilateral peripheral vestibular loss.[2,3,23,25,26] Each laboratory must determine its own normal range; however, in most testing centers a caloric paresis of greater than 22 to 25% indicates unilateral peripheral vestibular loss. Directional preponderance indicates nystagmus greater in one direction than in the other during caloric testing. In most laboratories, directional preponderance of greater than 26 to 30% indicates an abnormal asymmetry between right-beating nystagmus (right warm and left cool) and left-beating nystagmus (left warm and right cool) evoked by the caloric irrigations.[18] Ice water caloric irrigation is an even stronger stimulus sometimes used as a supplement to bithermal calorics when the responses are poor, or in assessing comatose patients. In a comatose patient, an intact vestibular response causes slow, tonic movement of the eyes toward the side irrigated with ice water. In coma, there are no corrective fast phases of nystagmus so only the slow component of nystagmus is seen.

The disadvantage of caloric testing is interindividual variability of caloric vestibular responses. The wide variability in the strength of the caloric stimulus is due in part to differences from person to person in the size of the external ear canal and the efficiency of thermal energy transfer across the middle ear.

Conclusion. As reported in a previous American Academy of Neurology Technology Assessment, caloric vestibular testing is an established, strongly recommended technique that is widely accepted as particularly useful, particularly in determining unilateral vestibular hypofunction based on published studies determining its diagnostic accuracy.[23]

Passive rotational testing. *Rotational chair testing (motor-generated rotations).* Background. Passive rotational testing refers to head rotations in which the subject takes no active role in producing the movements. Rotational chair testing is a standard, commercially available example of passive rotational testing. The patient is placed in a chair that rotates under the control of a computer so that the patient's head and body move in unison with the chair. The eye movements are compared with the head movement to quantify the VOR in terms of gain and phase shift, as discussed earlier. The computer precisely controls the velocity and frequency of rotations so that the VOR may be tested at multiple frequencies in a single session. Commercial rotational chair systems in age-matched cohorts have established normative data for their respective products. Data has also been published from other laboratories indicating age-related normal values.[2,3,21]

Clinical uses. Rotational chair testing is most useful in determining the presence of bilateral peripheral vestibular loss.[17,21,27,28] It is more specific than caloric testing for bilateral vestibular loss, and may help distinguish whether reduced caloric responses are due to inadequate caloric stimulation or due to true vestibular loss. Caloric testing can result in artifactually reduced vestibular responses due to inadequate irrigation.[21,26,29] Rotational chair testing is also helpful in monitoring vestibular function when ototoxic medications such as gentamicin and cisplatin are administered,[28] in those with gait disequilibrium,[30] and in testing infants and young children, as will be discussed later. Knowing the degree of vestibular loss may also be useful in deciding whether a patient's balance rehabilitation should emphasize exercises that enhance residual vestibular function or those that retrain the individual to rely more on somatosensory and visual cues.[31,32]

Table 2 *Vestibular testing consensus recommendations on indications*

Symptom/disease	Recommended tests	Findings
Vestibular neuritis	ENG, audiogram	Unilateral vestibular loss
Labyrinthitis	ENG, audiogram	Unilateral vestibular and hearing symptoms
Benign paroxysmal positional vertigo	Clinical examination using Dix-Hallpike maneuver*	Paroxysmal positional nystagmus
Ménière's disease	ENG, audiogram	Unilateral vestibular loss, hearing reduction
Ototoxic vestibulopathy	Rotational chair and ENG	Bilateral vestibular loss
Acoustic neuroma (vestibular schwannoma)	Audiogram, MRI	Unilateral sensorineural hearing reduction, enhancing 8th cranial nerve tumor on MRI

* Electronystagmography (ENG) will often detect paroxysmal positional nystagmus but is usually unnecessary because it can be observed clinically

Rotational chair testing at low frequencies (<0.05 Hz) is at least as sensitive as caloric testing in determining bilateral vestibular loss.[17,21,33,34] The correlation between hypoactive caloric vestibular responses and reduced, low-frequency VOR gain by rotational chair testing is generally strong, especially when bilateral vestibular loss is severe. At higher frequencies (0.8 to 1.5 Hz), rotational VOR responses may actually be less sensitive than caloric testing.[17,21,28,33,34] However, rotational chair testing easily lends itself to the testing of VOR function at multiple frequencies using sinusoidal or impulse rotations.

Rotational chair testing is also more specific than caloric testing for bilateral vestibular hypofunction. In one study, some patients with absent ice water caloric responses actually had normal VOR at 0.05-Hz rotations,[28] though most studies have reported good correlation between low-frequency VOR gain reduction, increased phase lead, and reduced caloric responses.[17,21,33]

One disadvantage of rotational chair testing is that it is not widely available, owing in large part to its expense. The main limitation of rotational chair testing is that it is not sensitive in detecting chronic unilateral vestibular hypofunction,[21,29,35] though this may be improved to some degree by tilting the head forward during rotations.[36] When high-velocity impulse rotations and sinusoidal rotations are combined, the results are highly correlated with complete unilateral caloric weakness.[29] However, in patients with less than 50% caloric asymmetry, it can be detected only about one-third of the time by rotational testing.[29] Furthermore, if rotations are done only at low velocities, unilateral vestibular loss may be profound and still go undetected.

Passive head or whole body testing (examiner-generated rotations). Recently, passive head-only (head-on-body) and passive whole-body rotations have been studied by using EOG to measure eye movements while an angular velocity sensor on a head band measures head velocity.[37,38] The patient's head or entire body can be rotated by the examiner to the rhythm of a metronome. This technique is passive from the patient's standpoint, though it requires some degree of cooperation from the patient to allow the head to be turned by the examiner. This technique has the advantage of being portable and relatively inexpensive because it eliminates the need for a large and expensive rotational chair apparatus.

In a comparison of head-only, whole-body, and standard rotational chair testing, responses correlated closely, using all three techniques at frequencies between 0.025 and 1.0 Hz in 14 patients with bilateral and 21 with unilateral peripheral deficits.[37]

Neck turning from the head-only rotations might be expected to activate the cervico-ocular reflex (COR), which could supplement the VOR. Although it has been shown that augmentation of the VOR by the COR is negligible (<0.05°/s) in normal subjects,[39] evidence suggests the COR is of greater importance in patients with vestibular loss.[40,41] Hence, the influence of the COR in patients with bilateral vestibular deficiency needs further study.

Conclusion. Rotational chair testing is an effective and established technique for documenting bilateral peripheral vestibular hypofunction based on Class II,[21,28] Class III,[42] and Class IV[2,17,27,33,34] evidence. By expert consensus, rotational chair testing is considered the "gold standard" for documenting bilateral peripheral vestibular hypofunction,[43] though it is not the only method for determining bilateral vestibular loss. Passive head-only and whole-body rotations rely on the same principles as rotational chair testing; however, there are at present only two Class II studies of its use in bilateral vestibular loss[37,43] and one Class IV[38] study of its use in normal elderly patients. Table 2 outlines some guidelines for using rotational versus caloric testing based on the condition suspected. Table 3 summarizes the evidence-based conclusions of the vestibular testing techniques.

Active head rotational testing (AHR). *(Patient-generated rotations).* Background. In AHR, the patient is instructed to rotate the head from side to side horizontally or vertically to an auditory cue at frequencies ranging from 2 to 6 Hz. Eye movements are recorded using EOG and head movements are recorded using a velocity rate sensor attached to the head. It was originally developed in part to allow testing of the VOR high-frequency responses from 2 to 6 Hz,[52,53] which are encountered during normal locomotion.[19,20] Because many patients can turn their head from side to side at frequencies of greater than 1 Hz, it was reasoned that eye and head movements could be recorded during such voluntary head motions and the expense of rotational chair testing could be avoided.

Smooth pursuit causes higher than expected VOR responses during slower head movements (< 1.0 Hz)[41,54,55] but not during more rapid head turning (>2.0 Hz).[56,57] Because of this, AHR testing can be done in the light with the eyes open if the head movement is 2.0 Hz or more.

Table 3 *Comparison of vestibular test techniques*

Technique	Advantages	Limitations	Evidence status
Clinical head-shaking test[7]	Inexpensive, easily performed during examination	Nonquantitative; may not detect bilateral vestibular loss or mild unilateral vestibular loss	Class III[7,44-48]
Vibration-induced nystagmus[9]	Inexpensive, easily performed during examination	Nonquantitative; may not detect bilateral vestibular loss or mild unilateral vestibular loss	Class III[8,9]
Clinical head thrust sign[6]	Inexpensive, easily performed during examination	Nonquantitative; may not detect bilateral vestibular loss or mild unilateral vestibular loss	Class III[6,49-51]
Caloric testing (electronystagmography or infrared video nystagmography)	"Gold standard" study for detecting unilateral vestibular loss	Intensity of caloric stimulation depends on anatomy and technique of irrigation Less sensitive and specific than rotational chair testing for bilateral vestibular loss	Established as an effective testing technique (A rating) based on controlled studies[23] and by expert consensus
Rotational chair testing (computer-driven chair rotations)	"Gold standard" study for detecting bilateral vestibular loss	Not widely available, generally not effective for testing frequencies >1.0 Hz; less sensitive than caloric testing for unilateral vestibular hypofunction	Established as an effective testing technique (A rating) Class II,[21,28] Class III,[42] Class IV,[2,17,27,33,34] and expert consensus
Passive examiner-generated head rotation testing	A portable alternative to rotational chair testing in those unable to undergo rotational chair testing	Probably not practical at frequencies above 2 Hz and may be difficult to elicit in patients with neck pain Not sensitive to unilateral vestibular loss	Probably effective test technique (B rating) Class II[37,43] Not yet fully accepted by expert consensus
Active head rotation (self-generated head turns)	Allows testing of VOR from 1-5 Hz; portable, inexpensive	Normative data is still limited; some patients cannot rotate head sufficiently well to test at higher frequencies. May not detect partial unilateral vestibular loss	Probably effective test technique (B rating) Class II[37,43,51] Not yet fully accepted by expert consensus

An argument against AHR is that the VOR measurements are artificially increased by the fact that the head turns are voluntary and predictable.[19,20,41,58-62] Despite this concern, most of the evidence suggests that volitional head movements have relatively little effect on VOR gain and phase measurements, at least during AHR. At frequencies from 1.0 to 5.0 Hz, VOR gain is not significantly affected whether the head motion is active or passive.[38,43,63] The effect of volitional head turning tended to increase gain values only slightly or not at all when compared with passive head rotation, even at relatively low frequencies, in normal subjects[38,43,57,63] and in those with vestibular loss.[37,43] Hence, prediction and volition influence VOR measures during AHR only to a minor degree in normal subjects. In patients with vestibular deficiency, the influence of volition on AHR measurements also appears small but has been studied in only a small number of patients.

AHR can be performed with an inexpensive portable system and is tolerated well by most patients, though some patients are unable to shake their head at more than 4 Hz.[57,64-67]

Normative data. Normative data on AHR is limited and has resulted in some conflicting results that correlate poorly among institutions and equipment.[64,68-72] The accuracy of gain measurements of AHR, particularly at frequencies greater than 4 Hz,[72] needs further study. Some have found gain values well in excess of unity,[64,73-76] whereas others using the more reliable magnetic search coil technique did not find gain values greater than unity in high-frequency head rotations.[19,77] The increased gain does not appear to be explained by the COR.[74,78] The test–retest reliability of active horizontal head rotation at higher frequencies was poor in one study,[67] a finding at odds with a previous report.[79] There have been inconsistencies in vertical VOR measurements as well. Overall, normative data obtained in high-frequency, self-generated head movements are not well established.

Clinical uses. AHR has been utilized in the diagnosis of Menière's disease,[53,70,80,81] acoustic neuromas,[69,82] unilateral vestibular loss,[55,68,83,84] bilateral vestibular loss,[42,75,84,85] and panic disorder.[86]

There is no convincing evidence that AHR can correctly identify the abnormal labyrinth in Menière's disease. In a study of AHR testing from 2 to 6 Hz in patients with Menière's disease, 85% had some abnormality of gain or phase, but only above 5.0 Hz, and the test was not helpful in identifying the affected ear.[81] In another descriptive case series in patients with Menière's disease, the horizontal VOR gain and phase values were normal.[76]

AHR, as it has been used so far, is not sensitive to unilateral peripheral vestibular loss. In two studies, AHR did not reliably differentiate patients with known unilateral vestibular deficits from normal subjects.[68,71] In another report, AHR was not as sensitive as caloric testing for unilateral vestibular loss.[51] A study of nine patients with acoustic neuromas suggested that asymmetry of more than 3% lateralized to the side of the tumor, but the SD of the asymmetry values of normal subjects was not provided.[82]

Although the sensitivity of AHR to unilateral vestibular loss has been unimpressive using asymmetry during head rotations, there may be other ways to improve its performance. Head shaking[7] and possibly head thrust techniques,[6] as

outlined earlier, might be more sensitive for detecting unilateral vestibular loss if recorded using AHR techniques. No such studies are available, however.

AHR does appear to be sensitive in detecting severe bilateral vestibular loss as defined by caloric testing.[37,43,51] Limited data suggests that vestibular responses during AHR correlate fairly well with rotational chair testing in patients with bilateral vestibular loss.[37,43]

Only one prospective study has been performed using AHR to monitor for vestibular function during treatment with ototoxic medication.[85] However, this study pooled the data from all nine patients to show a decrease in VOR. Furthermore, no comparison was made to caloric or rotational chair responses in these patients, and there was no mention of symptoms that might have been associated with the reported vestibular deficit.

Conclusion. AHR is a technique that is probably useful in detecting bilateral peripheral vestibular loss when used at frequencies above 2 Hz, especially when rotational chair testing is unavailable. This conclusion is based on two published Class II studies from the same laboratory[37,43] and a second study reported in abstract form.[51] Because data is still limited, AHR is not yet accepted by the authors of this assessment as an established technique. Furthermore, based upon studies up to the current time, AHR does not appear useful in detecting unilateral vestibular loss (e.g., due to unilateral acoustic neuroma, Menière's disease, or vestibular neuritis).

Rotational and caloric vestibular testing produce sensations of vertigo that most patients tolerate without difficulty. Patients prone to motion sickness may experience nausea. Perforation of the tympanic membrane is a contraindication to water irrigation; in such cases, air caloric irrigation or closed loop irrigation can be used safely.

Emerging techniques. Galvanic vestibular stimulation and click-evoked myogenic potentials are two investigational techniques that have spawned recent reports. Galvanic vestibular stimulation is a technique whereby a direct current of 1 to 5 milliamperes is applied to the mastoid process to electrically stimulate the vestibular nerve. Nystagmus can be evoked and posture can be affected during galvanic vestibular stimulation.[87,88] This technique is being investigated as a method for distinguishing the vestibulocochlear nerve from labyrinthine lesions and as a possible test of otolith function, which may be preferentially affected by low-current intensities.[89,90]

Averaged surface EMG responses from the sternocleidomastoid muscles in response to repetitive auditory clicks has been proposed as a method of measuring vestibular (saccule) afferents that are eventually transmitted to anterior neck muscles.[91-93]

Vestibular testing in children. *Background.* Balance assessment in children has long been recognized as an important component of the developmental evaluation of children. Some vestibular disorders recognized only in adulthood actually had their origins in childhood,[94] and vestibular dysfunction may result in delayed postural control, episodic vertigo, incoordination, and paroxysmal head tilt in young children.[95-97]

In small children, balance is assessed by a series of clinical examination tests of postural control.[98] However, poor postural control is not specific for vestibular dysfunction. Surprisingly, there are no studies directly comparing clinical postural control tests with quantitative vestibular testing. In this section, we review the published literature on quantitative vestibular testing in healthy and dizzy children and offer suggestions on how to ensure successful testing in this population.

Vestibular system maturation. The vestibular system is anatomically developed and functionally responsive by birth,[99] although vestibular responses can be variable.[100-102] VOR responses in neonates 24 to 120 hours old are poor, but normalize by 2 months of age[103] and mature further in the first 2 years of life.[99] Eviatar and Eviatar[100] elicited vestibular responses to ice water and rotations in the vast majority of 276 neonates between birth and 48 months of age; responses were sometimes not initially obtained in premature neonates and in those less than 6 months old.

Pursuit and optokinetic system maturation. In children, there is a wider range of normal than in adults according to several studies.[102,104] Optokinetic nystagmus is present in some neonates,[105] but is usually not evident to a rotating drum until 3 to 6 months of age.[98] In 20 healthy children aged 3 to 6 years, the optokinetic responses were the same as in adults.[106] Smooth pursuit should be normal in healthy children by age 5.[107,108]

Normative data in children. Caloric responses have been successfully obtained in normal children as young as 1 year of age in several studies,[107,109] and ice water caloric irrigation has been performed in neonates at birth.[100] Although some favor air over water caloric testing,[109] none of the studies indicate significant technical difficulties in testing children with caloric irrigation, whether with air or water. Rotational testing, however, may have some advantages over caloric testing if the goal is primarily to assess for the presence or absence of vestibular function. Small children are able to sit in their mother's lap during the rotational chair testing,[110] and vertigo is less intense in rotational chair testing than during caloric testing. Caloric and rotational testing have been studied in normal, dizzy, and hearing-impaired children.[95,99,100,107-109,111]

In summary, the majority of normal children demonstrate vestibular responses to caloric and rotational stimuli by age 2 months. By age 10 months, the absence of VOR responses can be considered abnormal.[95,99,101,102,107-109,111-113] Ice water and rotational vestibular responses can sometimes be obtained in neonates, but lack of a response in a child less than 6 months of age is not necessarily abnormal.[95,100]

Technical modifications. Children are more likely to fear vestibular testing than are adults. Inattentiveness, lack of experience, and perhaps incomplete development of some components of the ocular motor system can make it difficult to calibrate EOG in children under 3 years of age. Some suggestions on how to adapt vestibular testing to children are listed in Appendix 3. There is a broader range of normal in young children, so results should be compared with age-matched control subjects.[108] If a unilateral vestibular lesion is suspected, caloric irrigation with air, a closed-loop system (irrigation of water through a silicone balloon place in the external ear canal),[18] or warm water is fairly well tolerated. If bilateral vestibular loss is of concern, a rotational chair test is preferred, and was successfully completed in 95% of children between 3 and 10 years of age in one study.[95]

Clinical uses. Vestibular responses have been studied in children with reading difficulty,[108] post-traumatic syndrome,[115] otitis media,[116,117] fetal-alcohol syndrome,[118] serous otitis media,[119] the CHARGE (Coloboma [eyes], Heart defects, Atresia of the choanae, Retarded growth, Genital hypoplasia, Ear anomalies) association,[120] learning disabilities, and dyslexia.[121-123] In none of the above conditions is vestibular testing useful in making those specific diagnoses. Vestibular testing has also been studied in children with congenital and acquired deafness and with vertigo.[108] Electronystagmography results have been reported in a number of vestibular disorders of childhood, including benign paroxysmal vertigo of childhood, vestibular neuronitis, trauma, and Menière's disease.[124] Vestibular testing in children, as in adults, may be appropriate for any conditions if the goal is to identify vestibular nystagmus or vestibular loss. Vestibular testing is most commonly ordered in children with vertigo, imbalance, recurrent unexplained falling, acquired jerk nystagmus, or suspected malformations affecting the inner ear.

Conclusion. Caloric (air or water) and rotational chair testing are considered established techniques for testing vestibular function in children. This is based primarily on expert opinion and consensus extrapolated from studies done in adults. In small children 3 years of age or younger, rotational testing may be more convenient, whereas in children 5 years of age or older, either caloric or rotational testing can usually be performed successfully. A number of Class IV studies have documented vestibular responses in normal children.[95,99,101,102,107,109,111-113] Two controlled studies have been done showing no vestibular loss in children with otitis media[120] and dyslexia[123] compared with age-matched control subjects. Published studies raise no safety concerns in children undergoing caloric or rotational testing.

Summary. Quantitative vestibular testing, whether caloric or rotational, may be used as a confirmatory test when the clinical history and examination suggest vestibular dysfunction. For suspected unilateral peripheral vestibular lesions (e.g., Menière's or vestibular neuronitis) caloric testing as done with electronystagmography is the most helpful. Patients suspected of having bilateral peripheral vestibular dysfunction (e.g., gentamicin ototoxicity) are best studied using rotational chair testing, though caloric testing is acceptable and AHR shows promise. Passive rotational testing without a motorized chair apparatus shows some promise as an alternative to a rotational chair testing in some instances, but the data in support of this are still limited. AHR techniques appear promising for detecting bilateral peripheral vestibular loss, but there is insufficient evidence to support recommending it to detect unilateral peripheral vestibular loss. Children can be tested using any of the techniques used in adults. There is more variability in the range of normal in children, but caloric and rotational vestibular studies can be performed in children with modest technique modifications.

Appendix 1

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Appendix 2

Evidence classification scheme

Quality of evidence ratings for diagnostic tests

Class I. Evidence provided by a prospective study in a broad spectrum of persons with the suspected condition, using a "gold standard" for case definition, in which the test is applied in a blinded evaluation, and enabling the assessment of appropriate measures of diagnostic accuracy.

Class II. Evidence provided by a prospective study of a narrow spectrum of persons with the suspected condition, or a well-designed retrospective study of a broad spectrum of persons with an established condition (by "gold standard") compared with a broad spectrum of control subjects, in which the test is applied in a blinded evaluation, and enabling the assessment of appropriate measures of diagnostic accuracy.

Class III. Evidence provided by a retrospective study, in which either persons with the established condition or control subjects are of a narrow spectrum, and in which the test is applied in a blinded evaluation.
Class IV. Any design in which the test is not applied in a blinded evaluation, OR evidence is provided by the expert opinion alone or in descriptive case series (without control subjects).

Strength of recommendations
Type A. Established as useful or predictive.
Type B. Probably useful or predictive.
Type C. Possibly useful or predictive.
Type D. Data inadequate or conflicting. Given current knowledge, test is unproven.

Definitions
Safe. A judgment of the acceptability of risk in a specified situation, e.g., for a given medical problem, by a provider with specified training, at a specified type of facility.
Effective. Producing a desired effect under conditions of actual use.
Established. Accepted as appropriate by the practicing medical community for the given indication in the specified patient population.
Possibly useful. Given current knowledge, this technology appears to be appropriate for the given indication in the specified patient population. If more experience and long-term follow-up are accumulated, this interim rating may change.
Investigational. Evidence insufficient to determine appropriateness, warrants further study. Use of this technology for given indication in the specified patient population should be confined largely to research protocols.
Doubtful. Given current knowledge, this technology appears to be inappropriate for the given indication in the specified patient population. If more experience and long-term follow-up are accumulated, this interim rating may change.
Unacceptable. Regarded by the practicing medical community as inappropriate for the given indication in the specified patient population.

Appendix 3

Helpful modifications of vestibular testing techniques in younger children

To reduce fearfulness
Use warm water caloric irrigations instead of cold, use air calorics if available, as the sensation is often less alarming to children[109]
Show an enlarged picture of a child wearing electrodes[107]
Allow parents to be present and to aid in testing
Permit small children to sit in their parent's lap; most children older than 3 years can sit in the chair alone[95]
Consider rotational testing if child becomes afraid of caloric testing; it is often better tolerated[108]

To improve calibrations, ocular motor recordings
Use a flashlight or blinking light or toy for pursuit tracking in those under 4 years of age[108,110]
Have the child look at the "stars" in gaze testing[114]
Make testing a game when possible
Consider using a blindfold as a "Halloween mask" to help remove the effects of visual fixation in children who are unable to keep their eyes closed[114]
Converse with the child to keep him/her alert
Use full-field optokinetic stimulation if available[108]

To enable completion
Test the most important item first and work as quickly and efficiently as possible; for example, if doing rotations, consider limiting testing to 0.01, 0.04, and 0.16 Hz[95]
Shorten the duration of caloric irrigations
Rotational testing and air or closed loop calorics are usually better tolerated

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