Recommended Procedure

Vestibular assessment — eye movement recordings

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General foreword

This document presents a Recommended Procedure by the British Society of Audiology (BSA). A Recommended Procedure provides a reference standard for the conduct of an audiological intervention that represents, to the best knowledge of the BSA, the evidence-base and consensus on good practice given the stated methodology and scope of the document and at the time of publication.

Although care has been taken in preparing this information, the BSA does not and cannot guarantee the interpretation and application of it. The BSA cannot be held responsible for any errors or omissions, and the BSA accepts no liability whatsoever for any loss or damage howsoever arising. This document supersedes any previous recommended procedure by the BSA and stands until superseded or withdrawn by the BSA.

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1. Contents

2. Abbreviations

BPPV	benign paroxysmal positional vertigo
CRP	corneo-retinal potential
ENG[1]	electro-nystagmography
INO	internuclear ophthalmoplegia
OKN	optokinetic nystagmus
SN	spontaneous nystagmus
SPV	slow phase velocity
VF	visual fixation
VNG	video-nystagmography
VOR	vestibular ocular reflex

3. Introduction

3.1. Development of the recommended procedure

The development of this recommended procedure was conducted by the Steering Committee of the Balance Interest Group (BIG) of the British Society of Audiology (BSA) in consultation with interested parties (see Appendix A).

The Steering Committee would like to acknowledge the advice received from a range of professionals (see Appendix A) as well as five anonymous reviewers and the wider membership of the BSA who were invited to provide comments and feedback on earlier draft editions. The document was developed in accordance with BSA Procedure for Processing Documents (2003).

[1] Used synonymously with EOG (electro-oculography) in this document.

3.2. Background and aims

Nystagmography, or oculography more generally, allows for examination of eye movements and nystagmus in a controlled and measurable way, both in the presence and absence of optic fixation. This is advantageous over direct observation, which is more subjective and un-quantifiable. However, nystagmography should not replace direct clinical observation.

As a minimum requirement, nystagmography recording requires assessment of smooth pursuit tracking and saccadic eye movement control systems, plus examination for the presence of spontaneous and gaze-evoked nystagmus. This is typically achieved using video- or electro-nystagmography (VNG/ENG) systems to record eye movements. These techniques provide a permanent record to document nystagmus and eye movements, allowing for their detailed analysis.

The aim of this recommended procedure is to clarify the methodology and interpretation of findings. This should allow a standardised method to be used in most cases. Alternative methodologies may be required in certain cases, but there must be robust evidence to justify doing so.

3.3. Scope

This protocol provides guidelines for testing using ENG or VNG with commercially available systems. The test battery is used for the assessment of adult and paediatric patients presenting with symptoms of vertigo, dizziness, or imbalance. This document covers those procedures where the objective recording of eye movements is of value in differentiating between peripheral and central sites of lesion. Head-shaking and positional tests are included but video head impulse testing (vHIT) is not included as this requires special goggles incorporating an accelerometer.

Although this document covers the techniques for testing adults, similar techniques can be used on adolescents and older children. For further information on paediatric testing see Appendix B.09.

It is recommended that simple oculomotor assessments be carried out before those tests that have the potential to induce vestibular symptoms (e.g. positional, head-shaking, rotational and caloric tests).

As conjugate eye movements are necessary to make a meaningful analysis of eye movement recordings it is essential that a thorough clinical examination is carried out prior to recording.

In order to avoid missing central (commonly cerebellar) pathology, it is recommended that vertical eye movements as well as horizontal are recorded.

The aim of this document is provide information on how to carry out, rather than interpret, eye movement assessments. The reader is directed towards the recommended textbooks, which are a good source of material and include many examples of normal and abnormal eye movement test results.

4. Patient preparation

This section is related to actions taken prior to starting the eye movement assessment tests and will ensure that the patient is adequately prepared to undertake the testing.

4.1. Referral and medication advice

Advice about stopping medication (e.g. vestibular sedatives) [2] should be given by the referring physician during the pre-test consultation. Ideally the physician should advise the patient to stop relevant medication at least 48 hours before the test. Patients should be advised not to consume alcohol for 48 hours before testing (Jacobson et al, 1993). Staff responsible for carrying out the VNG test should check whether the patient has adhered to this advice. If the patient has not, the procedure can still be carried out, but the tester needs to consider possible effects of this non-compliance on results.

The tester should make note of any medication, drugs or alcohol, which the patient has recently taken, which have a potential central nervous system effect and could influence the test results (including psychotropic, anti-convulsant, hypnotic, anti-depressant).

[2] Note – There is little evidence that vestibular sedatives affect oculomotor, head shake and positional tests (Patel et al, 2014). In the absence of robust evidence it still might be prudent to withdraw medication that might affect the results. It might be reasonable to assume that vestibular sedatives would reduce the responses from each side equally, if at all. They would therefore be unlikely to affect any canal paresis calculation although they might affect interpretation of results suggesting hyper / hypo function.

Patients should be advised not to wear any creams, foundations and eye make-up (especially mascara) as this may interfere with VNG recordings and make it more difficult to establish low electrode impedances with ENG.

Local protocol should be in place to establish who has responsibility for ensuring appropriate information is provided to the patient.

It is the responsibility of both the referring physician and tester to ensure that the patient is fit to undergo the test before it is conducted.

4.2. Patient travel

If the test battery is to be followed by the caloric test, check travel arrangements and ensure that the patient is aware that they will be advised not to drive immediately following the balance tests.

4.3. Room and recording conditions

4.3.1. Recording conditions

The optimal condition for recording eye movements in the absence of visual fixation is with the eyes open in complete darkness.

It is recommended that VNG should be the preferred choice for recording eye movements, using open-type video goggles unless complete darkness is not possible. In this case the design of the video goggles should be such that they may be covered at the appropriate time to remove visual fixation with eyes still visible to the infra-red camera.

In the event that complete darkness is not achievable in the clinic room, the lighting should remain constant (dim) throughout the test. In the case of electro-nystagmography recordings this should minimise any changes in the corneo-retinal potential.

Also in the case of ENG recordings, where it is not possible to obtain complete darkness it is suggested that un-illuminated Frenzel's glasses can be used with eyes open in a darkened room to eliminate visual cues (Baloh et al, 1977) although this is not a truly effective way of removing visual fixation.

4.3.2. Problem with making recordings with eyes closed

Although not recommended, some tests can be carried out with eyes closed (e.g. search for spontaneous or gaze-evoked nystagmus without visual fixation, rotational and caloric tests) but one should be aware of artefacts, such as non-pathological up-beating spontaneous nystagmus (SN) and Bell's phenomenon.

4.4. Visual impairments and ophthalmic disorders

Blindness or severe visual impairment may affect the results. If a patient with significant refractive error cannot clearly see any given target, they should wear their spectacles and eye movements should be recorded by ENG. In the case of ptosis, the eyelids can be held open for short periods using micropore tape.

The patient's eyes should be examined initially by direct observation to check that eye movements are conjugate. Observe the full range of eye movements including oblique movements, and check by direct observation for congenital nystagmus and strabismus (squint) using the cover test (See Appendix C). If spontaneous nystagmus (possibly consistent with a congenital pattern) is seen, it may be helpful to ask the patient (or parent, if patient is a child) if this has previously been observed or if they have ever been informed that they had congenital nystagmus. If in doubt consult the patient's General Practitioner (GP), parents, optician or ophthalmologist.

If a significant squint is present it is advisable to patch the weaker eye and record the eye movements of the 'good' eye. If only a monocular VNG system is available (i.e. where the eye that is tracking the target is different from the eye being recorded), ENG should be performed with electrodes across the 'good' eye. Similar care in choosing which eye to record should be taken with patients who have a prosthetic eye.

Consider ENG rather than VNG in patients who are likely to shut their eyes frequently e.g. children or highly anxious patients who tend to blink excessively. Some patients are too claustrophobic to cope with video goggles and may do better with ENG.

Tests that are likely to induce rapid eye movement (notably head-shaking, Dix-Hallpike positioning and caloric tests) are not recommended within three months of eye (especially cataract) surgery.

4.5. Patient instructions

Briefly explain that the tests will involve recording eye movements with the head remaining still (apart from the head-shaking test) and obtain verbal consent to proceed. Ask the patient to sit in the test position such that primary gaze (looking straight ahead) is in the horizontal plane.

5. Techniques

Several methods for recording eye movements are available, each with its own advantages and disadvantages. It is recommended that the following methods are available, if resources allow: measurement of the corneo-retinal potential (CRP) using electrodes (ENG) or direct measurement of movements of the pupils using infra-red video goggles (VNG). It is recommended that VNG is used in preference and that ENG is used only when VNG is technically difficult.

The purpose of this protocol is not to provide any recommendations on whether to purchase a system with ENG as well as VNG option. Some systems combine both options.

Interpretation of eye movements may be difficult or impossible when testing either blind patients with spontaneous 'roving' eye movements or patients with congenital nystagmus as baseline calibration is not possible and therefore test results should be interpreted with caution.

ENG recordings should be performed with eyes open in a totally dark room (except for the visual targets). Between recordings, lighting should be as dim as possible in order to minimise fluctuations in the corneo-retinal potential. Where total darkness is not possible, only VNG should be used. However, if VNG is not available, ENG may have to be carried out in dim light with eyes closed but this is subject to certain artefacts (especially spontaneous up-beat nystagmus) and cannot be recommended.[3]

Computerised systems may employ a light bar or a projection system for visual target presentation. For simplicity, in this document reference will be made to use of a light bar and the document should be interpreted in the light of the need to follow the manufacturer's

[3] Note – if there any concerns that VNG goggles cannot be made completely lightproof, VNG must also be carried out in a totally dark room.

instructions. The light bar should be placed centrally in front of the patient at eye level. This may necessitate adjusting the height of the chair or the light-bar, whichever is appropriate for the local department set up. The target should be at the manufacturer's recommended distance from the patient and this position should be marked as part of the equipment installation process. A distance sensor, which may be equipment specific, will indicate whether the patient's distance from the light bar is within the acceptable range. Calibration may require the recording of regular horizontal smooth pursuit or fixed saccades, depending on the equipment type.

For non-computerised systems, two calibration points should be placed in the horizontal plane at a distance such that they subtend a visual angle of ± 20° at eye level. Instruct the patient to gaze alternately between the right and left calibration points (keeping their head still) and adjust the amplifier gain to produce a trace deflection of 20 mm ±1 mm. In addition, a marker defining the straight ahead point (0° azimuth) should be provided. Fully computerised systems that do not allow the tester/physician to examine the quality of the raw eye traces (e.g. for noise in the recording) should be avoided.

5.1. Testing using video-nystagmography

5.1.1. Camera placement

Place the goggles containing the video cameras on the patient's face so that they are comfortable. Adjust the position of the goggles and/or the cameras to achieve a clear view of the pupils of the eyes even if the patient looks to the extremes of gaze. If the patient has any obvious eye abnormality (such as a prosthetic eye, squint / strabismus, disconjugate eye movement) then monocular recording will be required, covering the weaker or problem eye with an eye patch when appropriate to do so. Many VNG systems' abilities to identify the pupil correctly are disrupted if eye make-up such as mascara is used. Appropriate instructions about not using make-up should be included in any appointment letter.

5.1.2. Calibration

Calibration of eye movements may be performed in a dimly lit room and carried out according to manufacturer's instructions. It is generally unnecessary to carry out further calibration, unless the cameras are moved within the goggles. If the goggles are removed or repositioned, further calibration is not usually required. Follow the procedure recommended by the

manufacturer for positioning the patient relative to the light bar and for performing the eye calibration.

5.1.3. Tracking software

The tester should ensure that a clear view of the pupils is maintained throughout the test, as the eye tracking software requires this. When VNG is carried out in a dimly lit room this serves to make the VNG goggles easier to adjust and allow accurate tracking of pupil movement. The tester should periodically check that the computer traces produced by the eye tracking software agree with the visual display of the eye movements: in other words that the eye tracking software is successfully locked onto the patient's eyes.

5.2. Testing using electro-nystagmography

5.2.1. Skin preparation and electrode attachment

Switch recording equipment on before connecting it to the patient. Do not switch off equipment whilst the patient is connected.

It is beyond the scope of this document to discuss the advantages and disadvantages of AC or DC recordings. (For example, slow phase morphology i.e. congenital versus central nystagmus against base-line drift). However, the tester should be aware of the type of system employed (see Appendix D).

Using mildly abrasive gel, carefully rub the skin prior to electrode placement. Electrodes are placed on the forehead, near the right and left outer canthi and for vertical eye movement recording above and below one eye. The two horizontal channel electrodes are placed such that they lie on an imaginary line passing through the patient's pupils when looking straight ahead. They should be as close to the outer canthi as possible, without restricting the patient's comfort or ability to blink normally and not causing excessive blinking (see Figure 1–A). This electrode montage allows 'combined binocular' horizontal as well as vertical eye movement recordings to be made. When the patient is connected and disconnected from the equipment, the common ('ground') lead should be connected first and disconnected last. With the leads to the horizontal channel electrodes connected to the recording equipment, eye movement to the right produces an upward deflection of the trace whilst eye movement to the left produces a downward deflection. In the case of the vertical channel electrodes, upward eye movement results in an upward movement of the trace and downward eye movement in a downward movement of the trace.

5.2.2. Calibration

If the patient has any obvious eye abnormality (such as a prosthetic eye or squint etc.) that may affect the ENG, then an altered electrode placement should be considered such as monocular recording of the better eye (and patching the affected eye). See Figure 1–B.

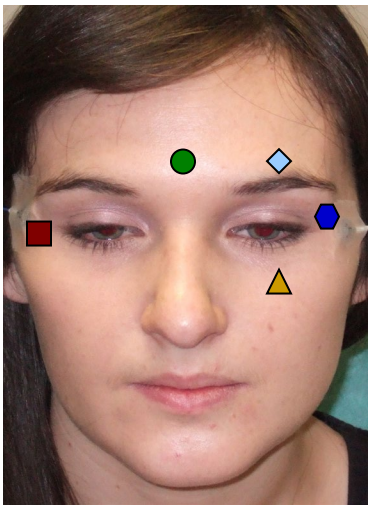
For separate eye movement recording see Figure 1–C for electrode placements.

Check the contact with an electrode impedance meter (ensure impedances below 10 kΩ and matched to within 2 kΩ). If the trace is contaminated with high-frequency noise, this may indicate poor electrode contact or may represent evidence for an abnormally low CRP.

Calibrate according to manufacturer's instructions. It is essential that calibration of eye movements be carried out in a dimly lit room. For computerised ENG systems with an integral light bar, follow the procedure recommended by the manufacturer for positioning the patient relative to the light bar and for performing the eye calibration.

For other systems, two calibration points should be placed in the horizontal plane symmetrically in front of the patient at a distance such that they subtend an angle of 20° at the patient's eye level. Instruct the patient to gaze alternately between the right and left calibration points and adjust the amplifier gain to produce a trace deflection of 20 mm (± 1 mm). In addition to the outer calibration points, a marker defining the straight-ahead position should be provided. For paper chart recorders a paper speed of 10 mm s^{-1} should be used.

For ENG, it is recommended that calibration is performed for each test or whenever there is a significant change in ambient lighting levels (e.g. dark to bright or dark to dim for 10 minutes). The corneo-retinal potential may change during the course of the session due to the change in ambient light that may be required for each ocular-motor function test. Light to dark and dark to light adaptation is non-linear (Davson, 1962) and not always predictable. Therefore if there is any doubt, recalibration is advisable.



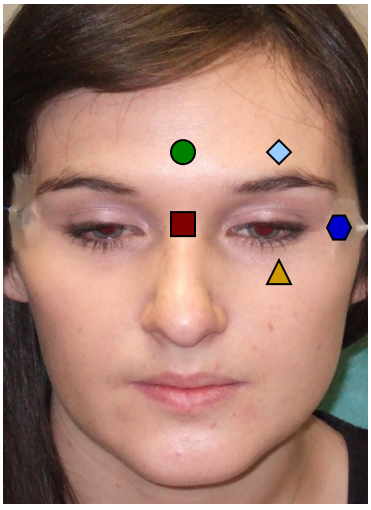


Figure 1-A

Binocular Eye Recordings.

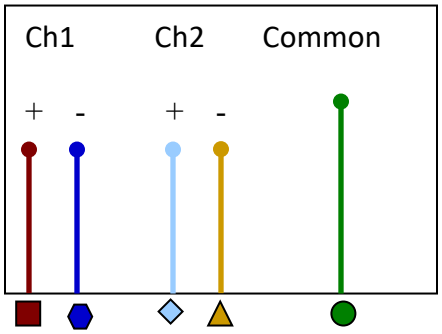
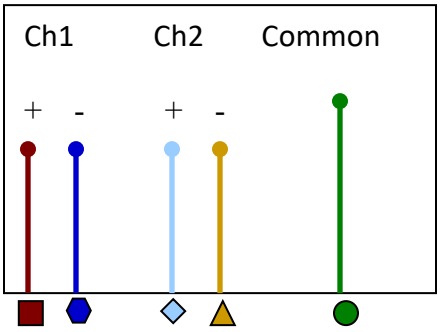
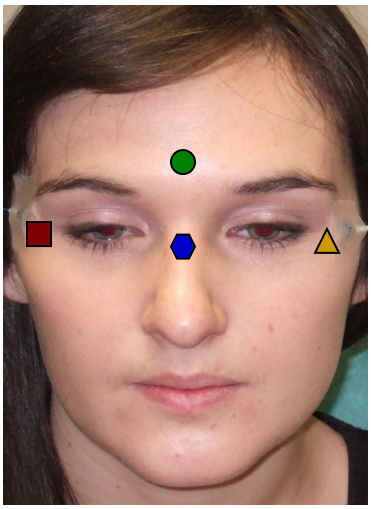


Figure 1-B

Monocular Eye Recordings.





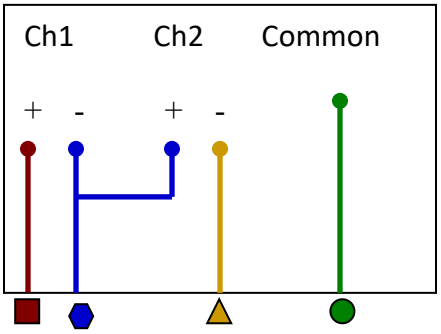


Figure 1-C

Separate Eye Recordings.

6. Recording of responses

This section describes the process of carrying out the VNG/ENG test battery. Section 8 describes the analysis of eye movements generated by each stimulus and subsequent interpretation.

6.1. Test order

1. Set up the eye movement recording system as described in Section 5.
2. The test should be performed in darkness (ENG) or dim lighting (VNG).
3. The patient sits upright with their eyes in the horizontal plane, facing 0° azimuth.
4. There is no recommended order for the following tests except where indicated. The actual tests carried out and order of tests will depend on a number of factors but may depend on the following: - availability of suitable equipment, time available, what is your most important question and what is going to make the patient symptomatic. Every appointment should be tailored around the needs of the individual patient. However, it may be advisable to do the saccadic test immediately after calibration if using saccadic calibration, or the smooth pursuit test if using smooth pursuit to calibrate. For example, tests may be performed in the following order:
    - Gaze testing[4] (centre; left; right; up; down if appropriate) looking for spontaneous or gaze-evoked nystagmus with and without visual (optic) fixation.[5]
    - Smooth pursuit (which must be tested specifically and not just as part of the calibration process).
    - Saccades (which must be tested specifically and not just as part of the calibration process).
    - Optokinetic nystagmus (which must use a full-field stimulus: the smaller the target, the more similar the test becomes to pursuit. The light bar does not constitute an

[4] Use targets at 30° angles.

[5] Spontaneous – centre position. Gaze evoked (gaze paretic) nystagmus – right and left position.

adequate optokinetic stimulus. Unfortunately, many commercial systems do NOT incorporate a full field stimulus.)

- Head-shaking test. This should not be carried out until after the positional tests, if horizontal canal benign paroxysmal positional vertigo (BPPV) is suspected.

- Static positional tests[6].

6.2. Spontaneous and gaze evoked nystagmus

The patient is instructed to maintain their head in the primary position and look at the target without moving their head[7]. Vertical, as well as horizontal, eye movements should be recorded. It is very important to observe the vertical eye movement on lateral gaze tests as downbeat nystagmus may be enhanced on lateral gaze.

For left/right recordings, the target angle should be ±30°. N.B. if the target angle is greater than 30°, "end-point" nystagmus may occur: some horizontal nystagmus is normal at extremes of gaze.

Recording for each test condition should be for a minimum of 15 seconds. If nystagmus appears, record for a further fixation period of at least 10 seconds. If mild nystagmus starts after a significant delay of 30 seconds or more, interpret with caution as it may potentially be caused by fatigue.

Despite the conflicting evidence currently available, the use of mental alerting is recommended. There is debate in the literature[8], and the evidence supporting or rejecting the use of mental

[6] As opposed to positioning tests (such as Dix-Hallpike, for which the reader is directed towards the BSA recommended procedure).

[7] Some thought should be given to maintaining the proper positioning of the patient's head during all of the subtests of the ocular motility test battery, perhaps a chin rest or head restraining device. A small amount of error can mean the difference between any gaze evoked nystagmus being clear, present, or absent.

[8] Humphriss et al, 2005 proposed that mental alerting could just as likely result in exacerbation as reduction in slow-phase velocity. Mental alerting may also result in an increase in noise, particularly if the alerting task is too complicated for the individual patient (McGovern and Fitzgerald, 2008). However, the authors indicated that there were advantages to appropriate mental alerting. Clearly this is an area that requires further research and studies have been implemented which may resolve this issue.

alerting is not clear cut, with studies using relatively small numbers of subjects. If a mental alerting task is used, it should be age appropriate but if it appears to be causing artefacts in the eye movement recordings, the alerting task should be modified or abandoned.

The suggested test order is as follows:

- Centre gaze with visual fixation (VF) / centre gaze without VF
- Right gaze with VF / right gaze without VF
- Left gaze with VF / left gaze without VF

If vertical nystagmus present during lateral gaze tests, proceed with vertical gaze tests:

- Up gaze with VF / up gaze without VF
- Centre gaze with VF
- Down gaze with VF / down gaze without VF

Vertical recordings may be helpful, although the lack of good normative data for all types of vertical recordings may render their interpretation problematic. Upbeat nystagmus is unlikely to be indicative of a potentially significant (usually central) disorder unless it is present with fixation.

In each test condition:

- Visual fixation target is provided by a bright[9] light, laser generated target, projection systems or LED
- Without visual fixation – switch off visual fixation target and with the subject either in a completely dark room, VNG goggles covered or with non-illuminated Frenzel's glasses in the case of ENG.

[9] it is beyond the scope of this procedure to provide guidance on recommended light output in lumens, but the light output from currently available commercial systems is considered to be satisfactory for patients with normal vision.

- Check for rebound nystagmus

The patient should be instructed to look towards the test position and try to maintain the gaze position even in the absence of visual fixation.

If any abnormalities are detected, that test condition should be repeated at least once or until consistent results obtained. If you see (what you think is) end-point nystagmus in gaze test without visual fixation, momentarily put fixation light on to allow patient to move their eyes to correct position.

6.3. Smooth pursuit tracking

The patient should be instructed to keep their head as still as possible, and to follow the moving target with their eyes, as accurately as possible, immediately when it moves. With amplitudes of 15° to 30°, conduct test at frequencies between 0.1 Hz and up to 0.7 Hz.

Patients should be encouraged to maintain attention throughout the test. Re-instruct and repeat as necessary. If recordings are abnormal, repeat at least once more. A common cause of pursuit 'abnormality' is poor attention, tiredness or psychotropic medication. Recording can be achieved with either fixed or variable target velocity. In the case of very elderly patients, consider using a lower frequency.[10] Smooth pursuit gain decreases with age leading to an increased tendency to saccadic intrusions. Hence age related normative data are important and should be taken into consideration.

Traces should be examined for the presence of overlying spontaneous or gaze-evoked nystagmus and saccadic intrusions ('cog-wheeling'). Note that a central pathology results in decreased gain: the eyes lag behind the target, with catch-up saccades. If the eyes are jumping ahead of the target, then waiting for it to catch up, the cause is a usually lack of concentration or anxiety and the patient should be re-instructed.

Horizontal pursuit should, and vertical pursuit may, be recorded. With the latter it may be difficult to interpret any abnormalities due to a likelihood of the presence of blink artefacts. The

[10] It is not unusual for subjects > 65 years of age to have difficulty tracking objects above 0.2Hz (30° arc). However, if testing against age-matched normative data this should be accounted for, and so results outside of the normal range should still be considered a central indicator.

appropriate equipment should be available, such as an additional light bar (or a horizontal bar that can be rotated).

6.4. Saccade testing

6.4.1. Random saccades

Record for at least 30 seconds. Depending on the software used, the target will usually move pseudo-randomly over an arc (5° to 30°), at a specified time interval (1 to 2 seconds). Some systems allow the target to move at random time intervals to random positions. During recording, examine the eye movement traces and compare with that of the moving target.[11]

6.4.2. Fixed saccades

Fixed saccades are less sensitive in the detection of central lesions (Isotalo et al 1995) because individuals can quickly learn to make appropriate corrections to a regular, repeatable stimulus and therefore should not be used.

6.4.3. Individual eye recordings

If initial examination reveals disconjugate eye movement, calibrate each eye separately. Examine recordings from each eye to determine whether there are asymmetrical responses, which may occur in the case of, for example, internuclear ophthalmoplegia (INO).

6.4.4. Vertical saccades

Vertical saccades may be recorded. The appropriate equipment should be available, such as an additional light bar (or a horizontal bar that can be rotated) as well as appropriate age matched normative data. However, beware of prominent blink related artefacts. Vertical saccades (and indeed vertical smooth pursuit) should not be considered to be part of a standard test battery and have more relevance in patients with suspected central problems.

[11] Up to 20° saccades are accurate in normal subjects, but over 20° it is not unusual for subjects to need two saccadic eye movements to reach target and therefore one correction should be allowed at such angles.

6.5. Optokinetic nystagmus

Optokinetic nystagmus (OKN) refers to movement of the eyes in response to movement of visual stimuli across the full-field (at least 180°) of vision. The full-field should be well illuminated and be fully encapsulating peripheral visual fixation if possible. The ideal stimulus is a coherent motion of large segments of the visual field (e.g. series of black and white stripes or cute animals if testing children) completely surrounding the test subject). Projector screens have their limitations (and must be totally free of marks) but providing the edges of the projected image are not visible to the patient this stimulus meets the definition of an OKN stimulus.

Light bars, and small hand-held "OKN" drums, do not generate optokinetic nystagmus and are little more than smooth pursuit tests using constant velocity rather than the traditional sinusoidal stimulus.

The target should be moved across the subject's field of vision at velocities of $20°s^{-1}$ and $40°s^{-1}$ for 10 to 15 seconds in each direction.

Patient instructions are very important. The patient should be instructed to look straight ahead at the stimulus and "watch" the pattern as it moves across. If subjects "ignore" the pattern or "look beyond" this is likely to suppress the OKN. It is important that patients do not track or follow the movement as this would simply result in a smooth pursuit response.

Note this test can make the patient feel unwell, and therefore consider using a low velocity stimulus if the patient reports any difficulty with the procedure. If the morphology of the recorded responses is not clear, the test should be repeated.

OKN tests are neither mandatory nor essential, as OKN abnormalities in the absence of other test abnormalities are uncommon. There have been incidences in which the stimulus has triggered a seizure and therefore this test should be avoided in patents with epilepsy.[12]

[12] Personal experiences of one of the authors.

6.6. Static positional testing

Nystagmus present in a static position represents an imbalance in neural activity within the peripheral or central vestibular pathways. In acute peripheral cases it can be explained by otolith-canal interaction on the remaining intact side (Baloh and Honrubia, 1990). Positional nystagmus is present when an individual is maintaining a position, as differentiated from nystagmus evoked by moving from one position into another, which is positioning nystagmus (most commonly Benign Paroxysmal Positional vertigo[13]). Only the positions considered the most sensitive for pathology need be tested, rather than the up to 10 positions that have been used in the past (Brandt, 1990; Gans & Yellin, 2007).

The four test conditions required are:

- Supine
- Body right[14]
- Body left
- Supine with neck flexion at 30° (Caloric Test Condition)

In addition, it may also be helpful to ask the patient to assume any positions that evoke their dizziness when these are different from the four test conditions above.

Care should be taken when moving patient from one position to the next if they have musculoskeletal problems, particularly of the neck and / or back.

Positional nystagmus can occur with or without subjective dizziness so the patient history may not give a clear indication of who requires testing. Testing of static positional nystagmus, unless contraindicated, should therefore be considered in all patients having a full vestibular assessment. Testing for spontaneous nystagmus and positioning nystagmus, (usually BPPV),

[13] Although positioning is the more correct term (in order to differentiate it from static positional testing), positional remains in common usage.

[14] Whole body left and right is preferable to just neck torsion as avoids the effect of neck torsion which may cause a neck positional nystagmus.

should be carried out before testing for static positional nystagmus. Recording is carried out for 30 seconds in each static positional test position if no nystagmus occurs and up to several minutes if nystagmus is elicited. This should allow the clinician to differentiate paroxysmal positioning nystagmus from static positional nystagmus (Brandt, 1993). Any positional nystagmus should be interpreted in relation to any spontaneous nystagmus present in the neutral position of seated, gaze centre, as this is likely to contaminate the results of static positional testing. Initially static positional testing should be performed without vision. If any nystagmus is recorded then the patient should be tested with fixation present to test for suppression of the nystagmus. Opinions differ on the need for mental alerting during nystagmography tasks (Davis and Mann, 1987; Humphriss et al, 2005; McGovern and & Fitzgerald, 2008). A suggested approach would be to test with mental alerting but be prepared to remove the alerting if it appears to be introducing too much noise into the trace.

6.7. Head-shaking test

6.7.1. Procedure

With patient seated and looking straight ahead, the tester should check for the presence of any baseline spontaneous nystagmus,

The test should be performed with visual fixation removed.

The patient should be instructed to maintain eyes open throughout the test for VNG. For ENG the test should be performed in complete darkness or with eyes closed.

Recording should take place with the head still for 10 seconds prior to start of head-shake to record any baseline spontaneous nystagmus in the test position.

The tester needs to decide whether active (patient shakes their own head) or passive (head held and moved by tester) head-shake is appropriate for the patient. Caution should be exercised in patients who have a neck injury or stiffness.

It is important to limit head movement to the horizontal plane of rotation to avoid inducing physiologic post-rotatory nystagmus due to rotation about another axis of the head (e.g. circular head movements should be avoided as these generate nystagmus in normal individuals).

6.7.2. Active head shake

The patient should be instructed that head movements should be low amplitude (20° either side) and at a frequency of approximately 2 Hz. It may help to demonstrate the desired movement, and/or use a metronome to guide the speed. Gentle guidance with the hands may be also used to set the correct speed; for example instruct the patient to 'shake your head with me'. After 20 head-shakes, the head is kept still in the original test position with the eyes open. Continue recording for a minimum of 30 seconds with the head still to check for the presence of nystagmus.

6.7.3. Passive head shake

With hands either side of the forehead, gently move the patient's head at a speed of approximately 2 Hz in an arc of approx ±20° for 20 repetitions. Do not force the head to move if resistance is offered. Inform the patient before you start shaking. On stopping, the patient may need to be reminded to keep eyes open and look ahead. Record responses as above.

7. Analysis of responses

The reader is directed towards Appendix B on common pitfalls in interpreting the results in oculomotor testing.

7.1. Spontaneous and gaze evoked nystagmus

For automatic computerised eye movement measurement systems, verify that any nystagmus has been correctly identified by examining the trace and editing where necessary. Establish the slow component velocity of any nystagmus, where it occurs and its duration. Any nystagmus recorded during gaze testing with fixation must be considered abnormal. In the absence of robust normative data, any spontaneous or gaze-evoked nystagmus present with fixation removed needs to be interpreted in light of the overall pattern of test results and the patient's

complaint.[15,16] Low levels of such nystagmus may not necessarily be of pathological significance.

Determine whether the nystagmus follows Alexander's law, i.e., if peripheral in origin, nystagmus should increase in magnitude with gaze in the direction of the fast-phase, particularly with removal of visual fixation. In the case of vertical nystagmus, particularly in primary gaze when artefacts are less likely, central aetiology should be considered.

7.2. Smooth pursuit tracking

Test results will be influenced by factors such as level of patient mental alertness, age and medication such as tranquillisers and anticonvulsants.

The following parameters are usually measured:

- Velocity gain (maximum eye velocity divided by target velocity)
- Phase difference (between eye and target) for each test frequency executed by the patient.

One or more 'normal' cycle/s (e.g. one positive peak to the next positive peak) is sufficient for the recording to be regarded as within normal limits but compare to normative data for age. Normative data are usually provided with most commercial systems. If these are not available, local normal limits should be established.

It is also important to assess the degree of saccadic intrusions. Patients with significant 'cog-wheeling' may have normal gain and phase difference. Some systems will provide an objective measure of this in the form of the parameters spectral purity or percentage of saccadic

[15] There are few recent published data in this area and more research is needed. It is recommended that each department develop their own normative data. Recent work by Patel and Rogers (Poster presentation BAA conference 2012) and others, suggest that the lower limit of abnormal may be considered to be as low as ≥1ºs^{-1}. Recent communication with Barin suggested upper limit for normals of 3.73º s^{-1} (mean 1.42º s^{-1}). With ENG recording, nystagmus has been considered to be significant if there are at least four or five consecutive nystagmus beats and these have a magnitude of ≥4º s^{-1} (Luxon, 1995).

[16] Any persistent repeatable nystagmus (1-2 º s^{-1} and above) when in conjunction with other significant test results (caloric directional preponderance, rotating chair etc) and a vestibular history, may be taken as probably significant e.g. patient with vestibular history, right lateral gaze 2 º s^{-1} right beat, central 1º s^{-1} right beat, left; nil then that may be considered to be significant nystagmus.

components. (It is beyond the scope of this document to discuss these in detail). Some systems will also provide asymmetry values (tracking leftwards compared to rightwards).

7.3. Saccades

The following parameters are usually measured:

- Velocity
- Accuracy ("overshooting" aka hypermetria, or "undershooting" aka hypometria)
- Latency (time difference between appearance of target and patient recording of saccade initiation).
- Conjugacy i.e. whether the two eyes are moving at the same speed.

Compare recordings with normative data, and for symmetry within the same person. Although normative data are usually provided by the manufacturer they will not always cover the full age ranges of patients tested. Saccades are considered normal when at least two saccadic eye movements to each left and right are normal.

It is not uncommon for patients to display very minor under- or overshoots – these need to be judged against normal limits. Undershoot is less significant than overshoot (unless clearly asymmetrical). If there is dysmetria, determine whether this is bidirectional or asymmetrical. Asymmetrical physical signs are always more significant as indicators of potentially localising pathology. Slow saccades are a very powerful indicator of central or peripheral (neuromuscular) disease**.** Delay in latency of saccade onset can be entirely 'state' dependant and is the weakest of the measures. However, it may be interpreted as a sign of central dysfunction but may also be due to medication.

There are limited published normative data for vertical pursuit and/or saccades. However, even in the presence of published data, it is recommended that departments establish their own normative data. This process allows testers to 'get a feeling' for the range of eye movements expected.

7.4. Optokinetic nystagmus

Physiological nystagmus should be generated which changes direction with the change of direction of the stimulus. Calculate the gain (slow phase eye velocity / target velocity) for each direction and the corresponding directional preponderance (or asymmetry).

Abnormalities of optokinetic nystagmus may arise from peripheral or central lesions. Although mainly central, OKN abnormalities may also arise during the acute / sub-acute phase, if for example spontaneous nystagmus is present.

Provided that a peripheral vestibular disorder is not acutely active, OKN abnormalities are likely to be due to central disorders.

Lack of reversal of OKN to stimulus direction change is also diagnostic in confirming congenital nystagmus.

7.5. Static positional testing

When interpreting any nystagmus obtained during static positional testing, it is important to consider other possible causes of the nystagmus such as ingestion of alcohol (positional alcohol nystagmus), vestibular migraine or BPPV, especially that of the horizontal canal or cupulolithiasis variant. The history needs to clarify whether alcohol or medication are an issue in relation to this testing or whether vestibular migraine or BPPV could be a diagnosis. With positional alcohol nystagmus, one would expect a geotropic positional nystagmus during the first 3-5 hours and with periodic alternating nystagmus an apogeotropic positional nystagmus that occurs after 5 hours (Shepard & Telian, 1996). Vestibular migraine can cause long lasting central positional nystagmus (Cephaligia 33(9), 2013). BPPV of the cupulolithiasis type can cause long lasting, non habituating nystagmus present with fixation, and horizontal canal BPPV causes horizontal nystagmus which in some cases can appear similar to positional nystagmus. A full discussion of this subject is beyond the scope of this document and the reader is directed to the International Headache Society website for further information. (http://www.ihs-headache.org/)

Static positional nystagmus should be interpreted as follows.

Abnormal results: if nystagmus changes direction in a single position; and/or nystagmus of 6ºs^{-1} or greater in any one position and/or nystagmus greater than 3ºs^{-1} in the majority of positions (at least three out of four).

These levels of significance characterise 95% of healthy subjects as normal. Jacobson et al, 1997, quoting Barber & Wright, 1973. Shepard & Telian, 1996 give a similar set of criteria without specifying the 3ºs^{-1} in a majority of positions.

Although static positional nystagmus is considered non-localising (Maire & Duvoisin, 1999), it can generally be interpreted as a peripheral finding unless there are particular central features to the nystagmus or another test in the test battery gives a central indicator. Some like to interpret static positional nystagmus in light of the patient history, presumably attaching greater significance if nystagmus, that would normally not be considered to be abnormal, is induced in a position which tends to provoke dizziness (Jacobson & Shepard, 2008).

Direction changing (that is, different direction when in different positions) and direction fixed nystagmus are generally interpreted as peripheral findings, although they can also occur with central lesions.

If the nystagmus changes direction in a single position this is a central indicator and lack of fixation suppression (Baloh & Honrubia, 1990) suggests a central finding.

7.6. Head-shaking test

7.6.1. Definition of a positive head-shake test

Head-shaking nystagmus should be considered to be present when ≥ 5 clear nystagmus beats of ≥ 3ºs^{-1} SPV are observed. The nystagmus may decay and disappear, or decay and then reverse direction. If there is a pre-existing spontaneous nystagmus, a positive result would be a temporary enhancement or reversal of the pre-existing nystagmus. There is no clear evidence yet to clarify how much enhancement is significant, so this remains a subjective judgement on the part of the clinician.

7.6.2. Localisation of lesion

The head-shake test is not a reliable indicator of side of lesion (e.g. Asawavichiangianda et al. 1999, Takahashi et al, 1990). It should always be interpreted in conjunction with other findings,

such as spontaneous nystagmus and side of caloric weakness. The direction of head-shaking nystagmus may change during the course of recovery from a peripheral lesion.

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- International Headache Society (http://www.ihs-headache.org/)

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Appendix B. Common pitfalls when interpreting the results in oculomotor testing

B.01 Factors affecting oculomotor tests

Oculomotor test results can be affected by a variety of factors. If these factors are not taken into account, results may be reported as abnormal when they are within normal limits and vice versa. The following are suggestions on how to ensure that test results reflect the true status of the function of the patient's oculomotor system, ensuring that true abnormalities are identified (as opposed to artefacts) which can then be acted on appropriately.

Test results can be affected by any of the following:

- Eye problems: disconjugate eye movements, (e.g. squints), visual acuity problems
- Other background eye movements such as nystagmus and blinks
- Medication/alcohol
- Patient non compliance due to tiredness/poor concentration/ not following instructions (e.g. moving their head) or subjective responses of dizziness when doing test
- Age
- Calibration issues
- Incorrect computer analysis of trace

B.02 Before testing: eye examination

Patients should be assessed for all of the following- positive results may necessitate modifications to testing.

Patients should be asked about their visual acuity and use of spectacles, contact lenses. If these problems are significant testing should be performed with visual aids on, but these should be single lens (and caution with varifocals or bifocals).

Patients should be checked clinically (bedside examination) for:

- Conjugate eye movements (separate eye recording may be necessary e.g. INO)
- Squint (monocular recording may be necessary so record from better eye)
- Congenital or other nystagmus present with fixation (or marked nystagmus without fixation) may lead to difficulty in analysis. To determine whether nystagmus seen is congenital, other markers such as reversal of OKN, exponential decrease of slow phase velocity, and a null point for the nystagmus can be used.
- Ptosis (which may cause artefacts on recording)
- Poor compliance to bedside testing may alert clinician to possible difficulties with VNG.

B.03 Before testing: lifestyle and medication

The patient should be checked for the following as all may affect test results:

- Centrally acting medication may affect the test results e.g. anti-depressants, anti-psychotics, anti epileptics, sleeping tablets, tranquilizers
- Alcohol dependency or alcohol intake in the previous 48 hrs
- Ability to understand test instructions. Care must be taken with patients with severe / profound hearing loss to ensure they understand the test instructions, particularly as testing is done in dim lighting/dark. Poor results may also be obtained from adults with diminished cognitive ability. Extra time may be needed for testing for both such patient groups
- Levels of fatigue and concentration e.g. have they come from a night shift, looking after children, sleeping poorly

B.04 Before testing: calibration

Ensure this has been done correctly. Often overly shortened amplitudes or abnormally fast velocity on saccades are due to calibration errors (and rarely by opsoclonus and ocular flutter which can be identified on the clinical eye movement assessment).

Gain > 1 on smooth pursuit is also normally due to calibration errors.

Test instructions, compliance and artefacts

- Test instructions are fundamental as they may radically affect test results- they should be given in a simple format which the patient understands. For example:
    - Smooth pursuit: 'Keeping your head still, follow the light smoothly with your eyes as it moves to the right and the left; let your eyes be dragged by the light. Try not to anticipate the movement of the light'.
    - Saccades: 'Keeping your head still follow the light as it jumps around with quick accurate eye movements'
    - OKN 'look passively forwards' or 'watch the pattern as it moves across' (they should not track it otherwise pursuit pathways will be involved
- Not following the target correctly e.g. pre-empting/getting ahead of the target is a common finding.
    - This may lead to an abnormally short latency on saccades (very rarely an abnormality) and may also look like hypometria
    - On smooth pursuit this may look like catch up saccades (but these will be the wrong way- i.e. back to the target rather than a true abnormality (cog-wheeling) of falling behind the target and then catching up
- Encouragement often helps improve traces- e.g. if patient's eyes are not moving smoothly or if they are getting ahead of the target
    - 'Try not to pre-empt the target moving. Let the target move and then move your eyes quickly and accurately to it'

- If poor on OKN response ask to look at dots/stripes ('active' OKN), improves trace

- If a test makes a patient feel dizzy this should also be reported
- Blinks can also cause artefacts (but should be readily identifiable on vertical recordings).

B.05 Analysis of results: computer analysis of trace

This should never be relied upon independently and the clinician must always review the traces themselves and compare results with those of clinical bedside assessment of eye movements.

Common pitfalls involve:

- Computer not accepting sufficient traces for a robust average (for example, computer should accept >50% of saccades and this test needs to be done for a minimum of 50 seconds for a robust average)
- Computer rejecting traces that are actually pathological.

If these have all been ruled out abnormalities must still be consistent and repeatable. If there is any doubt of this then repeat the test before reporting the results.

B.06 Analysis of results: smooth pursuit

- A patient will either be able to do the test or not. If the patient is able to do the test some of the time (e.g. has good pursuit for at least a cycle at a given frequency) this means they probably can do it. If this is not the case then repeat
- If a patient can do smooth pursuit at ≤0.4 Hz, but not at >0.4 Hz, this is unlikely to be pathological. Abnormalities in higher frequencies only (e.g. 0.7 Hz) are unlikely to be due to an abnormality that is of clinical concern, but should be reported
- It is usual to have some drift from target at top and bottom of pursuit trace as direction or speed (e.g. especially from 0.1 to 0.2 Hz) changes
- There is evidence supporting a strong link between abnormal smooth pursuit and poor VOR suppression (Halmagyi, Gresty 1979) but also papers that demonstrate the reverse i.e. that the results of smooth pursuit and VOR suppression tests are not always in

agreement (Barin and Davis 2003). Therefore smooth pursuit may be carried out in a test battery that also includes VOR suppression tests.

B.07 Analysis of results: saccades

- Based on authors' own normative data, a little over- or under-shooting may be normal especially transiently whilst the patient familiarises themselves with the task. Always use the manufacturers' or your own department's normative data as a guide.

B.08 Analysis of results: age

Ensure that you use age related normative data for all testing- results which maybe considered abnormal on a young adult may be considered age appropriate on an elderly one. For example, it is normal for an elderly patient's smooth pursuit to be slightly saccadic at higher frequencies (give age and frequency and reference).

Computerised systems may report as abnormal the trace in which the patient's eyes jump ahead of the target and then slow, waiting for the target to catch up. This is usually the result of patient anxiety or inattention. Truly pathological pursuit involves the eyes lagging behind the target, with catch-up saccades. Always examine the traces and do not rely on computer-measured parameters. Abnormal smooth pursuit is a central indicator. Check for blinks & vertical pursuit.

B.09 Analysis of results: paediatric testing

It is assumed that testing will typically be performed on adults or children aged five years and above. It is feasible to perform some tests on very young children (Harrop-Griffiths 2009; Snashall 2009; Raglan 2009). The vestibular system is structurally and functionally responsive at birth (Ornitz 1970), although there are differences in the responsiveness of this system in children as compared to adults and this is reflected in the appropriate normal limits for each test. The vestibular ocular reflex (VOR) response normalises at two months of age (Weissmann 1989); the optokinetic nystagmus may be elicited by a rotating drum in children from 3 to 6 months of age (Eviatar 1978) and higher and smooth pursuit should be normal from 5 yrs of age (Levens 1988). It is beyond the scope of this document to describe the problems and pitfalls in testing children and the reader is directed towards Journal of Audiological Medicine Special Edition Volume 7 No 3 2009 and the many other peer reviewed articles on this subject.

Appendix C. Cover test

As conjugate eye movements are necessary if meaningful analysis of eye movement recordings is to be made, it is essential that a thorough clinical examination is carried out prior to recording.

The cover test is a clinical test that reveals misalignment of the visual axes and will identify any strabismus.

Before performing the cover test examine the eyes with the patient looking in the primary position. An exotropion (divergent squint) affected eye is turned outwards and esotropion (convergent squint) affected eye is turned inwards

The cover test is performed by asking the subject to fixate on a (usually hand held) target. The target should present some level of detail (i.e. Snellen letters in the distance or a reading chart at near; either distance or near targets are legitimate). First the patient fixates the target binocularly and then while one eye is covered at a time. The examiner looks for corrective eye movements seen on uncovering the eye.

- Exophorion - covered eye moves inwards
- Esophorion - covered eye moves outwards

Note that if the cover test reveals latent nystagmus (i.e. uncovered eye develops horizontal nystagmus beating away from the covered eye) this is a contra indication to patching the affected eye and binocular recordings should be performed.

Skew eye deviation is characterised by a vertical misalignment of the visual axis and when accompanied by head tilt and ocular torsion is referred to as “ocular tilt reaction”. It has been suggested that this may be caused by a host of central vestibular lesions and care should be taken when considering recording eye movement in patients with this presentation.

Appendix D. Considerations with AC and DC electro-nystagmography eye movement recordings

It should be noted that many commercial systems that allow ENG eye movement recordings to be made employ AC, DC or AC and DC biological (usually optically-isolated) preamplifiers.

DC recordings:

- Faithfully reproduce eye movement without compensating for electrode drift
- Useful in evaluating central versus congenital nystagmus

AC recordings:

- Commercial AC amplifiers are invariably cheaper than DC
- Compensate for mild electrode drift.

These considerations are applicable only to recordings made with ENG and not VNG.

Appendix E. Positional and head-shaking tests

E.01 Positional tests

There is disagreement in the literature as to whether normal subjects commonly have static positional nystagmus or whether static positional nystagmus must indicate an asymmetry of the vestibular afferent tone in the peripheral or central vestibular system. The strength of evidence would appear to support the former view that static positional nystagmus is present in normals. Barber and Wright (1973) found that 82% (92/112) of healthy subjects demonstrated a position-induced nystagmus in at least one position with eyes closed and that this nystagmus could be either geotropic or apogeotropic. Criteria for significance therefore have to be used to differentiate physiological from pathological nystagmus.

Positional nystagmus of peripheral origin should be direction-fixed and horizontal. One would expect the fast phase of any nystagmus to beat toward the intact ear but this will not always be the case due to irritative or recovery nystagmus. In this way static positional nystagmus alone does not localize the site of lesion or affected ear. The clinician may be able to correlate the static positional nystagmus with the patient history, symptoms and other test results in order to localize. Static positional nystagmus suppressed by fixation is more likely to be peripheral in origin (Maire and Duvoisin, 1999). Peripheral static positional nystagmus may not persist within a given test position.

Central static positional nystagmus is usually of low frequency and will persist whilst the patient remains in the evoking position. Failure of fixation suppression is a sign of a central lesion (Maire and Duvoisin, 1999). Vertical nystagmus during static positional testing is a central sign, as is purely torsional nystagmus. Static positional nystagmus with no subjective impression of vertigo or dizziness is more likely to be central in nature. Significant positional nystagmus in the presence of abnormal oculomotor tests (that is, smooth pursuit or saccades) or other central indicators and no other indications of a peripheral vestibular lesion, is most likely central in origin.

Central type static positional nystagmus has been attributed in the literature to damage to the posterior fossa, brainstem or cerebellum, Arnold-Chiari (Chiari I) malformation, multiple sclerosis, vertebrobasilar insufficiency, and centrally-acting medications (Brandt, 1990). Migrainous positional vertigo, often an apogeotropic nystagmus, is also documented in the literature (Roberts et al, 2006, 2008). CT and MRI scanning, however, are often unable to

determine the location of the lesion. Central positional nystagmus occurs frequently in the elderly and often resolves spontaneously.

Static positional nystagmus can be differentiated from BPPV by the direction of the nystagmus, the absence of a latent period, by not being paroxysmal, and by a lack of fatigability and of habituation on repetitive stimulation. Cupulotlithiasis of the horizontal canal can result in apogeotropic nystagmus beating for longer than a minute, however, and so nystagmus with these characteristics is not necessarily central in origin.

E.02 Head shaking test

The sensitivity of the head-shake test to known unilateral peripheral vestibular lesions has been estimated at between 21% and 95% (Asawavichiangianda et al. 1999; Burgio et al. 1991; Fujimoto et al 1993; Guidetti et al. 2006; Humphriss et al. 2003; Iwasaki et al. 2004; Jacobson et al. 1990; Kamei et al. 1964; Takahashi et al. 1990; Tseng and Chao 1997; Wei et al. 1989).

The head-shake test is not sufficiently sensitive to be used in isolation as a screening test for vestibular dysfunction (Humphriss et al 2003).

The specificity of the test is somewhat better and has been estimated at between 77% and 98%. A small proportion of normal individuals can be expected to have head-shaking nystagmus.

With peripheral lesions, the observed nystagmus is typically monophasic or biphasic. The response is rarely triphasic in 0.5 % of cases (Fuijmoto et al 1993). In peripheral biphasic responses, typically the initial nystagmus is briefer and stronger, followed by weaker and more prolonged nystagmus in the opposite direction (exponential decay pattern). It has been reported that posterior canal BPPV may occasionally cause a torsional nystagmus in response to head-shaking; therefore this condition should be excluded prior to performing the test. (Califano et al 2001)

Central lesions may also cause head-shaking nystagmus. Centrally mediated nystagmus may present identically to a peripheral lesion, but specific indicators of central dysfunction include:

- Perverted nystagmus: Vertical or torsional nystagmus caused by horizontal head-shaking.

- Unusual biphasic responses: e.g. reversal phase much stronger than initial phase, extremely prolonged nystagmus without decay.
- Head-shaking nystagmus that is prominent with fixation and not significantly enhanced by its removal.

Central lesions that have been reported to cause perverted head-shaking nystagmus include cerebellar lesions, multisystem atrophy, lateral medullary infarct, multiple sclerosis, migraine & lamotrigine overdose. Note that this is not an exhaustive list of central causes (e.g. Kim et al. 2005; Minagar et al. 2001, Choi et al. 2007).