The Journal of Laryngology & Otology

cambridge.org/jlo

Main Article

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Cite this article: Lennox-Bowley A, Dasgupta S. Modernising vestibular assessment. *J Laryngol Otol* 2024;1–5. https://doi.org/10.1017/S0022215123002128

Received: 17 March 2023
Revised: 30 June 2023
Accepted: 18 July 2023

Keywords:
Inner ear; postural balance; vertigo; diagnosis; audiology

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Modernising vestibular assessment

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Abstract

Background. There is a high prevalence of dizziness, vertigo and balance symptoms in the general population. Symptoms can be generated by many inner-ear vestibular disorders and there are several diagnostic tests available that can help identify the site of the vestibular lesion. There is little consensus on what diagnostic tests are appropriate, with diagnostics either not completed or minimally performed, leading to missed diagnosis, unsatisfactory results for patients and costs to healthcare systems.
Methods. This study explored the literature for different neuro-vestibular diagnostic tests not currently considered in the traditional standard vestibular test battery, and examined how they fit effectively into a patient care pathway to help quickly and succinctly identify vestibular function.
Results. A vestibular patient care pathway is presented for acute and subacute presentation of vestibular disorders.
Conclusion. An accurate diagnosis following a rigorous anamnesis and vestibular testing is paramount for successful management and favourable outcomes.

Introduction

The first objective, quantifiable vestibular test was the caloric test, as described by Bárány[1] and refined by Fitzgerald and Hallpike.[2] Bárány is also credited for the rotatory chair test.[3] These quintessential and time-honoured tests are still in use today. Then came electronystagmography, in 1937; this accurately records chorioretinal potential as a function of the vestibulo-ocular reflex at rest or on provocation, allowing quantification of the caloric and the chair tests.[3] This test is an integral part of the current audiology vestibular test battery with the infrared videonystagmography technique.

Post-war vestibular technology advanced well, but focused primarily on refining techniques discovered previously. Landmark innovations defined diagnostic vestibulometry during this time until the turn of the millennium, including the head impulse test in 1988,[4] followed by the vestibulocolic reflex measured with muscle electrodes in 1994.[5] The frequency-specific response of the vestibular sensory epithelia was another landmark, detected in experimental animals[6] towards the end of the previous century, and established recently by electrical stimulation of the inner-ear vestibular system by vestibular implants.[7]

Technological advancements evolved rapidly thereafter, with digital technology used to investigate these frequency responses. These technologies now allow clinicians to assess the integrity of the peripheral and central systems more thoroughly,[8] in individual vestibular organs and in different frequencies used to provoke the vestibulo-ocular reflex.

With exponential growth in related research,[9] deciding on a customised test battery for individual patients can be challenging for clinicians. Within the UK, vestibular assessment pathways can be lengthy and complex, with patients taking, on average, just under five years to receive a diagnosis and subsequent management of their balance problem.[10] Patients see, on average, 4.5 specialists before receiving a diagnosis,[10] resulting in an obvious financial burden to services and resources, and a possible unnecessary delay in treatment.

Utilising advancements in vestibular diagnostics to help provide quick, succinct information rather than lengthy appointments may be vital in improving these outcomes. This article describes the newer tests for quantifying vestibular function that can be performed in addition to the tests already in existence (for example, the calorics, rotatory chair, dynamic visual acuity and headshake tests).

Role of anamnesis in vestibular assessment

The Bárány Society has recently started to infiltrate consensus documents, including the International Classifications for Vestibular Disorders,[11] aiming to standardise diagnosis for different vestibular syndromes.

A thorough history is always essential to understand patients' symptomology and to begin categorising which disorder the patient's symptoms most likely sit within. In this respect, the role of a good history is paramount, as it leads to the formulation of a differential diagnosis, especially from an aetiological point of view. Indeed, vestibular pathologies in more cases than not follow a definite pattern that can only be gleaned subjectively from adult patients, and in a surrogate way from carers in children, by noting vestibular behaviour.[12] This vital part of assessment is then followed by objective vestibular quantification to measure vestibular weakness that would play a crucial role in eventual vestibular rehabilitation.[13] Thus, vestibular quantification on its own is not sufficient to make an informed judgement; rather, it needs to be backed up by symptoms.

Current trends in vestibular assessment

Semi-circular canals and their pathways

The semi-circular canals are canals filled with endolymph that are orientated in three planes within each ear, lateral, posterior and anterior.[14] Each has a corresponding canal on the other side, with the lateral canals paired; the right anterior canal is paired with the left posterior canal and the left anterior canal is paired with the right posterior canal. The semi-circular canals sense angular rotation in different frequencies and head displacement. A peripheral vestibular insult results in unilateral or bilateral hypofunction that can be objectively quantified.

Video head impulse test

The video head impulse test is a vestibulo-ocular reflex measurement; it measures all six semi-circular canals utilising Ewald's first and second laws.[15] The patients are to maintain their vision on a fixed target whilst their head is displaced quickly in the plane of the test canal. The head movement generates reflex eye movement to the direction opposite to the head movement that is equal to the head movement; this is defined as the vestibulo-ocular reflex. If vestibulopathy is present, the eyes' ability to maintain gaze fixed on the target diminishes, and the brain makes a corrective or compensatory catch-up saccade to the direction opposite to the head movement in order to bring back the target in focus.

Two parameters are important for making inferences: firstly, the vestibulo-ocular reflex gain – i.e. the ratio of the velocity of the eye and the head movements; and, secondly, whether a saccade is produced if there is a lag between the two. Normalcy is indicated by a vestibulo-ocular reflex gain between 0.7–0.8 (vertical canals – i.e. the anterior and the posterior canals) and 0.8–1 (lateral canals), with no catch-up covert or overt saccades on head movement at velocities up to 300 degrees per second. An abnormal result is indicated when the gain drops down to below 0.7, with catch-up overt or covert saccades. This indicates peripheral vestibular abnormalities and is the only objective test that can assess all semi-circular canals.

This test complement is a quick and effective way of ascertaining the integrity of the semi-circular canals in the high-frequency domain.[16,17] Additionally, the evidence suggests some instances of central vestibular pathology may also exhibit abnormalities with this test.[18,19]

There is varying sensitivity and specificity reported in the literature for the video head impulse test, depending on the site of lesion, clinical setting and parameters used for positive findings. When measuring vestibular weakness, there is varying sensitivity and specificity reported, ranging from as low as 40 per cent to as high as 100 per cent for both parameters.[20] The variation in reported accuracy may be accounted for by the fact that although high-frequency vestibular weakness is a common frequency deficit encountered in semi-circular canal pathology, it does not yield information about the whole system, but rather just a part of it. Therefore, if these findings are normal, in the absence of other test results, this normalcy should not lead to an inference that the vestibular system is normal. Other frequency responses – for example, the low and the middle frequency responses – might still be abnormal.[21] Additionally, there are instances where patients with peripheral vestibular disorders in the compensated phase show normal vestibulo-ocular reflex gain but with catch-up saccades.[22–24]

Suppression head impulse test

The suppression head impulse test utilises the principle that one can voluntarily suppress the vestibulo-ocular reflex on head movement by deliberately moving the eyes towards the direction of the head movement (i.e. opposite to the vestibulo-ocular reflex), thereby suppressing or cancelling the vestibulo-ocular reflex.[24] In this paradigm, the target moves with the passive movement of the patient's head, which entails head thrusts when the eyes are following a moving target. Here, normalcy is inferred by quick saccades in the direction opposite to the ones that appear on the video head impulse test at about 200 milliseconds, which are called anti-compensatory saccades, indicating peripheral and central vestibular function. If the vestibulo-ocular reflex is deranged, anti-compensatory saccades will have a low peak velocity, as observed in patients with a peripheral insult who also show a low vestibulo-ocular reflex gain. Over a period of time, however, the vestibulo-ocular reflex gain recovers but the velocity remains low, indicating compensation.[24,25]

Emerging evidence shows high sensitivity and specificity for measuring vestibular weakness, of more than 87 per cent and more than 83 per cent respectively, especially when paired with the video head impulse test.[26]

Visually enhanced vestibulo-ocular reflex and suppression tests

The visually enhanced vestibulo-ocular reflex stabilises an image on the retina; the patient maintains fixation on a target, similar to video head impulse test, but the head displacement is much slower than that of the video head impulse test. Visually enhanced vestibulo-ocular reflex suppression is utilised to overcome inappropriate vestibulo-ocular reflex correction. When a visual target is moving in addition to the head, the smooth pursuit reflex should override the vestibulo-ocular reflex in a healthy individual. Visually enhanced vestibulo-ocular reflex and visually enhanced vestibulo-ocular reflex suppression resemble the video head impulse test and the suppression head impulse test, but, unlike them, measure low frequency vestibulo-ocular reflexes rather than high-frequency ones.[25]

Although it is yet to emerge, the sensitivity and specificity of these tests both could be in line with other tests for unilateral and bilateral peripheral weakness,[27–29] as well as being a marker in central conditions such as cerebellar ataxia with neuropathy and vestibular areflexia syndrome ('CANVAS').[30]

Measuring otoliths and their pathways

The otolith organs, namely the saccule and utricle, encode spatial awareness, gravitational awareness, linear acceleration and deceleration.[31,32] Prior to recent years, the measurement of these organs was not included as standard in the vestibular

https://doi.org/10.1017/S0022215123002128 Published online by Cambridge University Press

function test battery. However, emerging knowledge, technologies and equipment such as vestibular-evoked myogenic potentials testing are being used to address this gap in diagnostic vestibulometry.

Vestibular-evoked myogenic potentials test

The vestibular-evoked myogenic potentials test consists of two electrophysiology measurements: cervical and ocular vestibular-evoked myogenic potentials. Studies show both modalities can have excellent sensitivity and specificity, 90–100 per cent and 80–100 per cent respectively.[33] Cervical vestibular-evoked myogenic potentials are primarily generated from the saccule with collection from the ipsilateral sternocleidomastoid muscle (P = approximately 13 ms to 'positive peak' with an average latency of 13 ms; P13). Ocular vestibular-evoked myogenic potentials are primarily generated from the utricle with collection from the contralateral ocular muscles (N = approximately 10 ms to 'negative peak' with an average latency of 10 ms; N1).[33]

A sound stimulus is presented at a loud level (95 dB nHL = 128 dB sound pressure level). The energy from the sound does not directly stimulate the vestibular system, but does so via secondary vibrotactile energy provoking the hair cells in the otoliths.[34,35] Asymmetry in the amplitudes between ears is the critical diagnostic criteria for peripheral vestibulopathy, with 13.4–37.7 per cent being the normative cut-off value.[36] The optimal frequency was originally thought to be 500 Hz; however, studies into Ménière's patients have found multi-frequencies to have more diagnostic accuracy.[35] Additionally, the absence of a vestibular-evoked myogenic potentials response should be measured at a lower stimulus level of 75 dB nHL, to rule out third window pathology such as semi-circular canal dehiscence.[37,38] Latency has less diagnostic relevance; however, changes in latency have been described as significant in neurological cases and multiple sclerosis cases.[39]

Subjective visual vertical tilt

The otolith organs contribute to a sense of what is vertical,[40] with this test measuring whether a patient can subjectively identify what 0-degree vertical is. With the patient's peripheral vision taken away, by either placing them in a darkened room or putting their head in a bucket, they are to line up what is vertical with an illuminated rod or to straighten a line drawn at the end of the bucket.[41] It is well established that patients with normal vestibular function can subjectively identify a vertical axis extremely accurately within −1 to +2 degrees.[42] Patients with vestibular dysfunction may be unable to do this accurately, and may identify vertical with as much as an 8 degree tilt.[43] The site of lesion sensitivity is moderate, so this test should not be used in isolation. Those with brainstem lesions may also have a positive subjective visual vertical tilt,[42,44] whereas those with cerebellum lesions appear to perform well.

The subjective visual vertical tilt test has been around for a long time; it is well researched, easy to perform and cheap to administer.[41] Recently, it has become even easier to carry out this test with technology, using a mobile telephone application or via its integration into the newer video-oculography machines. The ability to use technology to measure subjective visual vertical tilt has increased the efficacy of this test, with 89 per cent sensitivity and 94 per cent specificity.[45]

Special considerations for acute vestibular syndrome

Patients with 'continuous' vertigo, nystagmus, associated nausea, vomiting and head motion intolerance may have a benign ear problem due to an acute vestibular syndrome or be experiencing a life-threatening transient ischaemic attack.[46–48]

The Head Impulse-Nystagmus-Test of Skew ('HINTS') examination consists of a vestibular-ocular assessment that includes a head impulse test, quantifying the direction of nystagmus present, and a test of skew. The 'HINTS+' is a revised version of the Head Impulse-Nystagmus-Test of Skew that includes a hearing screen. [49–51] The application quickly differentiates between the triad of eye signs being central (normal head impulse with bi-directional nystagmus and a positive skew deviation) or peripheral (abnormal head impulse findings with nystagmus based on Alexander's Law, and a normal test of skew). With sensitivity surpassing magnetic resonance imaging in the first 24 hours, it is an excellent tool to triage and manage patients quickly, which benefits patients and avoids unnecessary admissions to stroke units as patients can be directed onto the correct management plan quicker.[49,50]

Discussion

Modernising vestibular assessment relies on multiple components, including: the modernisation of the patient pathway, patient journey time, correct anamnesis and vestibular laboratory tests. The latter could include the tests mentioned in this article, along with the established videonystagmography assessment, rotatory chair test, dynamic visual acuity and the caloric test. It is acknowledged that changing components of a vestibular service is not always a simple task, with clinician training, equipment costs and service provision all needing to be considered.

In terms of patients, the presentation dictates the customisation of tests so they are unique to the individual. In that respect, some of the measurements suggested could be considered screening tests given the speed in which they can be performed; in addition, these techniques are less invasive, yet have reasonable diagnostic accuracy. Recognition of the different needs and dilemmas for patients accessing both acute/emergency and chronic settings should be considered, alongside deliberation regarding how acute and chronic services interlink. Patients who present with vestibular phenotypes and yet test normal for these screening tests should be referred for a more comprehensive diagnostic investigation. This approach may help services become more efficient and improve patient outcomes, with fewer and shorter clinical visits and less invasive tests. Figure 1 is an example patient pathway matrix that illustrates how both the emergency and chronic settings may be linked.

- Peripheral and central vestibular quantification with objective vestibulometry is feasible and should be performed according to patients' requirements and in line with condition-specific guidelines
- Information can be gained on frequency-specific vestibular responses and central vestibular integration pathways, to support clinical examination findings
- An accurate diagnosis following a rigorous anamnesis and vestibular testing is paramount for successful management and favourable outcomes

Recent research highlights a cohort of patients with vestibular weakness who present with non-rotational dizziness, symptoms not typical of traditional peripheral disorders.[51] At the time of writing, the International Classification of Vestibular Disorders classification of isolated otolith dysfunction has yet to be finalised; however, Suh *et al.* (2021) has revised the

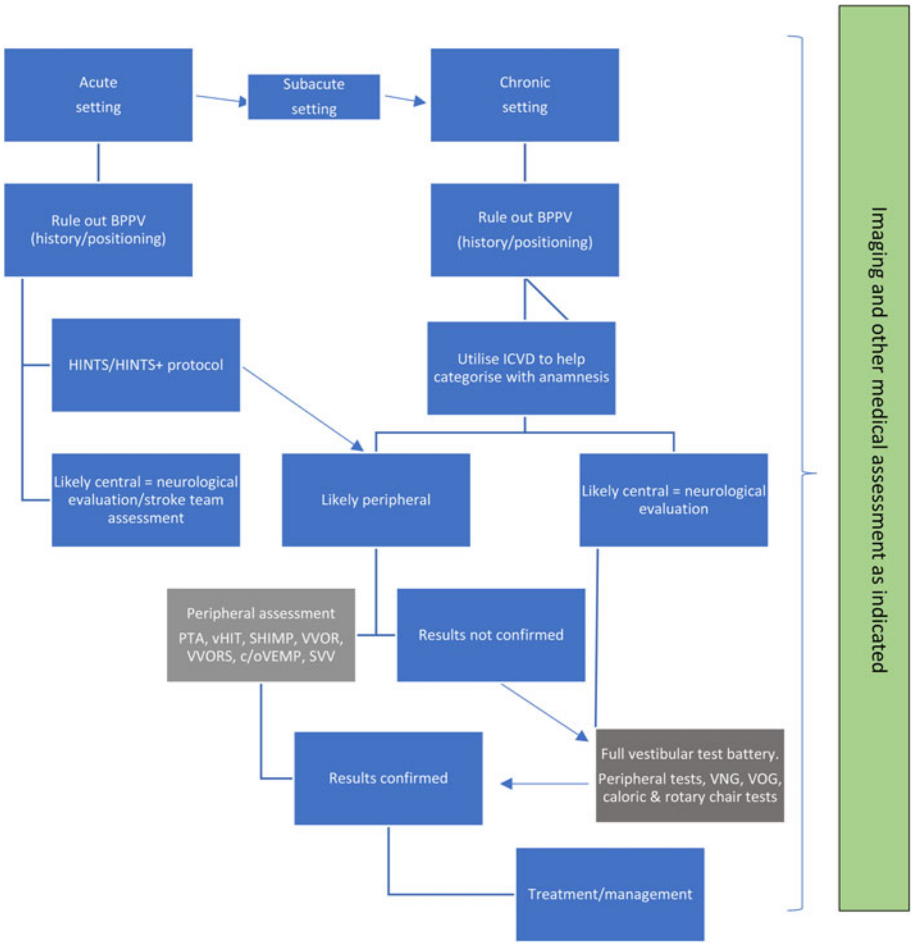

Figure 1. Suggested pathway of a vestibular patient, with considerations for both acute and subacute patients. The tertiary vestibular assessment sessions are denoted in grey. If the patient history indicates a peripheral disorder, the suggested assessment can be completed within 1 hour, reducing the need for all patients needing long (over 2.5-hour) appointments. The peripheral assessment utilises tests that measure and confirm both semi-circular canal and otolithic weakness, but can also screen some central pathways. If a patient's results are not confirmed after this hour, further vestibular testing is still recommended. BPPV = benign paroxysmal positional vertigo; HINTS = Head Impulse-Nystagmus-Test of Skew; HINTS+ = revised version of Head Impulse-Nystagmus-Test of Skew (includes hearing screen); ICVD = International Classification of Vestibular Disorders; PTA = pure tone audiometry; vHIT = video head impulse test; SHIMP = suppression head impulse; VVOR = visually enhanced vestibulo-ocular reflex; VVORS = visually enhanced vestibulo-ocular reflex suppression; c/oVEMP = cervical/ocular vestibular-evoked myogenic potentials test; SVV = subjective visual vertical tilt; VNG = videonystagmography; VOG = video-oculography

latest proposed criteria.[52] Isolated otolith dysfunction without semi-circular canal involvement is a distinct clinical entity that can be diagnosed with some accuracy.[53] If traditional vestibular function tests are performed without any measurement of the otoliths, there is the possibility of a missed diagnosis.

An additional concern is that symptomology can overlap with patients with persistent postural perceptual dizziness, which may lead to a lengthy and inappropriate management plan involving multiple clinicians and services.[54] Further emphasis on the importance of understanding damage to the otoliths and their pathways is needed. There are currently trials emerging into treatments, both surgical and non-surgical, which show promising outcomes.[9] The management of otolith dysfunction rehabilitation for the best outcome is likely different from that of the more common semi-circular dysfunction.[55] Traditional vestibular exercises aim to stimulate vestibulo-ocular reflex compensation via the semi-circular canals using gaze stability exercises; however, there is emerging evidence into the rehabilitation of the otolith organs using centrifugation or linear acceleration, suggesting rehabilitation tasks should be different for those with isolated otolith dysfunction.[56]

Conclusion

Peripheral and central vestibular quantification with objective vestibulometry is feasible and should be performed according to patients' requirements. This testing yields information on frequency-specific vestibular responses and central vestibular integration pathways. A diagnosis following a rigorous anamnesis and more targeted vestibular testing is paramount for successful management, and for favourable outcomes for the patient, including quicker diagnosis, less timely and intrusive diagnostic tests, and more targeted rehabilitation.

Acknowledgement. The authors would like to thank Hypatia Training for their support.

Competing interests. None declared

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https://doi.org/10.1017/S0022215123002128 Published online by Cambridge University Press