ANSI/ASA S3.45-2009
(Revision of ANSI S3.45-1999)

AMERICAN NATIONAL STANDARD

Procedures for Testing Basic Vestibular Function

ANSI/ASA S3.45-2009

Accredited Standards Committee S3, Bioacoustics

Standards Secretariat
Acoustical Society of America
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Procedures for Testing Basic Vestibular Function

Secretariat:

Acoustical Society of America

Approved January 8, 2009:

American National Standards Institute, Inc.

Abstract

This Standard defines procedures for performing and reporting a battery of tests for the evaluation of human vestibular function. Six different tests are specified. Stimuli are presented to evoke eye movement by a subject whose response is determined either by measurement of electrical signals generated by the eye movements or by image processing methods applied to video eye movements. The Standard specifies test procedures, measurements, data analysis, and data reporting requirements. These tests, including the data analysis and reporting procedures, are called the Basic Vestibular Function Test Battery. Test interpretation is not a part of this Standard.

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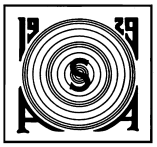

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Foreword

[*This Foreword is for information only, and is not a part of the American National Standard ANSI/ASA S3.45-2009 American National Standard Procedures for Testing Basic Vestibular Function.*]

This standard comprises a part of a group of definitions, standards, and specifications for use in bioacoustics. It was developed and approved by Accredited Standards Committee S3, Bioacoustics, under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S3 is as follows:

> *Standards, specifications, methods of measurement and test, and terminology in the fields of psychological and physiological acoustics, including aspects of general acoustics which pertain to biological safety, tolerance and comfort.*

This standard is a revision of ANSI S3.45-1999, which has been technically revised. An alternate means for the measurement of eye movements using video-oculography (VOG) has been added, since this method has advantages of being less invasive, and can be used to display and measure torsional eye movements that are not possible with electro-oculography.

A 5-year exception to the standard, which permitted use of older computerized equipment which sampled ENG signals at 50 samples per second, was eliminated since current technology is capable of supporting the 100-sample-per-second rate specified in the standard.

The issues that needed to be addressed before the use of air as a medium for caloric irrigations could be incorporated into the standard have been added in an informative annex.

One normative reference was added in Clause 2, and additional informative resources were added to the bibliography, primarily regarding the use of video-oculography.

This standard is not comparable to any existing ISO Standard.

At the time this Standard was submitted to Accredited Standards Committee S3, Bioacoustics, for approval, the membership was as follows:

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R.F. Burkard, *Vice-Chair*

S.B. Blaeser, *Secretary*

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A.J. Brammer	K.D. Kryter	L.A. Wilber
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Working Group S3/WG 82, Basic Vestibular Function Test Battery, which assisted Accredited Standards Committee S3, Bioacoustics, in the development of this standard, had the following membership.

C. Wall, III, Chair

R. Burkard
J.M. Furman
R. Miles
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N.T. Shepard

Suggestions for improvements of this standard will be welcomed. They should be sent to Accredited Standards Committee S3, Bioacoustics, in care of the Standards Secretariat of the Acoustical Society of America, 35 Pinelawn Road, Suite 114E, Melville, New York 11747-3177. Telephone: 631-390-0215; FAX: 631-390-0217; E-mail: asastds@aip.org.

Introduction

The vestibular system provides information related to a person's orientation in space using information from five organs in each inner ear. Three of these organs sense angular acceleration in approximately orthogonal planes, while two sense linear acceleration and gravity. This peripheral information is integrated with that of other senses, including vision and proprioception, to give information about the orientation of the individual in space and to allow for appropriate compensatory reflexive movements. These reflexes can adapt in ways that enhance a person's ability to cope with changing conditions.

Two major reflexes involved are the vestibulo-ocular reflex and the vestibulo-spinal reflex. The former allows one to keep visual objects of interest stable on the retina while the person is in motion. The latter allows one to maintain postural stability when subjected to motion. These reflexive movements can be used to evaluate the response to vestibular stimuli. This Standard utilizes the vestibulo-ocular reflex as its basis for test procedures.

A variety of test methods has been used in clinical and research evaluations of vestibular function. Some require relatively modest test equipment; others require relatively complex and expensive mechanical equipment. Lack of standardization in test protocols and data reporting often makes comparison of data between facilities and test conductors difficult. The goal of this Standard is to specify a battery of tests that use defined stimuli, data collection and recording methods, data analysis procedures, and data reporting requirements.

Depending on the system used to measure the movement in the eyes, the test battery is commonly known as "Electronystagmography" or "Videonystagmography." Electronystagmography (ENG) measures eye movements using the method of electro-oculography (EOG). In this method, skin-mounted electrodes measure changes in potentials across the eyeball due to movement of the eye in its socket. The corneal retinal potential is the source of the measured voltage. Videonystagmography (VNG) measures eye movements using video-oculography (VOG). In this method images of the eyes from video cameras are processed to give two dimensional (2D) or three dimensional (3D) eye position estimates. For VNG, 2D (horizontal and vertical) eye movements are typically provided, although some systems can also provide torsional eye movement estimates.

Use of the Standard will greatly facilitate comparison of data among different clinical settings as well as between these data and the data from research laboratories.

American National Standard

Procedures for Testing Basic Vestibular Function

1 Scope, purpose, and applications

1.1 Scope

1.1.1 General

This Standard specifies procedures for conducting six separate tests, which, together with the data analysis and reporting requirements specified in this Standard, constitute the Basic Vestibular Function Test Battery. The six tests cover:

(a) spontaneous nystagmus (see 5.2);

(b) gaze-evoked nystagmus (see 5.3);

(c) saccade test (see 6);

(d) pursuit testing (see 7);

(e) positioning and positional nystagmus (see 8); and

(f) caloric testing (see 9).

Each of these tests evaluates a response of the vestibular system by the vestibulo-ocular reflex through the measurement of electrical signals generated by eye movements recorded by electro-oculography.

1.1.2 Subjects

This Standard may be used to evaluate basic vestibular function in any human subject without restriction on age or sex.

NOTE Children under the age of about 4 may not be able to participate in all tests for various reasons, e.g., inability to follow verbal instructions.

Test subjects, however, must have functional retinas in both eyes and be able to see light through each eye separately to determine conjugacy of eye movements (i.e., ability to move both eyes synchronously or together).

Applicability of this Standard to some subjects may be limited by two variables. The test utilizing caloric stimulation depends upon heat transfer to the vestibular end organ, and is highly variable among individuals. The electro-oculogram, one method of measuring eye movement used in this Standard, depends on the existence of a corneoretinal potential which may be absent in certain cases of visual pathology. The use of video methods to measure eye movements requires that the eye can be visualized by video cameras well enough so that image processing methodology (e.g., tracking the iris-pupil limbus) can be effectively applied.

1.2 Purpose

The purpose of this Standard is to define a basic battery of tests to evaluate the vestibular function in humans. These tests define a minimum set of procedures for the purpose of establishing a common basis for comparison of data on subjects with both normal and dysfunctional vestibular function. These tests are not necessarily intended to replace more extensive tests used for detailed clinical or research purposes in specific applications but are intended to form a minimal base to be included in such studies.

1.3 Applications

Evaluation of vestibular function may be used in assessing disease, aging, and ability to function in certain occupations. Susceptibility to falling down, vertigo, motion sickness, and the ability to adapt to a weightless environment are related in greater or lesser degree to vestibular function.

This Standard does not include interpretation of the tests of vestibular function. For informational purposes, examples of test interpretations for subjects with normal and abnormal test results are provided in Annex A.

2 Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI Z136.1-2007, *American National Standard for Safe Use of Lasers*

IEC 60825-1 *Safety of laser products - Part 1: Equipment classification and requirements*

UL 544, *Standard for Safety for Medical and Dental Equipment*

3 Terms and definitions

For the purposes of this Standard, the following definitions apply. More detailed discussion of the terminology employed is found in the references listed in the Bibliography.

3.1
electro-oculogram
record, usually made on a strip-chart recorder, of the differences in electrical potentials, at the skin at the sides of the eyes, that result from changes of the eyeball's gaze position

NOTE Abbreviation: EOG.

3.2
fast component
portion of the asymmetrical, sawtooth-shaped wave form of vestibular nystagmus having the greater slope magnitude

3.3
Frenzel lens
Plano lens with a built-in light source for the purpose of preventing fixation, used in a darkened room in the detection of nystagmus

NOTE Prevention of fixation while using video nystagmography can be provided by alternative means, e.g., a light-proof enclosure that is part of the video goggle system.

3.4
Hallpike maneuver
rapid movement of a subject from a sitting to a supine position, head hanging right, with a subsequent return to sitting; movement sequence is then repeated to include: (1) the supine, head hanging left, and (2) the supine, head extended in sagittal plane positions

3.5
nystagmus
regularly repetitive to-and-fro movement of the eyes that is usually rapid and usually involuntary

NOTE See also 3.10.

3.6
primary position
position of the eye in the head when the direction of gaze is straight ahead

3.7
saccade
rapid jumps made by the eyes from one point to another, as in reading

3.8
slow component
portion of the asymmetrical, sawtooth-shaped wave form of vestibular nystagmus having the lesser slope magnitude

NOTE See 5.5. This component is usually associated with vestibular function. The term ‘‘component’’ is used instead of the term ‘‘phase’’ in order to avoid confusion with the use of the latter term in rotational testing, which reports results using the parameters of gain and phase.

3.9
slow component velocity
average slope of the angular displacement of the eyes during the slow component of nystagmus

NOTE See 5.5. Unit: degrees per second; abbreviation: SCV.

3.10
vestibular nystagmus
nystagmus that is typically composed of alternating fast and slow jerks or components to form a sawtooth-like pattern

3.11
video-oculogram
record, made from the processing of video images of the eyeball, that provide estimates of the eyeball's gaze position

4 Instrumentation

4.1 Overview of instrumentation

Measurement of response of the vestibular system is obtained in this Standard by measuring the movement of the subject's eyeballs in response to various stimuli, usually sources of light, but in one case, irrigation of the ear canal with liquid at controlled temperatures. The recorded output of the tests consists of electro-oculograms or video-oculograms, obtained with instrumentation meeting the requirements described in this Standard.

4.2 Component and setup features common to and needed for both methods of eye movement measurement

4.2.1 Light sources

NOTE The distance requirement for stationary and moving sources is meant to insure that both eyes will see essentially the same target, so that conjugacy of eye movements can be determined. This can be achieved by alternative methods while using video nystagmography, e.g., by having identical visual light source displays for each eye, either sequentially or simultaneously.

4.2.1.1 Stationary sources

Visual stimuli shall consist of bright lights, such as light emitting diodes (LEDs), small enough so that each will subtend a visual angle of 1° or less when presented at a distance of 1 to 2 m in front of the subject. Yellow-green lights are preferable to red. It is useful to arrange the lights in a fixed diamond array, with at least five lights, one on-axis, and the others arranged to produce eye deviations of ±10° to ±20° vertically and horizontally, when viewed from the 1 to 2 m viewing distance. The vertical and horizontal lights need not be displaced the same amount, but both shall be symmetrically displaced about the on-center light. All angular displacements shall be accurate within 0.5°.

4.2.1.2 Moving sources

Light source used to test ocular pursuit shall be a spot of light or small object subtending a visual arc of 2° to 3° from a distance of not less than 1 m from the subject. The source shall have periodic movement in a horizontal plane as seen by the subject, with either a triangular or sinusoidal motion. If the motion is a triangular wave, it shall have a peak displacement of 20° and a velocity of 40°/s. If the waves are sinusoidal, they shall have a peak displacement of 20° from the primary position and fundamental frequencies of 0.2 Hz and 0.4 Hz.

4.2.2 Subject preparation

Subjects should be instructed to abstain from alcohol or drugs for 2 days prior to testing. Any medication specifically for vertigo or dizziness should be discontinued. Life-supporting medication should be continued but reported to the tester and that information included in the test report. The subject's eyes shall be examined to see that both eyeballs are present and that the subject can see light using each eye separately.

NOTE Neither tracking method will work without a moving eyeball. Movements of both eyes are needed to determine if they move conjugately.

The external auditory canal of the subject shall be inspected by the tester prior to conducting the tests. Any excessive ear wax or other obstruction shall be removed.

CAUTION: Removal of cerumen should be done by qualified personnel, e.g., an otolaryngologist or audiologist.

4.2.3 Recording

Signals sensed by the EOG electrodes or VOG cameras shall be recorded on a data recording device. The recording device may be a strip-chart recorder or a digital data-logging system. If the data are recorded on a digital system, a graphic means for displaying the equivalent analog recorded signal in real-time shall also be provided. All items of the data acquisition system shall provide isolation protection in accordance with UL 544 and less than 1 μA leakage.

4.2.4 Calibration

4.2.4.1 General

The overall data acquisition/data recording system shall be calibrated to measure degrees of angular displacement of the eyes, as a function of time, during various tests specified in this Standard. Calibration thus consists of an “end-to-end” assessment of the deflection of the pen on a strip-chart recorder, or other graphic output device, in response to the subject’s shifts of gaze between small visual targets that are displaced by a specific angular amount. This calibration is to be performed in a dimly lit room, having a luminance of less than approximately 0.25 candela/m^2.

4.2.4.2 Horizontal displacement

Select targets at ±20° from on-center, in the horizontal plane, shall be used. Position the subject relative to the targets so that the on-center target is directly in front of the subject, at a distance of no less than 1 m and preferably 2 m. Center the output graphic of the display to its baseline position with the subject’s eyes in the primary gaze position, viewing the on-center target. Require the subject to make a minimum of eight voluntary horizontal saccades, alternating between 20° right and 20° left gaze, returning to the primary gaze position. Each eye position should be held for a minimum of 1 s. Vary timing slightly between each instruction for the subject to shift gaze in order to minimize the subject’s developing a rhythmic, ‘‘predictive’’ shift.

4.2.4.3 Vertical displacement

Repeat 4.2.4.2, with targets at ±10° displaced vertically from the on-center gaze position.

4.2.4.4 Calculation of calibration

Calibration of the graphic output recorder is obtained by measuring the average displacement of the display trace for a specified angular displacement of the eye. An alternative is to adjust the gain of the measurement system to the desired calibration factor: e.g., 1 mm/°.

An example of an EOG calibration is shown in Figure 1. In this figure a 24 mm vertical displacement of the pen recording corresponds to a 20° gaze change. The corresponding calibration factor is:

$$c = 24 \text{ mm} / 20^{o} = 1.2 \text{ mm/deg.} \quad (1)$$

NOTE 1 Polarity of the inputs to the graphic recorder should be selected so that horizontal eye movements to the subject’s right side and vertical eye movements upward toward the forehead give upward deflections on the recorder.

NOTE 2 The greater angular displacement of the horizontal calibration will provide greater calibration accuracy than that provided by the lesser angular displacement for the vertical calibration test. Unless the amplifier gain of the vertical displacement measurement channel is varied to provide the same calibration as that of the horizontal channel, separate calibrations will be required for the horizontal and vertical measurements.

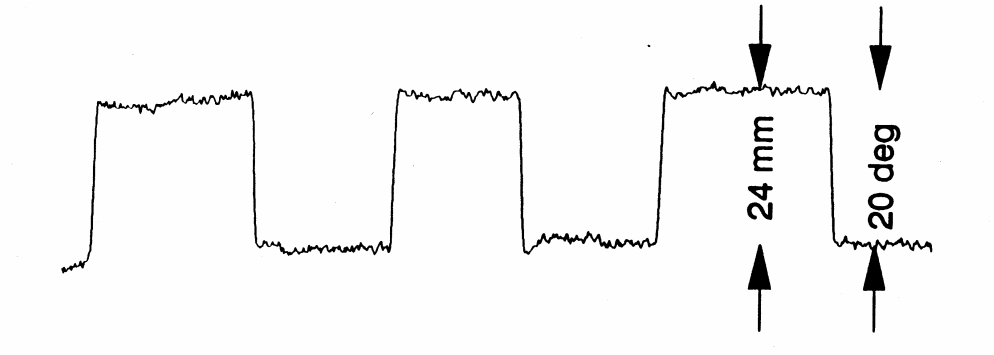


Figure 1 — Example of electro-oculogram (EOG) calibration

4.3 Components and setup features specific to electro-oculography

4.3.1 Electrodes and their installation

4.3.1.1 Electrodes

Five silver-silver chloride electrodes are required. The electrode shall be no greater than 12 mm in diameter, and have a recessed surface area to be used with electrode gel. The maximum impedance of the electrode when applied to the skin shall not exceed 10 kΩ measured within a frequency range of 0.1 to 40 Hz.

4.3.1.2 Electrode placement

Electrodes to sense eye movements in the horizontal plane shall be placed at the outer canthus of each eye. Electrodes to sense vertical eye movements shall be placed above and below one eye, centered on the pupil with the eye in the primary position. A ground electrode shall be placed near the center of the forehead. See Figure 2.

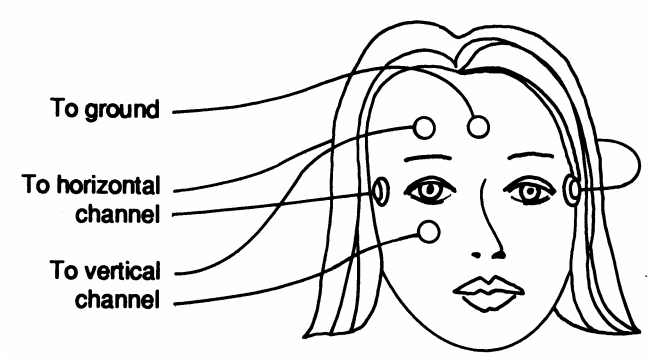


Figure 2 — Normal electrode placement

4.3.1.3 Recording channels

Two recording channels are required, one for horizontal eye movements and one for vertical eye movements. The recording channel frequency response shall be sufficient to permit the graphic output capabilities listed in 4.3.1.5.

NOTE If horizontal eye movements are observed to be disconjugate (see 6.4) then the two amplifier channels can be used to record the horizontal movement of each eye separately by placing electrodes on the inner canthus of each eye. The paired electrodes from inner and outer canthi for each eye are the recording channel inputs.

If analog to digital conversion is employed, a minimum of 12-bit accuracy is required. The sampling rate shall be at least 100 samples/s. An antialiasing filter shall be used with a cutoff frequency of less than one half the sampling frequency. The computer system shall be capable of storing the digitized eye-displacement data, and not just the calculated results of an analysis.

4.3.1.4 Amplifiers

Amplifiers shall be DC-coupled, with differential inputs to reject common mode noise. The common mode rejection shall be at least 100 dB measured at 60 Hz. Frequency response shall have a bandpass from nominally 0 to 40 Hz, uniform within ±1 dB between 0.1 Hz and 30 Hz. Frequency filters shall be non-ringing to impulses (e.g., Bessel filter) and shall incorporate at least second-order filter dynamics.

NOTE One can expect a filter with second-order dynamics to cause the value of the filtered signal at frequency, f, to fall as $1/f^2$ (-12 dB/octave) when the signal is well into the frequency region where the filter is attenuating any signals.

Amplifiers shall provide a minimum of 60 dB gain, and the gain shall be adjustable in both coarse and fine gradations for use in calibration of output displays.

4.3.1.5 Graphic display

A rectilinear strip-chart recorder or other means for graphic display of electrical signals as a function of time shall be provided. The desired objective is to obtain a pen deflection of approximately 1 mm per degree of eyeball movement. The output device shall permit display of deviations up to a minimum of ±25 mm from a neutral center position within 2% of full-scale accuracy. The display shall have a standard rate of change of vertical display with time of 10 mm/s. In addition, a slower speed of 5 mm/s and a higher speed of 25–100 mm/s are highly desirable for displaying spontaneous activity and observing saccades. The response characteristics of the display system shall be at least capable of meeting the frequency response requirements cited in 4.3.1.4 for amplifiers.

4.3.1.6 Overall system performance

The data acquisition, recording, and display system shall permit resolution of eye movements with an overall accuracy of ±1°. The tracking system shall meet the accuracy specifications when eye movement rates are less than 2 degrees/second. End-to-end system electrical noise shall not exceed 5.0 rms μV at the input using a 10 kΩ source impedance for a passband of 0–50 Hz.

4.4 Videonystagmography and display

4.4.1 General

Videonystagmography (VNG), the use of video-oculography to record eye movements during the vestibular test battery, is desirable because VNG eliminates skin-mounted recording electrodes, records vertical eye movements more accurately, and live eye movement video is generated. Furthermore, some VNG systems can track torsional movements that cannot be captured with ENG. Subjects don a mask or set of goggles that house infrared light sensitive video cameras aimed at the eye(s). Infrared light emitting diodes (IR-LEDs) are used to illuminate the eyes without providing undesirable visual fixation points. Eye movement video is displayed in real time to the operator and can be stored for subsequent review. Algorithms allow for automatic tracking of the position of the eyes. Parameters affecting overall quality of measurement include: (1) the type and resolution of the cameras, (2) the design of the mask or goggles, (3) the illumination of the eyes, (4) the ability of the operator to control parts of the video processing, and (5) the overall resolution and linearity of the waveforms generated.

4.4.2 Video cameras

One camera is the minimal requirement, with the option of two if recording individual eye movements is necessary.

NOTE During a Hallpike maneuver, eye movements of the left and right eyes typically can be different; thus two cameras are needed.

Eye imaging shall be aligned within ±10º to primary ocular axis to minimize parallax. Cameras should use charge coupled device (CCD) technology, since CCD currently yields superior resolution to that of CMOS Video. The camera system shall have at least 0.2º of resolution over a range of ±60º, and at least 30 full frames/s (yielding 60 interlaced fields/s).

NOTE Eye movements that occur at frequencies greater than one half the sampling frequency of the video camera cannot be distinguished from those that occur at lower frequencies due to the Nyquist sampling theorem. Thus, the full frame rate should be increased to at least 60 full frames/s when this technology becomes economically feasible.

4.4.3 Mask/goggles

The mask or goggles shall be designed to fit the 95th percentile of the adult population (2.5 percentile to 97.5 percentile [e.g., using the database Diffrient, Tilley & Bardagjy, 1978, Human Scale, MIT Press, Cambridge, MA, or similar]), shall occlude visible light to prevent suppression of nystagmus, and shall not generate any visible light with the IR-LEDs. The design shall be such that the range motion of each eye of at least ±30º horizontal and ±20º vertical can be measured without any obstruction from components of the measurement system.

4.4.4 Illumination of the eyes

The illumination in the infrared (IR) range shall not exceed 2 mW/cm/cm per eye in accordance with ANSI Z136.1-2007, *American National Standard for Safe Use of Lasers*, or IEC 60825-1 *Safety of laser products - Part 1: Equipment classification and requirements.* The illuminated field should be distributed uniformly enough to allow accurate pupil tracking over the gaze range of ±30º horizontal and ±20º vertical.

4.4.5 Output and control of video processing

The online video display rate shall be at least 30 frames/second. If the eye tracking system uses an image of the pupil, then both a manually adjustable and an automatically adjustable pupil threshold feature shall be provided.

4.4.6 System accuracy and linearity

The VNG system should be capable of graphically displaying a 0.2 degree change in horizontal eye position and a 0.4 degree change in vertical eye position.

5 Spontaneous and gaze-evoked nystagmus

5.1 Test purpose

The purpose of these two tests is to identify nystagmus that is evoked without vestibular stimulus by certain positions of gaze while body position is fixed. The subject is seated upright, head level.

5.2 Spontaneous test

The subject's eye movements are recorded, for a minimum duration of 20 s, for each of three conditions, without any visual target. The subject is instructed to maintain vision in the primary position for each of the conditions:

(a) while fixating, under normal room lighting;

(b) with eyes closed (EC); and

(c) with eyes open in the dark (EOD).

NOTE The eyes closed portion can be omitted if VNG is used.

5.3 Gaze test

In this test the subject is required to shift eye position to each of four eccentric positions: 30° right, 30° left, 25° up, 25° down. Recordings are made for 10 s in each position. As in 5.2, three conditions are to be evaluated:

(a) while fixating on the center target;

(b) with eyes closed (EC); and

(c) with eyes open in the dark (EOD).

NOTE The eyes closed portion can be omitted if VNG is used.

5.4 Data reporting

Reported nystagmus shall state duration of consecutive beats and slow component velocity. In addition, inability to maintain the gaze at the specified eccentric position is to be noted, together with the direction in which the gaze shift occurred.

5.5 Measurement of slow component velocity

5.5.1 Slope of nystagmus slow component

In practice, the wave form of the angular movement of the eye with time is recorded as a function of time and displayed graphically on a strip chart recorder or similar graphic display device. The first step in determining slow component velocity is to obtain the slope, m, of the slow component in terms of displacement per unit time. A straight line approximation to the slope of the slow component is made to determine the displacement, d_2-d_1, between the start and the end of a slow component. The time interval, t_2-t_1, between these two displacements is also determined. The slope, in mm/s, is the ratio of the peak-to-peak displacement in mm divided by the time increment in s. See Figure 3.

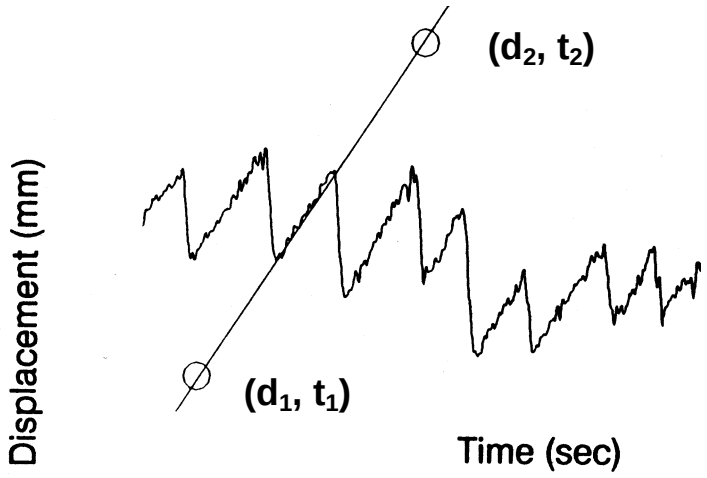


Figure 3 — Estimate of slope of slow component of nystagmus

5.5.2 Slow component velocity

Slow component velocity, v, in deg/s, is the slope obtained in 5.5.1 divided by the calibration factor for the specific subject/measurement system, determined as in 4.2.4.4. Specifically:

$$v = m/c \tag{2}$$

In practice, five or more well-formed (‘‘best’’) slow components should be used to obtain an average for the slow component velocity in a recording of nystagmus. For an example, see Figure 5. Fewer than five beats can be used if the subject produces fewer than five usable beats. In this case, the number of beats actually used for the calculation should be noted.

NOTE Very short, fast slow components are not considered to be "typical" and should be discarded from the SCV analysis, be it manual or computerized.

6 Saccade test

6.1 Test purpose

The purpose of this test is to assess the capability of the visual and oculomotor system for fast, accurate, goal-directed movements. Deficits in saccade production will affect interpretation of ocular nystagmus responses to vestibular stimulation. The subject is seated upright, head level.

6.2 Visual target

A horizontal target is located at least 1 m and preferably up to 2 m in front of the subject. Targets are placed on center, and one each at 20° left and 20° right of center.

NOTE The distance requirement for stationary and moving sources is meant to insure that both eyes will see essentially the same target so that conjugacy of eye movements can be measured. This can be achieved by alternative methods while using video nystagmography, e.g., by having identical visual light source displays for each eye, either sequentially or simultaneously.

6.3 Procedure

Electro-oculograms shall be recorded while the subject is directed to look from center to the right target, back to center, to the left target, and then back to center. Each eye position shall be held for at least 1 s to allow the subject to acquire the target. At least four trials shall be made of each of the specified deflections.

6.4 Evaluation

Examine data for position and velocity symmetry. Any disconjugate (inability to move both eyes synchronously or together) horizontal eye movements are indications that recordings of each eye separately should be made for the pursuit, positional, and caloric tests that follow. If the subject is diplopic (sees double), then separate monocular calibrations for each eye shall be made, with the other eye covered.

7 Pursuit test

7.1 Test purpose

This test is to evaluate whether a subject can follow a visual target moving continuously in a predictable path, using smooth voluntary eye movements. The subject is seated upright, head level.

7.2 Visual target

The visual target is a spot of light, or small object, that moves in a horizontal plane, located at least 1 m, and preferably up to 2 m, in front of the subject. The target shall subtend a visual arc of less than 3°. The movement of the target shall be periodic, with a wave shape that may vary either as a triangular or sinusoidal function of time. If the wave is triangular, it should have a velocity corresponding to a change in angular position of 40° per second, with a peak displacement of 20°. For sinusoidal movement, two sinusoids shall be used, having fundamental frequencies of 0.2 Hz and 0.4 Hz, with peak displacements in each case of 20°.

NOTE The distance requirement for stationary and moving sources is meant to insure that both eyes will see essentially the same target, so that conjugacy of eye movements can be measured. This can be achieved by alternative methods while using video nystagmography, e.g., by having identical visual light source displays for each eye, either sequentially or simultaneously.

7.3 Procedure

Electro-oculograms are recorded while the subject is directed to track the visual target. The tester shall monitor and encourage the subject during the test to ascertain that the target is actually being tracked in order to obtain good results.

NOTE It is desirable to record the position of the visual target as a function of time simultaneously when making the electro-oculogram.

7.4 Evaluation

Parameters to be reported from this test depend upon the methods available for analyses. At a minimum, the ability of the subject to follow the target during periods of best tracking shall be reported. The presence of catch-up saccades and any response asymmetries between right-left and left-right directions shall be noted. When both eye movement and stimulus movement data are recorded, the ratio of the velocity of the eye (neglecting catch-up saccades) to the velocity of the stimulus shall be reported. When computerized analysis procedures are available, the parameters of gain, phase, asymmetry, and harmonic distortion should be used in relating slow component tracking velocity (neglecting catch-up saccades) to target velocity. In systems that do not record pursued object position, it is acceptable to record only the gain (neglecting catch-up saccades).

8 Positioning and positional nystagmus

8.1 Test purpose

These tests evaluate the occurrence of nystagmus that occurs from dynamic or static changes in subject orientation with respect to gravity. Both *dynamic* (positioning) and *static* (positional) tests are used.

The subject is prepared for EOG or VOG measurements. For the dynamic tests the subject wears lighted Frenzel lenses, or other apparatus designed to prevent visual fixation. A reclining chair or examining table is required on which the subject can be seated and moved from an upright sitting position to a supine position.

8.2 Dynamic (positioning) tests

Tests are conducted in a darkened room with eyes open, while wearing lighted Frenzel lenses or other apparatus designed to prevent visual fixation.

NOTE An example of an alternative means of preventing visual fixation is to provide a light-tight cover for VOG goggles.

Eye movements are recorded and the tester observes the subject's eyes for rotary nystagmus that can occur upon completion of the positioning maneuvers. While in the sitting position, the subject's head is placed in the starting position listed in Table 1. The subject is asked to gaze straight ahead. The subject is then moved quickly, but not precipitously, from the starting position to the final supine position listed in Table 1. When possible this maneuver should take place in no more than 1 s. Record

eye movements for at least 20 s. Return the subject to the sitting position, continuing to record nystagmus, before executing the next maneuver listed in Table 1.

8.3 Static (positional) tests

Tests are conducted with eyes closed (EC) when using EOG, but with eyes open when using VOG since VOG cannot track the pupil when the eye is closed. During the supine series listed in Table 1, the subject lies on the back and is asked to turn the head while keeping gaze straight ahead. Eye movement recordings are made for 20 s in each position while performing mental alerting tasks.

NOTE Mental alerting tasks should be matched to the abilities of the subject and can include, for example, counting backwards by a fixed interval or naming women's names alphabetically.

During the lateral series listed in Table 1, the subject lies on the side and gazes straight ahead while performing mental alerting tasks.

NOTE 1 The tester should exercise appropriate caution as to the speed of the positioning maneuvers and the degree of head turning, depending upon the physical condition of the subject.

NOTE 2 Figure 4 shows some representative start positions and end positions mentioned in Table 1.

Table 1 — Positioning and positional maneuvers

Test series	Start position	End position
1. Dynamic (positioning or Hallpike maneuver)	Sitting, head right Sitting, head left Sitting, head straight	Supine, head hanging right Supine, head hanging left Supine, head extended, sagittal position
2. Static (positional)	Supine, head left Supine, head extended Supine, head right Lateral, head and body left Lateral, head and body right	Supine, head left Supine, head extended Supine, head right Lateral, head and body left Lateral, head and body right

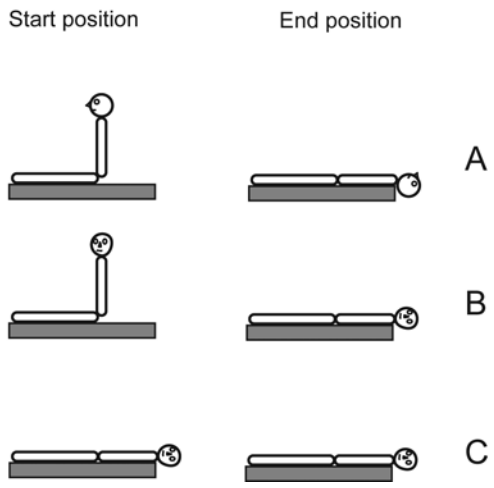


Figure 4 — Start and end positions for example positioning (dynamic) and positional (static) maneuvers: A) Positioning, head straight while sitting, and head extended while supine; B) Positioning, head left; C) Positioning, supine, head left

8.4 Results to be reported

8.4.1 Nystagmus parameters

(a) Presence, absence, or change of nystagmus;

(b) Axis of movement: horizontal, vertical, oblique, rotary;

(c) Direction of trajectory of the 12 o'clock point of the limbus (corneal-scleral border for visual observation, pupilary-irial border for video);

(d) Latency and duration;

(e) Fatigability, as appropriate;

(f) Slow component velocity.

8.4.2 Other factors

(a) Vertigo associated with nystagmus;

(b) Speed of the positioning maneuvers, if not standard.

9 Caloric test

9.1 Test purpose

The purpose of this test is to stimulate the lateral semicircular canal of each inner ear by stimuli designed to excite or to inhibit the vestibular end organ, and to measure the resulting eye movement (nystagmus) responses. This yields a sequence of four responses to right ear excitation, right ear

inhibition, left ear excitation, and left ear inhibition. From this series of responses it is possible to make inferences concerning peripheral and central vestibular function.

9.2 Test environment

The subject lies supine in a dimly lit or dark room with the head propped up so that the plane of the lateral semicircular canals is aligned to the vertical. This can be accomplished by aligning an imaginary line between the center of the external auditory canal and the outer canthus of the eye with the vertical plane.

The subject is prepared for EOG or VOG measurements. Equipment to permit irrigation of the external auditory canals by a warm or cool fluid is required.

9.3 Data acquisition

Prior to each test run the eye movement measurement system is calibrated. During each run recordings of eye movements are made. For each test run, three epochs are selected for analysis and reporting:

(a) Prior to the onset of caloric irrigation (spontaneous nystagmus);

(b) Response at the time of maximal caloric response;

(c) Immediately following the period of maximal response, but with the addition of a stationary visual target on which the subject is instructed to fixate.

9.4 General test method

All recordings are to be made with eyes open in the dark (EOD), except during the fixation suppression portion of the test.

NOTE The EOD condition can be achieved by other means than using a completely darkened room, e.g., blacked out ski goggles whose size and configuration do not contact or move the recording electrodes if EOG is used to measure eye movements.

The following sequence of events takes place for each run:

(a) Prior to each run, the eye movement recording system is calibrated. Room illumination during the calibration should be kept dim; an illumination level equivalent to that provided by a 15-W incandescent light is appropriate.

(b) The subject is then given a mental alerting task while a recording is made, EOD, prior to the introduction of the caloric stimulation, to measure spontaneous nystagmus if it exists.

(c) The caloric stimulus is introduced while recording and mental alerting are continued with the purpose of eliciting and recording the EOD response during the period of maximal caloric stimulation.

(d) During runs when fixation suppression is measured, an additional stationary visual stimulus is introduced while the response to a caloric stimulus is still strong compared with the maximum response. The subject is instructed to fixate this visual condition with continued mental alerting.

(e) After a rest interval, another caloric run commences.

9.5 Fixation suppression

Starting 100 s from stimulus onset, the subject's test environment is changed from the EOD condition to a condition where the subject can fixate on a small object (1° of visual arc) in a dark or dim room.

NOTE The fixation suppression condition can be achieved by other means than using a lit object in a completely darkened room, e.g., by means a light-tight cover that has built-in light sources (1° of visual arc) for VOG goggles.

While remaining supine, the subject is asked to fixate on the target for 10 s and then is returned to the EOD condition. It is desirable to attempt fixation suppression using caloric irrigations which produce robust nystagmus in the unfixated, EOD condition. When possible, the right and left warm runs should be used.

9.6 Test details

The test specified in this Standard is a sequential, bithermal, binaural caloric test using water as the fluid medium.

NOTE Caloric stimulation using air is discussed in Annex B.

Irrigations are given in sequence to the right and left ears using warm and cool irrigations in each. The sequence is: right warm, left warm, right cool, left cool, with a rest of 5 min between the end of the previous recording and the start of the next test. The time between successive irrigations shall be kept constant in order to standardize any effect of one test upon the successive test and to allow for adequate post-stimulus response reduction. Table 2 specifies the caloric stimulus values.

Table 2 — Standard caloric stimulus values

	Type of stimulator	
Variable	**Closed-loop water**	**Open-loop water**
Flow rate	350 ± 35 ml / min	200 ± 20 ml / min
Flow duration	40 ± 1.0 s	40 ± 1.0 s
Warm temperature (at irrigator tip)	44 ± 0.5 °C	44 ± 0.5 °C
Cool temperature (at irrigator tip)	27 ± 0.5 °C	30 ± 0.5 °C

9.7 Role of the tester

The functions of the tester are threefold:

1) Effective stimulus delivery

This involves correct and consistent placement of the irrigator tip within the external auditory canal, confirming the standard stimulus conditions, and placement of the subject's head so that the lateral semicircular canals are vertically aligned.

During the period in which suppression of nystagmus using visual fixation is evaluated, the tester shall introduce an additional stimulus consisting of a lighted stationary visual target and shall make sure the subject is attempting to fixate on the target.

2) Effective maintenance of subject alertness

This involves an assertive approach which uses challenging questions to make the subject remain alert to prevent the subject from possible nystagmus suppression during the period beginning 15 s prior to stimulus delivery and lasting for 2 to 3 min after the irrigation while eye movements are recorded. Mental alerting tasks should be matched to the abilities of the subject.

3) Effective recording

This involves pre-test determination of proper recorder and electrode function, careful EOG calibration, adjusting the recorder to keep it on scale, and recording the data for the duration of each test. This period shall start 15 s before the beginning of the stimulus, to record spontaneous nystagmus if present, and last for 2 to 3 min after the start of irrigation in order to record the period of maximum nystagmus and to record fixation suppression.

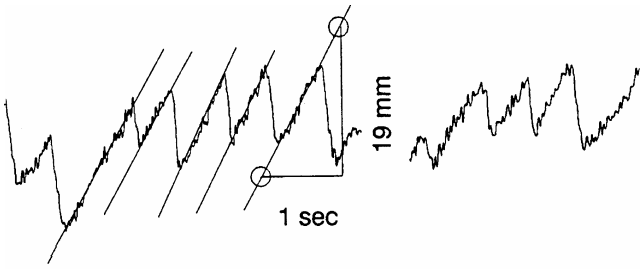
9.8 Analysis of test data

The slope of the slow component of nystagmus is the primary information required from the recorded horizontal EOG or VOG for further analysis (see 5.5 and Figures 3 and 5). For this Standard, the slow component velocity is the average determined for each evaluation. In analyzing the data from one caloric run, three distinct epochs shall be considered:

(a) The 15 s interval prior to the introduction of the caloric stimulus shall be analyzed during the time when any spontaneous nystagmus is strongest and most regular, using an average of at least three beats.

(b) The 10 s interval when nystagmus is most active during caloric stimulation, usually about 60 to 90 s after stimulus onset. The data may be analyzed in one of two ways: 1) the average of all slow components in the 10 s interval; or 2) the average of the five fastest beats disregarding artifacts. An example of five strong beats is shown in Figure 5. The slope of one of the beats is shown being calculated, but in practice five such slopes are calculated and their values averaged. The report shall state which of these two methods was used in the analysis.

(c) The time interval containing the first few (three to five) ‘‘typical’’ beats during fixation. These beats are used to calculate average slow component velocity slope. They should be selected after making allowance for the subject's varying attention and ability to maintain prolonged fixation.



Example:

$$m = \frac{19\ \text{mm}}{1\ \text{sec}} = 19\ \text{mm/sec}$$

$$v = \frac{m}{c} = \frac{19\ \text{mm/sec}}{1.2\ \text{mm/deg}} = 15.8\ \text{deg/sec}$$

Figure 5 — Example of calculation of slow component velocity of nystagmus

9.9 Data to be reported

9.9.1 Overview

Average slow component velocities are reported for four caloric irrigation conditions. When all four responses are below normal limits, a bilateral reduced response shall be reported. When a response is greater than normal limits, a hyperactive response shall be reported.

9.9.2 Slow component velocities

The primary data to be reported from the caloric test are four slow component velocities, in degrees per second, derived from nystagmus associated with their respective irrigations. These are, with their associated symbols:

(1) right warm: V_{rw}

(2) left warm: V_{lw}

(3) right cool: V_{rc}

(4) left cool: V_{lc}

NOTE The normal directions for the nystagmus slow components are left-beating for the right warm and left cool irrigations, and right-beating for the left warm and right cool ones. In practice, only the magnitudes (and not the algebraic signs) of the slow velocity components are recorded. All individual slow component velocities are assumed to have a positive algebraic sign in the calculations of reduced vestibular response and directional preponderance, given by equations (3) and (4), respectively. A perverted response (nystagmus in the wrong direction) will render the calculations of reduced vestibular response and directional preponderance invalid. A suggested procedure in this case is to give only the four slow component velocities above and to note any perverted responses. In the case of a persistent and steady spontaneous nystagmus prior to irrigation (allowing

ample time for any response to a previous irrigation to subside), it is common practice to adjust the response to an irrigation by the magnitude and direction of the spontaneous nystagmus.

9.9.3 Percent reduced vestibular response

Percent reduced vestibular response, abbreviated and (for the purposes of this Standard) also symbolized as %RVR, is the ratio of the sum of the slow component velocities obtained from the right ear warm and cool irrigations, minus the sum of the slow component velocities obtained from the left ear warm and cool irrigations, divided by the sum of all four slow component velocities, multiplied by 100. In equation format:

$$\%\mathrm{RVR} = \left\{\left[\left(V_{\mathrm{rw}} + V_{\mathrm{rc}}\right) - \left(V_{\mathrm{lw}} + V_{\mathrm{lc}}\right)\right] / \left(V_{\mathrm{rw}} + V_{\mathrm{rc}} + V_{\mathrm{lw}} + V_{\mathrm{lc}}\right)\right\} \times 100. \quad (3)$$

NOTE A negative value indicates a reduced response to the right, and a positive value indicates a reduced response to the left.

9.9.4 Percent directional preponderance

Percent directional preponderance, abbreviated and (for the purposes of this Standard) also symbolized as %DP, is the ratio of the sum of the slow component velocities obtained from the right ear warm and left ear cool irrigations, minus the sum of the slow component velocities obtained from the left ear warm and right ear cool irrigations, divided by the sum of all four slow component velocities, multiplied by 100. In equation format:

$$\%\mathrm{DP} = \left\{\left[\left(V_{\mathrm{rw}} + V_{\mathrm{lc}}\right) - \left(V_{\mathrm{lw}} + V_{\mathrm{rc}}\right)\right] / \left(V_{\mathrm{rw}} + V_{\mathrm{rc}} + V_{\mathrm{lw}} + V_{\mathrm{lc}}\right)\right\} \times 100. \quad (4)$$

NOTE A positive value means a stronger right beating nystagmus over a left beating nystagmus.

9.9.5 Fixation suppression index

Fixation suppression is measured by the fixation suppression index (FI), in percent, computed from the slow component velocities from one right beating (RB) test and one left beating (LB) test. The index, abbreviated and (for the purposes of this Standard) also symbolized as FI, is calculated for both right beating, with the subscript ‘‘rb,’’ and left beating, with the subscript ‘‘lb,’’ from the ratio of the respective slow component velocity with eyes open fixed upon a lit target to the slow component velocity with eyes open in the dark, EOD, times 100. In equation format:

$$\%\mathrm{FI}_{\mathrm{rb}} = \left[V_{\mathrm{rb}}\left(\text{eyes open fixed upon lit target}\right) / V_{\mathrm{rb}}\left(\mathrm{EOD}\right)\right] \times 100, \quad (5)$$

and

$$\%\mathrm{FI}_{\mathrm{lb}} = \left[V_{\mathrm{lb}}\left(\text{eyes open fixed upon lit target}\right) / V_{\mathrm{lb}}\left(\mathrm{EOD}\right)\right] \times 100. \quad (6)$$

10 Report of test results

10.1 Form of report

The data from each of the six tests comprising the Basic Vestibular Test Battery are reduced as specified in this Standard and then entered on a worksheet. A sample worksheet is shown in Figure 6. This worksheet, together with the strip-chart electro-ocular recordings or computer-based recordings of the eye movements associated with each test, provide the basis for interpretation of test results.

This Standard does not provide an interpretation of these test results. However, for informational purposes, examples of test interpretations are provided in Annex A. The test report should include the statement that the test was done in accordance with ANSI/ASA S3.45-2009.

10.2 Standardized worksheet

The worksheet for providing a uniform description of results obtained with the Basic Vestibular Test Battery is shown in Figure 6. While this specific format need not be followed, all the items of information that are shown in Figure 6 should be obtained and recorded.

Name:	Occupation:
Birth date:	Age:
SS#:	Dx:
Date tested:	Medication:
Physician:	Technician:

	NORMAL	ABNORMAL	COMMENTS
Calibration			
Saccade			
Spontaneous			
Gaze			
Pursuit			
Positioning/Positional			
Dynamic, Sitting			
Head hanging right			
Head hanging left			
Head hanging			
Static			
Supine, head left			
Supine, head			
Supine, head right			
Lateral, left			
Lateral, right			

Caloric

	PEAK SCV	NYST DIR	FIX SUPP	DIZZINESS	COMMENTS
RIGHT-WARM					
LEFT-WARM					
RIGHT-COOL					
LEFT-COOL					

Percent Reduced Vestibular Response (%RVR):

$$\%RVR = \frac{\left[\left(V_{rw} + V_{rc}\right) - \left(V_{lw} + V_{lc}\right)\right]}{\left(V_{rw} + V_{rc} + V_{lw} + V_{lc}\right)} \text{ x } 100 =$$

Percent Directional Preponderance (%DP):

$$\%DP = \frac{\left[\left(V_{rw} + V_{lc}\right) - \left(V_{lw} + V_{rc}\right)\right]}{\left(V_{rw} + V_{rc} + V_{lw} + V_{lc}\right)} \text{ x } 100 =$$

$$\%FI_{rb} = \left[V_{rb}\left(\text{eyes open fixed upon lit target}\right) / V_{rb}\left(\text{EOD}\right)\right] \times 100 =$$

$$\%FI_{lb} = \left[V_{lb}\left(\text{eyes open fixed upon lit target}\right) / V_{lb}\left(\text{EOD}\right)\right] \times 100 =$$

Remarks and Interpretation (overall)

Figure 6 — Worksheet for the basic vestibular function test battery

Explanation of abbreviations for the caloric test: Peak SCV is the peak slow component velocity; NYST DIR is the direction of the nystagmus slow component; and FIX SUPP and DIZZINESS are subjective observations of the tester about the subject's ability to fixate, and subject's response to questions about how dizzy they feel during and after an irrigation.

Annex A

(informative)

Test interpretation

Test interpretation can be put in two steps:

1. For each sub-test, a limited number of observations can be made. For example, ‘‘There was spontaneous nystagmus present during the test.’’

2. The information from the sub-tests is reviewed by an individual familiar with the testing procedure and familiar with vestibular physiology and pathophysiology. This process can provide a test interpretation, usually in the form of a letter or a short report. An example of a complete interpretation of test results for a normal subject is shown in Figure A.1. An example of a complete interpretation of test results for an abnormal subject is shown in Figure A.2.

Patient's Name: Test Date of Test: 31 May 20__
Social Security No: 111-11-111
Birth date: 01 January 19__
Physician's Name: Dr. Doctor

OCULOMOTOR SCREENING BATTERY: NORMAL

Saccadic eye movements were normal. With eyes open in the primary position, the patient had no nystagmus. With eyes closed or eyes open in darkness, no spontaneous vestibular nystagmus was seen. With 30 degrees of gaze deviation to the right and left, the patient developed no nystagmus. In addition, with upward and downward gaze, the patient developed no nystagmus. Horizontal pursuit tracking was within normal limits.

STATIC POSITIONING AND HALLPIKE'S MANEUVER: NORMAL

There was no nystagmus seen on static testing including the supine, head right, right lateral, head left, and left lateral positions. Hallpike's maneuvers revealed no paroxysmal nystagmus.

ALTERNATE BINAURAL BITHERMAL CALORIC IRRIGATIONS: NORMAL

Alternate binaural caloric testing with 30**°** and 44**°** water produced responses which were within normal limits.

Impressions: All findings normal.

Figure A.1 — Sample test report – normal subject

Patient's Name: Test Date of Test: 31 May 20__
Social Security No: 111-11-111
Birth date: 01 January 19__
Physician's Name: Dr. Doctor

OCULOMOTOR SCREENING BATTERY: NORMAL

Saccadic eye movements were normal. With eyes open in the primary position, the patient had no nystagmus. With eyes closed or eyes open in darkness, no spontaneous vestibular nystagmus was seen. With 30 degrees of gaze deviation to the right and left, the patient developed no nystagmus. In addition, with upward and downward gaze, the patient developed no nystagmus. Horizontal pursuit tracking was within normal limits. Horizontal optokinetic nystagmus was normal in both directions.

STATIC POSITIONING AND HALLPIKE'S MANEUVER: NORMAL

There was no nystagmus seen on static positional testing including the supine, head right, right lateral, head left, and left lateral positions. Hallpike's maneuvers revealed no paroxysmal positioning nystagmus.

ALTERNATE BINAURAL BITHERMAL CALORIC IRRIGATIONS: ABNORMAL

Alternate binaural caloric testing with 30° and 44° water was indicative of a significant induced vestibular response on the right of 44 percent.

Impressions: Findings are consistent with a right-peripheral vestibular lesion.

Figure A.2 — Sample test report – abnormal subject

Annex B

(informative)

Air caloric stimulation

Warm and cool air is in common use as a caloric stimulus. Such stimulation might be valid and appropriate for many, but published data available at this time are insufficient to establish response variability equivalent to water calorics. The Working Group's concern about defining the limits of variability to this stimulus does not allow for the specification of a standard that includes air caloric stimulation at this revision. When there is consistent published data from several sources that show variability associated with air calorics does not produce greater variability in the reduced vestibular response (RVR) and directional preponderance (DP) estimates compared to those of water, then the air caloric should be included in this Standard.

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