Hands-on Course 3

Bedside examination of the vestibular and ocular motor system - Level 2

How to examine the vestibular system

Raymond van de Berg
Maastricht, The Netherlands

Email: raymond.vande.berg@mumc.nl
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Introduction

A complete and thorough neuro-otological and vestibular examination is necessary to find any signs of vestibular hypofunction or any neurological diseases, particularly ataxia. Keep in mind that when testing the vestibular system, each test has its own limitations in terms of sensitivity, specificity, patient acceptance, costs and duration. During the neuro-otological assessment, one should pay especially close attention to the oculomotor examination, since abnormal oculomotor findings may be the only or first presenting central signs that may explain the vestibular symptoms [2]. The oculomotor examination is best performed before inducing the substantial head movements that are typical for some major components of the vestibular examination. The vestibular examination includes the Dix-Hallpike and the lateral roll test, positional testing, (V)HIT, the test for Dynamic Visual Acuity (DVA), the visually enhanced vestibulo-ocular reflex test, fixation suppression, the Valsalva maneuver (straining against the closed glottis and blowing out against pinched nostrils), the head shake test, the vibration test, the hyperventilation test and the Romberg test on foam rubber or in tandem [3, 4]. The Romberg, (V)HIT, DVA and head shake test will be discussed more in detail in this hands-on course.
The Romberg test

The Romberg test mainly diagnoses ataxia and is not specific for a vestibular loss, since it also detects cerebellar and proprioceptive impairment [3, 5]. However, the sensitivity for detecting vestibular deficits increases when the patient stands on foam rubber [6]. The Romberg test on foam rubber has a sensitivity of up to 79% and a specificity of up to 80% for detecting both patients with unilateral and those with bilateral vestibular loss [3, 7].

Head impulse testing

A brief, high-acceleration head ‘impulse’ can test vestibular function of all semicircular canals. Depending on the semicircular canal tested, the head is rotated in a different direction [8, 9]. A corrective catch-up saccade is made in case of vestibular hypofunction. HIT can be performed with or without the use of a noninvasive video-oculography device (i.e. Video Head Impulse Test: VHIT). This device consists of goggles that contain a high-speed infrared video camera that tracks eye movements and accelerometers that track head movements [10].

Although applying HIT may sound simple at first, some challenges are met when performing it. The first challenge is to adequately deliver the stimulus: it should be a high acceleration (1,000-6,000°/s²), rapid (100-200°/s), low-amplitude (10-20°) head rotation. The horizontal as well as the vertical canals can be tested. For the horizontal canals, the head is moved in the horizontal plane. This is different for the vertical canals. For this, it is important to know that the vertical canals form two pairs: The left anterior and the right posterior canal (they are called LARP) and the right anterior and left posterior canal (they are called RALP). They form
pairs, since the anterior canal of one side, is oriented in the same plane as the posterior canal of the other side. This can be seen in Figure 1 [11].

![Diagram of canal orientations]

**Figure 1. Orientation of the canals**

This means that a head movement in the plane of for example LARP, has effect on both canals. The anterior canal is sensitive for rotations going down in its plane, and the posterior canal is sensitive for rotations going up in its plane. Therefore, if you want to test the left anterior canal for example, the following steps have to be taken: First bring the head in line of the canal, so turn the head to the right. Secondly, have the patient fixate on a target, for example your nose. Thirdly, make an impulse in line of the canal and use the direction in which the canal is most sensitive. Since the anterior canal is most sensitive for moving down, make a downwards movement. The same paradigm can be used for the other canals. This is shown in Figure 2a and 2b [11].

![Images of testing LARP and RALP]

**Figure 2a. Testing LARP**  **Figure 2b. Testing RALP**
For both horizontal and vertical impulses, the head movements can be applied inward or outwards (figure 3). With the inward impulses, the head is first displaced laterally and then rapidly rotated back to the center. With the outward impulses, the head is put in neutral position and then rapidly rotated toward either side. The inward impulses might be easier to interpret in patients with acute unilateral peripheral vestibulopathy, where spontaneous nystagmus will vary in intensity depending on orbital position (figure 3). Also, less bounce artifacts are present. However, outward impulses are less predictable, since the neck offers no clue as to the direction of the next impulse. This might reduce the risk of covert saccades (see below). Therefore, the risk of erroneously identifying a normal HIT is higher using the inward technique [12].

![Figure 3. Two head impulse techniques in a patient with left unilateral vestibular deficit: inward HITs toward the deficient labyrinth with an eccentric head and eye position before the HIT, and outward HITs to the left, where the head and eye start moving from a centered position. The final resting head and eye position, which is eccentric in outward HITs, is important. Such an eccentric eye position would enhance an underlying spontaneous nystagmus according to Alexander's law and, thus, potentially confound test interpretation [12].](image)
When using VHIT, one should pay attention by avoiding a loose strap, wrong calibration, pupil tracking loss, (mini-)blinks, touching the goggles, patient inattention and investigator induced bounce; if these are not avoided, they will result in artifacts [13].

The second challenge is not to be fooled by preprogrammed compensatory saccades (‘covert saccades’) that can be invisible to the naked eye of the examiner and can occur (not only) in bilateral vestibulopathy patients. Consequently, vestibulopathy may be missed [14]. A recent study by Strupp et al. indicated that HIT observed by the naked eye of experts is false negative for about 50% of the patients when compared to VHIT [15]. This clearly supports the use of the VHIT device, which is able to track these saccades. Examples of normal and abnormal VHIT recordings with overt and covert saccades are presented in Figure 4.1a-c.

The third challenge is to correctly interpret the traces. VHIT traces can have many artifacts, leading up to 42% of uninterpretable traces [13]. Besides these artifacts, eye movements in patients with a vestibular hypofunction can show patterns that challenge interpretations. Ideally, vestibulo-ocular reflex gain is calculated by peak eye velocity divided by peak head velocity [16]. However, artifacts and abnormal patterns distort the process of correct gain calculation, and commercially available software is not yet able to adequately compensate for it. An example of an eye movement pattern that interferes with gain calculation is presented in Figure 4.2. In order not to miss a bilateral vestibulopathy, a physician should not yet solely rely on software processing for gain calculation, but should be trained in assessing the raw data and should be aware of the impact of deviant eye movement patterns and measurement artefacts [13].
Figure 4.1 Raw VHIT recordings of different subjects, recorded with the EyeSeeCam system (EyeSeeCam VOG; EyeSeeCam, Munich, Germany). Head velocity traces are shown in gray, eye velocity traces in black. a VHIT recordings of head impulses to the right in a healthy subject. The eye movements compensate for the passive head movements. b VHIT recordings of head impulses to the left in a patient with a peripheral vestibular deficit, resulting in overt saccades (peaks in eye velocity after head movements). The eye movements do not compensate for the passive head movements. c VHIT recordings of head impulses to the right in a patient with a peripheral vestibular deficit, mainly resulting in covert saccades (peaks in eye velocity during head movements).
Figure 4.2 Example of an eye movement pattern that interferes with gain calculation. Raw VHIT recordings of head impulses to the left in a patient with bilateral vestibulopathy are presented. Head velocity traces are shown in gray, eye velocity traces in black. Normally, gain is calculated by peak eye velocity divided by peak head velocity. In this case, gain calculation is challenged, since at the moment the peak head velocities are reached, the eyes are actually moving along with the head in the same direction. The passive head movements are not compensated by the eye movements. Although this is clearly an abnormal HIT, there is not yet any consensus about how to determine (or whether it is even possible to determine) the real peak eye velocity which is necessary for gain calculation.

The fourth challenge is to correctly interpret the end result. HIT provides a stimulus for measuring gain of the vestibulo-ocular reflex which is different from those used in other vestibular tests such as the rotatory chair tests or the caloric test; it includes many more high frequency components than the rotatory chair tests and the caloric test. Differences in response to the caloric test versus the rotation tests versus HIT are especially pointing to this difference in frequency content. It has been shown that a bilateral vestibular loss can be measured with the caloric test, while the responses as measured with HIT are relatively preserved [17, 18]. In other words, it is necessary to understand that the presence of a normal vestibulo-ocular reflex as measured with HIT does not rule out a vestibular deficiency.
Dynamic visual acuity

During head movements, efficient stabilization of the image on the retina is necessary to preserve visual acuity [19]. In (bilateral) vestibulopathy patients, gaze stabilization fails and can lead to significant deterioration in visual acuity during head movements [20, 21]. Visual acuity in dynamic conditions can be assessed by testing for DVA. DVA testing can be performed in many ways: the patient has to read letters from a visual acuity chart or a computer screen during active or passive, vertical or horizontal head movements, or while walking on a treadmill at different velocities [19, 22]. Passive high-angular-velocity movements (150°/s) have been shown to be most useful for discrimination between healthy subjects and patients with a unilateral or bilateral vestibular loss. However, that study did not include DVA testing by walking on a treadmill [23]. A decline of more than 2 lines on the optotype chart is considered abnormal [24], although a loss of 2 lines (0.2 logMAR) is not unusual for healthy subjects. In order to trade sensitivity for specificity, 4 lines may be required [25]. Moreover, DVA may show false negative results due to mechanisms that at least partially compensate for the retinal instability during head movements [3, 23]. However, in subjects with unilateral and bilateral vestibular loss, computerized DVA testing reached a sensitivity of 94.5% and a specificity of 95.2% [26]. In another group of bilateral vestibulopathy patients, DVA was impaired in 96% of the cases [27]. To conclude, DVA can help establishing the diagnosis of (bilateral) vestibulopathy, but a normal DVA does not definitely rule out bilateral vestibulopathy, and an impaired DVA does not imply vestibulopathy per se. It is still not understood by which specific vestibular deficits (which semicircular canals, which otolith organs and which frequencies) DVA decreases.
The head shake test is performed by shaking the head of the patient when the patient is wearing Frenzel or video goggles. The head is rotated at a comfortable range at a frequency of about 2 to 3 Hertz for 10- to 15 seconds. After shaking, the head remains in the center and the eyes of the patient are observed for nystagmus. The head shake test is used to look for signs of dynamic imbalance of vestibular function by evaluating the post-shaking nystagmus. This test is part of the whole diagnostic test battery and will not give enough information on its own.

Different types of nystagmus can be found when applying the head shake test. First a schematic representation of the process of head shaking will be used to explain the physiology: By shaking the head, the velocity storage within the vestibular nuclei is charged. So when the head is turned to the right a VOR is produced moving the eyes in the opposite direction. At the same time the velocity storage is charged with each head turn to the right. For schematic purposes, we will call this “the velocity storage on the right”. When the head is turned to the left, the velocity storage on the left is charged. However, in case of a vestibular hypofunction or imbalance, the velocity storage on the affected side cannot be charged as much as the velocity storage on the other side due to the hypofunction. This will become apparent when suddenly the head is stopped at the end of the shaking. At that moment, both velocity storages discharge. If one velocity storage was better charged than the other one, this will discharge more strongly. At that moment it gives the same result as if the head was turning to the side of the strongest velocity storage. This results in a nystagmus away from the affected side. Therefore, in for example an recent vestibular loss, a post-head shaking nystagmus might be found.
pointing towards the healthy side. In some cases, the nystagmus may reverse direction after the initial phase. This probably reflects an adaptation mechanism. However, it is not always this easy, since nystagmus does not always point to the affected side. In some cases, the brain already compensated to the hypofunction. This means, from a schematic point of view, that the velocity storage on the side of the hypofunction, is equally charged compared to the healthy side when the head is rotated. That is why, after a longer standing vestibular loss, the head shake test does often not show any post shaking nystagmus. However, if in the meantime the vestibular function on the paretic side was restored, the new level of velocity storage on the paretic side velocity storage becomes excessive relative to the compensation. During head shaking, the velocity storage on the paretic side becomes more charged than on the healthy side. At the end of head shaking, the velocity storage of the paretic side will therefore discharge stronger than the healthy side. Since nystagmus points to the strongest side, the post shaking nystagmus will point to the paretic or former paretic side. This is called a “recovery” nystagmus.

In some central cases, mainly of the cerebellum and brainstem, head shaking induced nystagmus can also be found. The nystagmus may beat ipsilaterally, but also a cross-coupled “perverted” nystagmus can be present. This means that horizontal head shaking induces a vertical post head shaking nystagmus. From a schematic point of view: horizontal vestibular input is calculated wrongly by the central system and this results in a vertical nystagmus. So when a vertical nystagmus results after the head shaking test, always take a central vestibular disorder into account.
Keypoints

Each vestibular test has its own sensitivity, specificity and challenges when applying it in clinical practice:

- The Romberg test is not a sensitive test for vestibular hypofunction. The Romberg test on foam rubber can increase sensitivity and specificity.

- An abnormal clinical head impulse test is a sign of vestibular hypofunction, but a normal clinical head impulse test does not rule out vestibular hypofunction, mainly due to adaptation mechanisms. A video head impulse test can help detecting these adaptive mechanisms.

- The Dynamic Visual Acuity test can help establishing the diagnosis of (bilateral) vestibulopathy, but a normal DVA does not definitely rule out bilateral vestibulopathy, and an impaired DVA does not imply vestibulopathy per se.

- The head shake test is used to look for signs of dynamic imbalance of vestibular function by evaluating the post-shaking nystagmus (slow phases directed toward affected ear, or recovery nystagmus, or perverted nystagmus). This test is part of the whole diagnostic test battery and will not give enough information on its own.
References


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