HHS Public Access

Author manuscript

Semin Neurol. Author manuscript; available in PMC 2022 May 20.

Published in final edited form as:

Semin Neurol. 2015 October ; 35(5): 506–521. doi:10.1055/s-0035-1564298.

Diagnosing Stroke in Acute Vertigo: The HINTS Family of Eye Movement Tests and the Future of the "Eye ECG"

David E. Newman-Toker, MD PhD [Associate Professor],
Neurology and Otolaryngology, The Johns Hopkins University School of Medicine

Ian S. Curthoys, PhD [Emeritus Professor],
School of Psychology, University of Sydney. NSW. Australia

G. Michael Halmagyi, MD, AO [Professor]
Department of Neurology, Royal Prince Alfred Hospital, Camperdown. NSW Australia

Abstract

Patients who present to the emergency department with symptoms of acute vertigo or dizziness are frequently misdiagnosed. Missed opportunities to promptly treat dangerous strokes can result in poor clinical outcomes. Inappropriate testing and incorrect treatments for those with benign peripheral vestibular disorders leads to patient harms and unnecessary costs. Over the past decade, novel bedside approaches to diagnose patients with the acute vestibular syndrome have been developed and refined. A battery of three bedside tests of ocular motor physiology known as 'HINTS' (Head Impulse, Nystagmus, Test of Skew) has been shown to identify acute strokes more accurately than even magnetic resonance imaging with diffusion-weighted imaging (MRI-DWI) when applied in the early acute period by eye movement specialists. Recent advances in lightweight, high-speed video-oculography (VOG) technology have made possible a future in which HINTS might be applied by non-specialists in frontline care settings using portable VOG. Use of technology to measure eye movements (VOG-HINTS) to diagnose stroke in the acute vestibular syndrome is analogous to use of electrocardiography (ECG) to diagnose heart attack in acute chest pain. This 'eye ECG' approach could transform care for patients with acute vertigo and dizziness around the world. In the United States alone, successful implementation would likely result in improved quality of ED care for hundreds of thousands of peripheral vestibular patients and tens of thousands of stroke patients, as well as an estimated national healthcare savings of roughly one billion per year. In this article we review the origins of the HINTS approach, empiric evidence and pathophysiologic principles supporting its use, and possible uses for the 'eye ECG' in teleconsultation, teaching, and triage.

Keywords

vertigo; dizziness; diagnosis; neurologic examination; reflex vestibulo-ocular; eye movement measurements; vestibulocochlear nerve diseases; stroke

Address for First and Corresponding Author (David E. Newman-Toker): Johns Hopkins Hospital, CRB-II, Room 2M-03 North, 1550 Orleans Street, Baltimore, MD 21231, toker@jhu.edu.

Introduction

There are over 4 million US emergency department (ED) visits per year for acute vertigo or dizziness at an estimated cost of ~$9 billion/yr.[1,2] The roughly 1 million with peripheral vestibular causes are over-tested,[3] misdiagnosed,[4] and undertreated.[5] Hundreds of millions of dollars are spent on brain imaging and hospital admissions trying to rule out dangerous central vestibular causes such as stroke,[1] yet approximately one third of vestibular strokes are missed initially.[6]

ED physicians around the world rank vertigo a top priority for developing better diagnostic tools.[7] Misconceptions[8–10] and lack of reliable tests for peripheral lesions drive ED practice, resulting in inappropriate testing.[3] Patients with inner ear conditions such as benign paroxysmal positional vertigo (BPPV) and vestibular neuritis are often imaged and admitted unnecessarily,[3] instead of being treated and discharged. Some patients with dangerous brainstem or cerebellar strokes are sent home without critical stroke treatments,[11] potentially resulting in serious harms.[12]

Research studies, systematic reviews, and guidelines confirm that correct diagnosis of BPPV,[13–17] vestibular neuritis,[18–20], and vestibular stroke,[21–25] should be based on vestibular eye exams. Unfortunately, eye findings (e.g., vestibulo-ocular reflex [VOR] failure, nystagmus type) require visual interpretation and can be subtle. Many clinicians are unfamiliar with their use.[4,5,26,27]

In this manuscript, we will review the role of eye movement diagnosis in differentiating acute stroke from benign inner ear conditions, focusing primarily on the ‘HINTS family’ of bedside ocular motor tests, including the horizontal head impulse test (h-HIT) of VOR function, that should be applied in patients presenting the acute vestibular syndrome.[21] We will discuss the origins of these tests (Figure 1), evidence supporting their use, physiologic underpinnings, and the future of quantitative eye movement-based diagnosis by video-oculography (VOG).[28]

History of the Head Impulse Test (HIT)

It has been known for over a century that the 8th cranial nerve conveys balance information to the brain, but until the late 1980s, there was no clinical method available to effectively test for unilateral vestibular hypofunction at the bedside. For a half century, comatose patients were examined using oculocephalic maneuvers (classically referred to as “doll’s eyes” and the “doll’s head phenomenon” by Bielschowsky in 1939[29]) or ice-water caloric testing to coarsely assess the vestibular system at the bedside, without the need for special equipment. However, this was used principally to determine whether the brainstem (especially the pons) was grossly intact or irrevocably damaged.[29] Partial or unilateral vestibular hypofunction could only be measured in a clinical or basic laboratory setting, using quantitative electro-oculography (EOG) as part of the bithermal caloric electronystagmogram (ENG).[30] The doll’s eye maneuver in awake patients generally produced no useful results that correlated with quantitative caloric weakness. In retrospect, the problem was that the test was not taxing enough for the vestibular system.

In 1988, the horizontal head impulse test (h-HIT) of VOR function was described by Halmagyi and Curthoys as a bedside test for peripheral vestibular disease.[31] The short, fast connections between the inner ear and the eye muscles mediate the eye movement response to a rapid head rotation (the VOR) and that response is used to assess the integrity of the inner ear structures and their brainstem connections in awake patients. The high-acceleration h-HIT maneuver (a faster version of the classic “doll’s head” maneuver) proved capable of identifying vestibular failure in a way that classic oculocephalic maneuvers could not. Moreover, the test was able to interrogate the function of each ear, due to a quirk of normal vestibular physiology in which excitatory labyrinthine responses carry more weight than inhibitory ones. Since the test’s original description, an abnormal h-HIT has repeatedly been shown to correlate with ipsilateral vestibular hypofunction, and, more specifically, to correlate with de-afferentation of the inputs from the ipsilateral horizontal semicircular canal.[32]

Over the quarter century since its original description, numerous aspects of HIT testing have been elucidated by Curthoys, Halmagyi, and colleagues (Figure 1). Of special importance, in 1998, similar maneuvers were described for vertical semicircular canal functions.[33] These occur in test planes aligned with either the right anterior and left posterior semicircular canals (RALP) or the left anterior and right posterior semicircular canals (LARP). These maneuvers have been used to refine our understanding of peripheral vestibular deficits, enabling us to test the function of all six semicircular canals and so discriminate between subtypes of vestibular neuritis. Patients with vestibular neuritis may have a complete lesion or a partial lesion; if partial, the lesion most often affects the superior branch of the vestibular nerve, rather than the inferior branch, leading to selective loss of input from one or more semicircular canals (Table 1).[18,35,40] These approaches, along with advances in otolithic testing have made it possible for us to specifically assess the integrity of each sub-structure within the labyrinth.[32,41] Other important advances are described in the ‘Localization’ section below.

Origins of the ‘HINTS to INFARCT’ Clinical Decision Rule

Since the 1970s, strokes and other central lesions had been known to sometimes closely mimic peripheral vestibular disorders, especially vestibular neuritis.[42–52] When strokes were identified as the cause of acute vertigo presentations, they were usually located in the inferior cerebellum or brainstem, most often in the territory of the posterior inferior cerebellar artery (PICA) or anterior inferior cerebellar artery (AICA). These patients typically presented clinically with a combination of acute, continuous vertigo, nausea, vomiting, and gait ataxia known as the acute vestibular syndrome.[53] Differences in nystagmus patterns such as failure of suppression with visual fixation or a gaze-evoked component were believed to reliably discriminate central from peripheral lesions,[53] but prospective studies were generally lacking. Some of these classic teachings (e.g., suppression by visual fixation = peripheral) have since been questioned.[54,55]

It was known that the h-HIT was abnormal in most cases of vestibular neuritis.[18,32,56,57] This finding led to a critical insight—if a patient presents with acute, continuous vertigo but has normal head impulse responses, then the clinician should suspect a central

cause. In the period from 2004 to 2008, clinical studies first appeared demonstrating the h-HIT was, indeed, often normal in patients with central lesions causing symptoms that mimicked vestibular neuritis (so-called “pseudo-neuritis” cases).[54,58–60] These lesions were mostly ischemic strokes in the PICA vascular territory, with or without lateral medullary involvement. Studies that included both peripheral and central patients found that h-HIT was a discriminating clinical feature that differentiated neuritis from central mimics in most cases.[54,60] However, some strokes, particularly those involving the AICA vascular territory, were sometimes associated with abnormal h-HIT results, mimicking acute peripheral vestibulopathy even more closely.[54]

In 2009, the ‘HINTS’ clinical decision rule was first described as a means for neuro-otologists to differentiate strokes and other central lesions from vestibular neuritis in patients presenting the acute vestibular syndrome.[21] HINTS (Head Impulse, Nystagmus, Test of Skew) is an acronym describing three specific vestibular eye movement tests (bilateral h-HIT for VOR integrity; inspection of spontaneous and gaze-evoked nystagmus for direction change; alternate cover test for vertical ocular misalignment) (Video 1). The ocular motor findings suggesting stroke were given a second acronym INFARCT (Impulse Normal, Fast-phase Alternating, Refixation on Cover Test). In the original study, which included 101 patients with the acute vestibular syndrome and at least one stroke risk factor (73/101 with stroke), the presence of any one of these three eye findings (i.e., bilaterally normal h-HIT, direction-changing gaze-evoked nystagmus, or skew deviation) were found to be 100% sensitive and 96% specific for stroke.[21] In that study, HINTS was noted to be more sensitive for stroke than initial magnetic resonance imaging with diffusion-weighted imaging (MRI-DWI), with reference to delayed MRI-DWI.[21] Subsequent studies from the same group have further refined diagnostic accuracy estimates for the HINTS test battery, demonstrating superiority over vascular risk factor stratification ($ABCD^2$ score[61]) and continued superiority over MRI-DWI,[23] particularly in patients with smaller strokes.[62] Similar findings have been confirmed by other groups[34,63,64] and two systematic reviews.[22,24]

HINTS ‘Plus’ and the Relevance of Acute Hearing Loss in Vestibular Presentations

In 2013, Newman-Toker and colleagues suggested that ‘HINTS plus Hearing’ (or ‘HINTS+’ for short) could improve diagnostic sensitivity for stroke cases associated with inner ear infarction, by classifying acute vestibular syndrome with new unilateral hearing loss identified at the bedside as a suspected stroke syndrome.[23] Hearing loss may occur in stroke via multiple mechanisms,[65] including direct involvement of the cochlea, but also infarction of the cochlear nucleus or auditory nerve root entry zone in the lateral pons; the AICA generally supplies blood to these pontine structures.[66] The blood supply to the inner ear (internal auditory artery) derives from the vertebrobasilar circulation, most often via the AICA (~80%) or the basilar artery trunk (~15–20%), and only rarely via the PICA (~2–3%).[65] These anatomic facts explain the high frequency of combined audio-vestibular presentations with AICA strokes,[37,67–76] the occasional occurrence of hearing loss as a harbinger to basilar occlusion,[77–82] and the relative rarity of reports describing hearing loss in patients with PICA strokes.[38,83,84] It also explains why patients with AICA-territory

infarctions can mimic the eye movement physiology of vestibular neuritis exactly—because the lesions may be located in the inner ear (i.e., labyrinthine infarction[72,85]).

Hearing loss is also seen in so-called "viral labyrinthitis" and "idiopathic sudden sensorineural hearing loss" (ISSHL) cases that are presumed to result from inflammatory viral or post-viral causes.[86] While technically vestibular neuritis refers to peripheral cases of acute vertigo without hearing loss,[39,87] ISSHL refers to peripheral cases of acute hearing loss without vertigo, and labyrinthitis refers to the combination of audio-vestibular symptoms, terminology is often used inconsistently (e.g., ISSHL with vertigo;[88–90] vestibular neuritis with hearing loss[18,35,91]). Most vertebrobasilar infarctions affecting hearing produce sudden hearing loss that is moderate, severe, or profound (83%, n=25/30),[37] but the same can be true in well-documented viral cases.[92] There appears to be no characteristic pattern of hearing loss that can consistently distinguish vascular from infectious or inflammatory causes, so relying on associated clinical features is essential.[93] The relative frequency of labyrinthitis versus labyrinthine infarction in patients presenting acute audio-vestibular symptoms is unknown, principally because most studies of vestibular neuritis and ISSHL have excluded such patients from study.[22] Pending further research, patients with acute, combined audio-vestibular loss should probably be considered potential stroke suspects in all but cases with clear viral or bacterial infections.[94]

Accuracy of the 'HINTS Family' of Tests Relative to Neuroimaging

The accuracy of the 'HINTS Family' of tests (h-HIT alone, HINTS, and HINTS+) in early, acute diagnosis may be compared to other approaches for differentiating strokes from vestibular neuritis and labyrinthitis, such as vascular risk stratification or neuroimaging (by CT or MRI) (Figure 2). As is evident from Figure 2, neither vascular risk stratification nor CT brain can be relied upon for adequate discrimination between central and peripheral causes. MRI-DWI is a reasonably good test for diagnosing stroke in the acute vestibular syndrome, with sensitivity of approximately 80% in the first 24 hours.[22] The h-HIT alone, however, has greater sensitivity than MRI-DWI in the first 48 hours after symptom onset.[23] As shown in Figure 2, the addition of other HINTS parameters (direction-changing, gaze-evoked nystagmus and skew deviation) increases sensitivity with a small sacrifice of specificity. The further addition of new, unilateral hearing loss as a stroke parameter in HINTS+ increases the sensitivity to approximately 99%, with an estimated specificity of 97% for central causes.[23] It is possible that the specificity of the approach will be lower when a wider spectrum of peripheral vestibular cases is considered.[95]

A comparison of sensitivity, specificity, time, risks, and costs is provided in Table 2. The practical implications for routine clinical practice are shown in Table 3, which compares the post-test residual probability of stroke after a negative test for the most commonly applied tests. As can be seen, a non-focal neurologic examination is a weak predictor of peripheral disease, and a negative CT similar. A negative MRI-DWI is a fairly strong predictor, but still leaves substantial uncertainty about stroke in the average or higher-risk patients presenting the acute vestibular syndrome. By contrast, a peripheral HINTS+ pattern is a strong enough predictor to give providers confidence that a central cause has been ruled out[110] in all but

the highest risk cases (e.g., acute vestibular syndrome in the week following vertebral artery stent placement).

These results show that bedside exams outperform neuroimaging for detecting acute stroke. This may initially surprise those who have trained in a neurological era replete with imaging, where the rule is usually “technology trumps tradition” or “scan first and ask questions later.” However, it is unsurprising that physiology ‘beats’ anatomy for early ischemic stroke detection. As soon as a patient becomes symptomatic with acute vertigo, their ocular motor physiology likely changes instantaneously. By contrast, anatomic changes in the posterior fossa from brainstem stroke, even by MRI-DWI, do not peak until ~75–100 hours after symptom onset.[111] Thus, even if structural neuroimaging improves in the future, physiology will likely still ‘win’.

Localization Principles and Pathophysiologic Basis of ‘HINTS’

It should be noted that the HINTS clinical decision rule has not yet been subjected to the full palette of studies generally expected for rigorously-developed decision rules.[112,113] However, HINTS is not a typical rule in that it is not purely empirical (as with the Ottawa ankle rules[114] or Ottawa subarachnoid hemorrhage rule[115]). The HINTS rule, by contrast, is based largely on anatomic and physiologic principles of neurologic lesion localization. There is a substantial body of basic vestibular science supporting its use for differentiating central from peripheral disorders. A thorough exegesis of these pathophysiologic and pathoanatomic principles is beyond the scope of this manuscript, but a few important underlying principles are described briefly below.

Physiology & Anatomic Localization of the h-HIT—The normal angular VOR response to a rapid, passive head rotation as a subject fixates on a central target is an equal and opposite eye movement that keeps the eyes stationary in space. This is referred to by neuro-otologists as a *VOR gain* equal to 1.0 (i.e., ratio of head rotation to eye rotation 1:1) (i.e., a normal or “negative” h-HIT). Loss of vestibular function results in the inability to maintain fixation during the rapid head rotation, because the eye movement response is less than the head movement (i.e., VOR gain < 1.0). During the h-HIT towards the affected side the eyes fall off the target due to inertia within the orbit (i.e., they are ‘dragged’ with the head). Once the head stops, a corrective gaze shift (refixation saccade) is needed to re-acquire visual fixation on the central target (i.e., an abnormal or “positive” h-HIT) (Video 2). A large-amplitude, visually obvious refixation saccade generally correlates with a substantially reduced ipsilateral VOR gain (<0.6–0.7), indicating at least moderate vestibular hypofunction on the affected side. The side tested is the one toward which the examiner is rotating the head (e.g., rotating the head horizontally towards the patient’s left tests the patient’s left horizontal VOR).

It is important to note that the HIT VOR response may be assessed either “clinically” (i.e., non-quantitatively) or “quantitatively” (i.e., using recording techniques such as scleral search coils within a magnetic field[116] or modern, high-speed VOG[117]). When tested clinically, the VOR gain is assessed indirectly, using the corrective refixation saccade described above (an “overt” saccade) as inferential evidence that the VOR gain is reduced.

However, some patients can generate this refixation saccade during (rather than after) the head turn (a “covert” saccade), so it is undetectable by the clinician (Video 2). Thus, the most accurate assessment demands quantitative measures. When tested quantitatively, the VOR gain is assessed directly by measuring the eye movement response relative to the head movement stimulus (Figure 3).

The simple localizing principle for the HIT is that if a lesion affects the primary VOR pathway, the HIT will be abnormal; if a lesion does not affect this pathway, the HIT will be clinically normal. Thus, it is expected that labyrinthine lesions affecting the horizontal canal (labyrinthitis, labyrinthine infarction, chemical or surgical labyrinthectomy, or selective canal plugging[118,119]) and vestibular nerve lesions affecting the horizontal canal afferents (total or superior branch vestibular neuritis, surgical vestibular neurectomy) will produce an abnormal h-HIT. It is also expected that AICA-territory brainstem lesions which happen to involve the 8th nerve root entry zone[62] or vestibular nucleus[120] will produce a clinically-abnormal h-HIT, mimicking a peripheral lesion. By contrast, lesions affecting the PICA territory (lateral medulla, cerebellum, or both) generally lie anatomically inferior to this pathway, and usually do not produce clinically-evident defects on h-HIT testing.[22,62] Finally, inferior vestibular neuritis cases will have a normal h-HIT (mimicking stroke by ‘HINTS’), because these lesions spare the horizontal canal afferents.[18,35,40]

The clinical value of h-HIT in distinguishing peripheral from central lesions, therefore, depends largely on the relative population prevalence of these specific disorders: (1) total/superior vs. inferior vestibular neuritis and (2) peripheral-pattern AICA-territory strokes vs. other strokes causing acute, continuous vertigo. Inferior vestibular neuritis is rare (1.3%, n=9/703),[35] so most neuritis cases have superior branch or total loss. Thus, it is not surprising that the specificity of a bilaterally normal h-HIT for central lesions in the acute vestibular syndrome is ~100%.[23] Only about 15–20% of strokes causing the acute vestibular syndrome are in the AICA territory,[54,121] and only about 50% of AICA strokes (n=15/29[22,25,122]) produce an abnormal h-HIT, so the h-HIT is misleading in only ~10% of all stroke patients, giving the h-HIT ~90% stroke sensitivity.[23]

Physiology & Anatomic Localization of Direction-Changing, Gaze-Evoked Nystagmus—Nystagmus from a unilateral vestibular lesion results from pathologic asymmetry of vestibular inputs to the brain that mimics the normal asymmetry seen during normal head rotations. With a right partial vestibular neuritis affecting only the horizontal canal afferents, for example, the loss of firing on the right mimics the normal leftward head rotation (left > right firing rate). The firing asymmetry creates the perception of sustained leftward head rotation, and the eyes drift slowly rightward in tonic fashion (i.e., the slow phase of the pathologic jerk nystagmus). Faced with this drift, an eye position reset mechanism maintains the eye close to the mid-position in the orbit by moving the eyes quickly back to the left (i.e., the fast phase of the pathologic jerk nystagmus).

This mechanism produces a unidirectional nystagmus that obeys *Alexander’s law* (nystagmus intensity increases with gaze in the direction of the fast phase and decreases with gaze in the direction of the slow phase) (Video 3).[123] This “peripheral type” of spontaneous

nystagmus is prototypical of vestibular neuritis, but is also seen in the majority of central vestibular lesions.[54]

Sometimes, however, central nystagmus presents the combined effects of a vestibular lesion and a gaze-holding pathway lesion (especially one affecting the flocculus, paraflocculus, or the medial vestibular nucleus-perihypoglossal nucleus complex in the postero-lateral medulla). This mixed nystagmus looks like a peripheral-type nystagmus, except that the fast phase reverses direction with gaze towards the slow phase of the primary-position nystagmus (Video 4).[53]

Gaze-dependent changes in nystagmus vector or direction are not compatible with purely peripheral vestibular lesions, since the gaze-holding mechanisms are centrally located. This includes bidirectional, gaze-evoked nystagmus described above, as well as rebound nystagmus on returning to the mid-position following sustained eccentric gaze.[124] Some recent evidence also suggests that a change in nystagmus vector or direction after vigorous horizontal head shaking may also be a central sign in patients with the acute vestibular syndrome,[34] although it is conceivable that horizontal canal BPPV could produce some similar findings.[125]

Ultimately, adding the rule that patients with gaze-dependent changes in nystagmus direction have central lesions increases the sensitivity for stroke detection over the head impulse test alone. This is because some of the central cases with abnormal head impulse results will have a direction-changing, gaze-evoked nystagmus (e.g., vestibular nucleus lesions[126]). While this sign alone is insensitive (~38%), it is fairly specific (~92%) for central pathology in the acute setting.[22]

It is unknown how often symptomatic treatment with anti-vertigo medications or normal central adaptation to a peripheral vestibulopathy in the days after illness onset produces a ‘central’ pattern despite a ‘peripheral’ lesion. These issues might account for some apparent neuritis cases with bilateral, gaze-evoked nystagmus[60] and could reduce the specificity of the HINTS rule, especially in treated cases or with delayed evaluations in the post-acute illness phase.

Physiology & Anatomic Localization of Skew Deviation—Otolithic reflexes control vertical eye position and static ocular torsion. Gravity-sensitive organs in the inner ear (principally the utricle) sense static tilts in the roll (coronal) plane. Graviceptive signals are relayed to the vestibular nucleus complex in the postero-lateral pons and medulla, and, from there, to the midbrain via the contralateral medial longitudinal fasciculus to control vertical eye position and ocular torsion as part of the utriculo-ocular reflex.[127] The resulting synkinesis depresses and extorts the right eye, and elevates and intorts the left eye, leading to ocular-counterroll (eyes both rotating opposite the head tilt) and vertical skew deviation (tilt-ipsilateral eye higher than the contralateral eye). This phylogenetically primitive ocular tilt reaction (OTR) is partially suppressed under normal circumstances in frontal eyed animals, including humans.[128] However, especially following lesions of the brainstem or cerebellar pathways controlling the utriculo-ocular reflex, an obvious pathologic OTR can develop.[128,129]

In the pathologic OTR, the loss of input from the utricle on one side results in bilateral ocular torsion, vertical skew deviation, and a compensatory head tilt. Thus, loss of the right utricular inputs mimics a leftward head tilt, resulting in rightward ocular counterroll (intorsion of the left eye and extorsion of the right eye), skew deviation with a left hyperdeviation, and compensatory rightward head tilt that decreases firing from the intact (left) utricle. It is noteworthy that a complete or partial pathologic OTR can occur with either central[129–137] or peripheral[138–143] lesions.

Historically, skew deviation (Video 5) (alone or with features of the complete pathologic OTR) has been associated primarily with central nervous system lesions, particularly those affecting the brainstem.[127] Although skew deviation does occur with well-documented peripheral lesions (e.g., following vestibular neurectomy[139,142]), it is unusual for idiopathic vestibular neuritis to produce a clinically-evident skew deviation by bedside alternate cover testing.[21] A systematic review of acute vestibular syndrome presentations found skew deviation by bedside testing in approximately 30% (n=36/119) of central but only 2% (n=1/65) of peripheral cases.[22] Likewise, a recent study seeking to distinguish AICA strokes from labyrinthitis cases found skew in 28% (n=5/18) of central cases and just 6% (n=1/17 examined for skew) of peripheral cases.[34]

Regardless of the reason for this disparity, it is likely that the size of the skew deviation matters. It is unusual for a clinical examiner to be able to routinely detect skew deviations smaller than ~2–4 prism diopters (~1.15–2.29 degrees) by alternate cover testing.[144] Smaller skew deviations may well be common in patients with vestibular neuritis, but larger ones are not typically seen.[22]

Quantitative HIT and the Future of the “Eye ECG” to Identify Stroke

The most accurate assessments of VOR using the HIT come from dual magnetic scleral search coil studies, but this technique is impractical outside of a laboratory-based setting. The rapid maturation of quantitative, portable VOG-based HIT devices[117,145–147] has enabled quantitative measurement in routine specialty-based clinical practice.[148–150] VOG-based HINTS is now being studied in the ED, where it may someday be used routinely to identify strokes in acute vertigo and dizziness.[25,28,151] Figure 4 shows how VOG-HINTS can be used in clinical practice.

The most common presentation of posterior circulation ischemia is isolated vertigo.[153] Most stroke patients without obvious focal neurologic signs (NIH stroke scale zero) have posterior circulation infarctions, principally located in the cerebellum or inferior brainstem.[154] Likewise, the majority of patients with acute vestibular syndrome resulting from stroke have no focal signs.[22] Furthermore, false negative MRI-DWI is more common with posterior circulation infarctions,[155] particularly with small brainstem strokes presenting acute dizziness or vertigo.[62] Our current ED diagnostic practices, particularly the use of neuroimaging,[101,156] are both inaccurate[3,10] and expensive.[1,2] ED physician training in and comfort with the diagnosis of neurological problems is limited.[157,158] An international survey of 1,150 ED physicians found the most requested clinical decision rule in adult emergency care was identifying central or serious causes of vertigo.[7] So there is reason to believe that technologies to enhance diagnosis would be welcomed.

These approaches have the potential to transform care not only for stroke patients but also for patients with peripheral vestibular disorders, since specific eye movement diagnosis is also possible for posterior canal BPPV, horizontal canal BPPV, and vestibular neuritis, likely the three most common peripheral vestibular disorders seen in the ED.[159,160] Technology-guided treatment of BPPV using canalith repositioning maneuvers is a realistic possibility. Even some patients with completely normal eye movements may benefit from VOG testing by confirming a non-vestibular cause for their dizziness or vertigo presentation, if they remain symptomatic.

VOG technology has been available since the early 1990s, but only in the past decade have high-speed devices been manufactured that are lightweight enough to assess the h-HIT without goggles slippage, which was a major technical barrier to accurate VOR measurement.[117,145,161] Two VOG devices capable of assessing the HIT response are already FDA-approved for use in routine clinical vestibular measurement.[162,163] An NIH clinical trial is now underway to assess accuracy of a novel diagnostic strategy using this technology in the ED.[164] There are three primary ways in which quantitative VOG technology could be used to enhance the accuracy of diagnosis of acute vertigo and dizziness—teleconsultation, training, and triage.

VOG technology could be placed in the field in EDs or ambulances and used as a means to enhance hospital-based[165] or mobile[166] telestroke diagnosis for patients with posterior circulation strokes, who currently often go unrecognized.[11] Tele-diagnosis by specialists (neurologists, neuro-otologists, or neuro-ophthalmologists) would rely on a combination of eye movement video recordings and quantitative eye movement traces to differentiate central from peripheral cases. This could occur in real time or asynchronously after a reasonable time delay.

VOG technology could be used as part of a systematic training program to enhance frontline clinician skills in eye movement examination.[167] Such devices provide immediate and direct feedback on psychomotor performance of the HIT, by rejecting all attempts that are beneath or above the target head velocity range. They can also be used to calibrate clinical interpretive skills for non-specialist clinicians, since they provide a quantitative measure of the VOR gain. Finally, review of videos and traces by sub-specialists with eye movement expertise could provide critical educational feedback to frontline clinicians that would otherwise be impossible without a tangible record of the eye examination from the initial ED evaluation.

Finally, VOG could also be paired with computerized algorithms to provide real-time, point-of-care diagnostic decision support for diagnosis of patients with dizziness. This approach would be similar to what has been done with electrocardiography for diagnosing heart attack in acute chest pain. Acute changes in cardiac electrophysiology are used to identify ST-elevation acute myocardial infarction (STEMI). The electrocardiogram (ECG) is performed by ED technicians, interpreted in real-time by ED physicians, and often over-read by cardiologists for confirmation. Real-time assessment is enhanced through the use of automated interpretation algorithms.[168] A similar approach could be implemented to leverage acute changes in eye physiology to identify stroke in dizziness. This ‘eye ECG’

approach is currently being studied in the AVERT (Acute Video-oculography for Vertigo in Emergency Rooms for Rapid Triage) Phase II clinical trial, sponsored by the National Institute on Deafness and Other Communication Disorders at NIH.[164]

These three approaches are not mutually exclusive, and one approach may be better suited to a particular clinical setting than the others. For example, academic centers with ready access to subspecialists may benefit most from teleconsultation. By contrast, small rural EDs without access to MRI may prefer automated approaches to determine if transfer for MRI is warranted.

Implications and Future Prospects for Implementing VOG-HINTS in the ED

Implementing VOG-HINTS in US EDs could lead to substantial clinical practice improvements. Of the ~130–215,000 patients (~3–5%[169] of 4.4 million[1]) with stroke causing their ED vertigo or dizziness presentation, data suggest that perhaps 45,000–75,000 (~35%[6]) are missed initially. Misdiagnosis appears to increase the risk of poor clinical outcomes generally (~1/3 result in death or serious harm[170]) and specifically with strokes causing dizziness,[12,22] so it is possible that 15,000–25,000 of these patients suffer significant harms from the initial misdiagnosis.

Peripheral vestibular patients would also benefit through reductions in unnecessary testing (e.g., harms from radiation with CT imaging plus consequences of incidental findings) and more specific, correct early treatments. There are likely over 1 million each year with peripheral vestibular causes; an estimated 80% of these are misclassified.[4] If VOG were also used to diagnose BPPV (in addition to vestibular neuritis and stroke) then hundreds of thousands of patients would likely benefit from prompt, effective treatments that are currently not used.[5]

Modern medicine is undergoing significant structural changes, including a transition towards bundled, capitated, or global payments, as well as accountable care organizations.[171] There will be strong financial incentives to adopt VOG in these reformed payment systems in order to reduce expensive neuroimaging.[172] For high-risk patients, the VOG approach would efficiently reduce morbidity via improved stroke care.[2] For low-risk patients, VOG could save an estimated $1 billion per year by safely reducing unnecessary CT scans and hospital admissions (Table 4).[2] This savings figure is realistic, given it represents ~10% of total current workup costs (Table 4).

Conclusions

There have been major clinical advances in the bedside diagnostic assessment of vertigo and dizziness over the past three decades. The Halmagyi & Curthoys HIT has revolutionized clinical examination of patients with peripheral vestibular disorders. Its inclusion as part of the HINTS battery has led to major advances in posterior fossa stroke diagnosis. Ocular motor physiology-based diagnosis has proven to be more accurate than even MRI-DWI, when correctly applied. VOG and related approaches to recording and quantifying eye movements likely will play a key role in frontline clinical assessment of acute vertigo and dizziness. The ‘eye ECG’ concept has the potential to transform ED diagnosis and

management of vestibular disorders and stroke. In addition to improving care for hundreds of thousands of peripheral vestibular patients and tens of thousands of stroke patients and each year, successful implementation of this approach could result in substantial US national healthcare savings of approximately $1 billion per year.

Acknowledgements:

Dr. Newman-Toker's effort was supported by a grant from the National Institutes of Health, National Institute on Deafness and Other Communication Disorders (1U01DC013778-01A1).

References

1. Saber Tehrani AS, Coughlan D, Hsieh YH, et al. . Rising annual costs of dizziness presentations to U.S. emergency departments. Acad Emerg Med. Jul 2013;20(7):689–696. [PubMed: 23859582]
2. Newman-Toker DE, McDonald KM, Meltzer DO. How much diagnostic safety can we afford, and how should we decide? A health economics perspective. BMJ Qual Saf. Oct 2013;22 Suppl 2:ii11–ii20.
3. Newman-Toker DE, Camargo CA, Jr., Hsieh YH, Pelletier AJ, Edlow JA. Disconnect between charted vestibular diagnoses and emergency department management decisions: a cross-sectional analysis from a nationally representative sample. Acad Emerg Med. Oct 2009;16(10):970–977. [PubMed: 19799573]
4. Kerber KA, Morgenstern LB, Meurer WJ, et al. . Nystagmus assessments documented by emergency physicians in acute dizziness presentations: a target for decision support? Acad Emerg Med. Jun 2011;18(6):619–626. [PubMed: 21676060]
5. Kerber KA, Burke JF, Skolarus LE, et al. . Use of BPPV processes in emergency department dizziness presentations: a population-based study. Otolaryngol Head Neck Surg. Mar 2013;148(3):425–430. [PubMed: 23264119]
6. Kerber KA, Brown DL, Lisabeth LD, Smith MA, Morgenstern LB. Stroke among patients with dizziness, vertigo, and imbalance in the emergency department: a population-based study. Stroke. Oct 2006;37(10):2484–2487. [PubMed: 16946161]
7. Eagles D, Stiell IG, Clement CM, et al. . International survey of emergency physicians' priorities for clinical decision rules. Acad Emerg Med. Feb 2008;15(2):177–182. [PubMed: 18275448]
8. Stanton VA, Hsieh YH, Camargo CA, Jr., et al. Overreliance on symptom quality in diagnosing dizziness: results of a multicenter survey of emergency physicians. Mayo Clin Proc. Nov 2007;82(11):1319–1328. [PubMed: 17976351]
9. Newman-Toker DE, Stanton VA, Hsieh YH, Rothman RE. Frontline providers harbor misconceptions about the bedside evaluation of dizzy patients. Acta Otolaryngol. May 2008;128(5):601–604. [PubMed: 18421619]
10. Kerber KA, Newman-Toker DE. Misdiagnosing the dizzy patient: common pitfalls in clinical practice. Neurol Clin. 2015 (in press).
11. Newman-Toker DE, Moy E, Valente E, Coffey R, Hines A. Missed diagnosis of stroke in the emergency department: a cross-sectional analysis of a large population-based sample. Diagnosis. 2014;1(2):155–166. [PubMed: 28344918]
12. Savitz SI, Caplan LR, Edlow JA. Pitfalls in the diagnosis of cerebellar infarction. Acad Emerg Med. 2007;14(1):63–68. [PubMed: 17200515]
13. Baloh RW, Honrubia V, Jacobson K. Benign positional vertigo: clinical and oculographic features in 240 cases. Neurology. 1987;37(3):371–378. [PubMed: 3822129]
14. Aw ST, Todd MJ, Aw GE, McGarvie LA, Halmagyi GM. Benign positional nystagmus: a study of its three-dimensional spatio-temporal characteristics. Neurology. Jun 14 2005;64(11):1897–1905. [PubMed: 15955941]
15. Bhattacharyya N, Baugh RF, Orvidas L, et al. . Clinical practice guideline: benign paroxysmal positional vertigo. Otolaryngol Head Neck Surg. 2008;139(5 Suppl 4):S47–S81. [PubMed: 18973840]

16. Fife TD, Iverson DJ, Lempert T, et al. . Practice parameter: therapies for benign paroxysmal positional vertigo (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology. Neurology. 2008;70(22):2067–2074. [PubMed: 18505980]
17. Ichijo H. Positional nystagmus of horizontal canalolithiasis. Acta Otolaryngol. Jan 2011;131(1):46–51. [PubMed: 21142901]
18. Aw ST, Fetter M, Cremer PD, Karlberg M, Halmagyi GM. Individual semicircular canal function in superior and inferior vestibular neuritis. Neurology. 2001;57(5):768–774. [PubMed: 11552001]
19. Weber KP, Aw ST, Todd MJ, McGarvie LA, Curthoys IS, Halmagyi GM. Head impulse test in unilateral vestibular loss: vestibulo-ocular reflex and catch-up saccades. Neurology. 2008;70(6):454–463. [PubMed: 18250290]
20. Halmagyi GM, Weber KP, Curthoys IS. Vestibular function after acute vestibular neuritis. Restor Neurol Neurosci. 2010;28(1):37–46. [PubMed: 20086281]
21. Kattah JC, Talkad AV, Wang DZ, Hsieh YH, Newman-Toker DE. HINTS to diagnose stroke in the acute vestibular syndrome: three-step bedside oculomotor examination more sensitive than early MRI diffusion-weighted imaging. Stroke. Nov 2009;40(11):3504–3510. [PubMed: 19762709]
22. Tarnutzer AA, Berkowitz AL, Robinson KA, Hsieh YH, Newman-Toker DE. Does my dizzy patient have a stroke? A systematic review of bedside diagnosis in acute vestibular syndrome. CMAJ. Jun 14 2011;183(9):E571–592. [PubMed: 21576300]
23. Newman-Toker DE, Kerber KA, Hsieh YH, et al. HINTS outperforms ABCD2 to screen for stroke in acute continuous vertigo and dizziness. Acad Emerg Med. Oct 2013;20(10):986–996.
24. Cohn B. Can Bedside Oculomotor (HINTS) Testing Differentiate Central From Peripheral Causes of Vertigo? Ann Emerg Med. Feb 12 2014.
25. Mantokoudis G, Tehrani AS, Wozniak A, et al. VOR gain by head impulse video-oculography differentiates acute vestibular neuritis from stroke. Otol Neurotol. Mar 2015;36(3):457–465.
26. Bashir K, Alessai GS, Salem WA, Irfan FB, Cameron PA. Physical maneuvers: effective but underutilized treatment of benign paroxysmal positional vertigo in the ED. Am J Emerg Med. Oct 14 2013.
27. Bashir K, Qotb MA, Alkahky S, Fathi AM, Mohamed MA, Cameron PA. Are emergency physicians and paramedics providing canalith repositioning manoeuvre for benign paroxysmal positional vertigo? Emerg Med Australas. Feb 4 2015.
28. Newman-Toker DE, Saber Tehrani AS, Mantokoudis G, et al. Quantitative video-oculography to help diagnose stroke in acute vertigo and dizziness: toward an ECG for the eyes. Stroke. Apr 2013;44(4):1158–1161.
29. Roberts TA, Jenkyn LR, Reeves AG. On the notion of doll's eyes. Arch Neurol. Dec 1984;41(12):1242–1243.
30. Furman JM, Jacob RG. Jongkees' formula re-evaluated: order effects in the response to alternate binaural bithermal caloric stimulation using closed-loop irrigation. Acta Otolaryngol. Jan 1993;113(1):3–10. [PubMed: 8442419]
31. Halmagyi GM, Curthoys IS. A clinical sign of canal paresis. Arch Neurol. 1988;45(7):737–739. [PubMed: 3390028]
32. Halmagyi GM, Aw ST, Cremer PD, Curthoys IS, Todd MJ. Impulsive testing of individual semicircular canal function. Ann N Y Acad Sci. 2001;942:192–200. [PubMed: 11710461]
33. Cremer PD, Halmagyi GM, Aw ST, et al. Semicircular canal plane head impulses detect absent function of individual semicircular canals. Brain. 1998;121 (Pt 4):699–716. [PubMed: 9577395]
34. Huh YE, Koo JW, Lee H, Kim JS. Head-Shaking Aids in the Diagnosis of Acute Audiovestibular Loss due to Anterior Inferior Cerebellar Artery Infarction. Audiol Neurotol. 2013;18(2):114–124.
35. Kim JS, Kim HJ. Inferior vestibular neuritis. J Neurol. Aug 2012;259(8):1553–1560.
36. Park HK, Kim JS, Strupp M, Zee DS. Isolated floccular infarction: impaired vestibular responses to horizontal head impulse. J Neurol. Jun 2013;260(6):1576–1582.
37. Lee H, Baloh RW. Sudden deafness in vertebrobasilar ischemia: clinical features, vascular topographical patterns and long-term outcome. J Neurol Sci. 2005;228(1):99–104. [PubMed: 15607217]

38. Lee H. Sudden deafness related to posterior circulation infarction in the territory of the nonanterior inferior cerebellar artery: frequency, origin, and vascular topographical pattern. Eur Neurol. 2008;59(6):302–306. [PubMed: 18408371]
39. Baloh RW. Clinical practice. Vestibular neuritis. N Engl J Med. 2003;348(11):1027–1032. [PubMed: 12637613]
40. Halmagyi GM, Aw ST, Karlberg M, Curthoys IS, Todd MJ. Inferior vestibular neuritis. Ann N Y Acad Sci. Apr 2002;956:306–313. [PubMed: 11960814]
41. Curthoys IS. The interpretation of clinical tests of peripheral vestibular function. Laryngoscope. Jun 2012;122(6):1342–1352.
42. Duncan GW, Parker SW, Fisher CM. Acute cerebellar infarction in the PICA territory. Arch Neurol. 1975;32(6):364–368. [PubMed: 1131070]
43. Guiang RL, Jr., Ellington OB. Acute pure vertiginous dysequilibrium in cerebellar infarction. Eur Neurol. 1977;16(1–6):11–15. [PubMed: 615701]
44. Rubenstein RL, Norman DM, Schindler RA, Kaseff L. Cerebellar infarction--a presentation of vertigo. Laryngoscope. 1980;90(3):505–514. [PubMed: 7359972]
45. Huang CY, Yu YL. Small cerebellar strokes may mimic labyrinthine lesions. J Neurol Neurosurg Psychiatry. 1985;48(3):263–265. [PubMed: 3981196]
46. Amarenco P, Roullet E, Hommel M, Chaine P, Marteau R. Infarction in the territory of the medial branch of the posterior inferior cerebellar artery. Journal Neurol Neurosurg Psychiatry. Sep 1990;53(9):731–735.
47. Disher MJ, Telian SA, Kemink JL. Evaluation of acute vertigo: unusual lesions imitating vestibular neuritis. Am J Otol. 1991;12(3):227–231. [PubMed: 1882974]
48. Magnusson M, Norrving B. Cerebellar infarctions as the cause of ‘vestibular neuritis’. Acta Otolaryngol Suppl. 1991;481:258–259. [PubMed: 1927388]
49. Kase CS, Norrving B, Levine SR, et al. Cerebellar infarction. Clinical and anatomic observations in 66 cases. Stroke. 1993;24(1):76–83. [PubMed: 8418555]
50. Magnusson M, Norrving B. Cerebellar infarctions and ‘vestibular neuritis’. Acta Otolaryngol Suppl. 1993;503:64–66.
51. Norrving B, Magnusson M, Holtas S. Isolated acute vertigo in the elderly; vestibular or vascular disease? Acta Neurol Scand. 1995;91(1):43–48. [PubMed: 7732773]
52. Thomke F, Hopf HC. Pontine lesions mimicking acute peripheral vestibulopathy. J Neurol Neurosurg Psychiatry. 1999;66(3):340–349. [PubMed: 10084533]
53. Hotson JR, Baloh RW. Acute vestibular syndrome. N Engl J Med. Sep 3 1998;339(10):680–685. [PubMed: 9725927]
54. Newman-Toker DE, Kattah JC, Alvernia JE, Wang DZ. Normal head impulse test differentiates acute cerebellar strokes from vestibular neuritis. Neurology. Jun 10 2008;70(24 Pt 2):2378–2385. [PubMed: 18541870]
55. Lee H, Kim HA. Nystagmus in SCA territory cerebellar infarction: pattern and a possible mechanism. Journal Neurol Neurosurg Psychiatry. Apr 2013;84(4):446–51.
56. Schmid-Priscoveanu A, Straumann D, Bohmer A, Obzina H. Vestibulo-ocular responses during static head roll and three-dimensional head impulses after vestibular neuritis. Acta Otolaryngol. 1999;119(7):750–757. [PubMed: 10687930]
57. Schmid-Priscoveanu A, Bohmer A, Obzina H, Straumann D. Caloric and search-coil head-impulse testing in patients after vestibular neuritis. J Assoc Res Otolaryngol. 2001;2(1):72–78. [PubMed: 11545152]
58. Kattah JC, Wang DZ, Zagardo MT, Pyle KR. Head impulse sign in cerebellar, medullary, and labyrinthine stroke. J Vestib Res. 2004;14:100–101.
59. Lee H, Sohn SI, Cho YW, et al. Cerebellar infarction presenting isolated vertigo: frequency and vascular topographical patterns. Neurology. 2006;67(7):1178–1183. [PubMed: 17030749]
60. Cnyrim CD, Newman-Toker D, Karch C, Brandt T, Strupp M. Bedside differentiation of vestibular neuritis from central “vestibular pseudoneuritis”. J Neurol Neurosurg Psychiatry. Apr 2008;79(4):458–460. [PubMed: 18344397]

61. Johnston SC, Rothwell PM, Nguyen-Huynh MN, et al. Validation and refinement of scores to predict very early stroke risk after transient ischaemic attack. Lancet. 2007;369(9558):283–292. [PubMed: 17258668]
62. Saber Tehrani AS, Kattah JC, Mantokoudis G, et al. Small strokes causing severe vertigo: frequency of false-negative MRIs and nonlacunar mechanisms. Neurology. Jul 8 2014;83(2):169–173. [PubMed: 24920847]
63. Chen L, Lee W, Chambers BR, Dewey HM. Diagnostic accuracy of acute vestibular syndrome at the bedside in a stroke unit. J Neurol. Dec 12 2010.
64. Batuecas-Caletrio A, Yanez-Gonzalez R, Sanchez-Blanco C, et al. [Peripheral vertigo versus central vertigo. Application of the HINTS protocol]. Rev Neurol. Oct 16 2014;59(8):349–353. [PubMed: 25297477]
65. Hausler R, Levine RA. Auditory dysfunction in stroke. Acta Otolaryngol. 2000;120(6):689–703. [PubMed: 11099144]
66. Tatu L, Moulin T, Bogousslavsky J, Duvernoy H. Arterial territories of human brain: brainstem and cerebellum. Neurology. 1996;47(5):1125–1135. [PubMed: 8909417]
67. Lee H, Sohn SI, Jung DK, et al. Sudden deafness and anterior inferior cerebellar artery infarction. Stroke. 2002;33(12):2807–2812. [PubMed: 12468774]
68. Lee H, Cho YW. Auditory disturbance as a prodrome of anterior inferior cerebellar artery infarction. J Neurol Neurosurg Psychiatry. 2003;74(12):1644–1648. [PubMed: 14638883]
69. Lee H, Ahn BH, Baloh RW. Sudden deafness with vertigo as a sole manifestation of anterior inferior cerebellar artery infarction. J Neurol Sci. 2004;222(1–2):105–107. [PubMed: 15240204]
70. Gerace C, Pianura C. Sudden deafness without vertigo as a sole manifestation of AICA infarct. Neurol Sci. Oct 2008;29(5):371–372. [PubMed: 18941944]
71. Park JH, Kim H, Han HJ. Recurrent audiovestibular disturbance initially mimicking Meniere's disease in a patient with anterior inferior cerebellar infarction. Neurol Sci. Oct 2008;29(5):359–362. [PubMed: 18941941]
72. Kim JS, Cho KH, Lee H. Isolated labyrinthine infarction as a harbinger of anterior inferior cerebellar artery territory infarction with normal diffusion-weighted brain MRI. J Neurol Sci. Mar 15 2009;278(1–2):82–84. [PubMed: 19135217]
73. Lee H, Kim JS, Chung EJ, et al. . Infarction in the territory of anterior inferior cerebellar artery: spectrum of audiovestibular loss. Stroke. 2009;40(12):3745–3751. [PubMed: 19797177]
74. Martines F, Dispenza F, Gagliardo C, Martines E, Bentivegna D. Sudden sensorineural hearing loss as prodromal symptom of anterior inferior cerebellar artery infarction. ORL J Otorhinolaryngol Relat Spec. 2011;73(3):137–140. [PubMed: 21494055]
75. Ikegami-Takada T, Izumikawa M, Doi T, Takada Y, Tomoda K. AICA syndrome with facial palsy following vertigo and acute sensorineural hearing loss. Auris Nasus Larynx. Apr 2012;39(2):244–248. [PubMed: 21862260]
76. Lee H. Audiovestibular loss in anterior inferior cerebellar artery territory infarction: a window to early detection? J Neurol Sci. Feb 15 2012;313(1–2):153–159. [PubMed: 21996273]
77. Stefan H, Wappenschmidt J, Kiefer H. Occlusions of the basilar artery: Pathologicanatomical and clinical findings in different occlusion types and their prognosis. Neurosurg Rev. 1981;4(1):41–52. [PubMed: 7301138]
78. Huang MH, Huang CC, Ryu SJ, Chu NS. Sudden bilateral hearing impairment in vertebrobasilar occlusive disease. Stroke. 1993;24(1):132–137. [PubMed: 8418537]
79. von Campe G, Regli F, Bogousslavsky J. Heralding manifestations of basilar artery occlusion with lethal or severe stroke. J Neurol Neurosurg Psychiatry. 2003;74(12):1621–1626. [PubMed: 14638878]
80. Yi HA, Lee SR, Lee H, Ahn BH, Park BR, Whitman GT. Sudden deafness as a sign of stroke with normal diffusion-weighted brain MRI. Acta Otolaryngol. 2005;125(10):1119–1121. [PubMed: 16298797]
81. Chiang CI, Chou CH, Hsueh CJ, Cheng CA, Peng GS. Acute bilateral hearing loss as a "worsening sign" in a patient with critical basilar artery stenosis. J Clin Neurosci. Jan 2013;20(1):177–179. [PubMed: 22989789]

82. Kim E, Son MK, Kang CK, Lee YB. Vertebrobasilar occlusion presenting as sudden isolated bilateral sensorineural hearing loss: case report. J Cerebrovasc Endovasc Neurosurg. Sep 2013;15(3):225–228. [PubMed: 24167804]
83. Raupp SF, Jellema K, Sluzewski M, de Kort PL, Visser LH. Sudden unilateral deafness due to a right vertebral artery dissection. Neurology. 2004;62(8):1442. [PubMed: 15111698]
84. Choi KD, Chun JU, Han MG, Park SH, Kim JS. Embolic internal auditory artery infarction from vertebral artery dissection. J Neurol Sci. 2006;246(1–2):169–172. [PubMed: 16580695]
85. Kim JS, Lopez I, DiPatre PL, Liu F, Ishiyama A, Baloh RW. Internal auditory artery infarction: clinicopathologic correlation. Neurology. 1999;52(1):40–44. [PubMed: 9921846]
86. Beyea JA, Agrawal SK, Parnes LS. Recent advances in viral inner ear disorders. Curr Opin Otolaryngol. Oct 2012;20(5):404–408.
87. Schuknecht HF, Kitamura K. Second Louis H. Clerf Lecture. Vestibular neuritis. Ann Otol Rhinol Laryngol Suppl. 1981;90(1 Pt 2):1–19.
88. Ben-David J, Luntz M, Podoshin L, Sabo E, Fradis M. Vertigo as a prognostic sign in sudden sensorineural hearing loss. Int Tinnitus J. 2002;8(2):127–128. [PubMed: 14763225]
89. Kitahara T, Takeda N, Nishiike S, Okumura S, Kubo T. Prognosis of inner ear periphery and central vestibular plasticity in sudden deafness with vertigo. Ann Otol Rhinol Laryngol. Oct 2005;114(10):786–791. [PubMed: 16285269]
90. Jung JY, Kim YH, Suh MW. Difference in the nature of dizziness between vestibular neuritis and sudden sensorineural hearing loss with vertigo. Otol Neurotol. Jun 2012;33(4):623–628.
91. Rahko T, Karma P. New clinical finding in vestibular neuritis: high-frequency audiometry hearing loss in the affected ear. Laryngoscope. Feb 1986;96(2):198–199. [PubMed: 3945150]
92. Wayman DM, Pham HN, Byl FM, Adour KK. Audiological manifestations of Ramsay Hunt syndrome. J Laryngol Otol. Feb 1990;104(2):104–108. [PubMed: 2324614]
93. Lee H. Recent advances in acute hearing loss due to posterior circulation ischemic stroke. J Neurol Sci. Mar 15 2014;338(1–2):23–29. [PubMed: 24433932]
94. Hyden D, Akerlind B, Peebo M. Inner ear and facial nerve complications of acute otitis media with focus on bacteriology and virology. Acta Otolaryngol. May 2006;126(5):460–466.
95. Newman-Toker DE, Kattah J. HINTS to identify stroke in ED patients with dizziness (in reply). Acad Emerg Med. Feb 13 2014.
96. Physician Fee Schedule Search. Centers for Medicare & Medicaid Services; 2014. Available from: http://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/PhysicianFeeSched/index.html?redirect=/PhysicianFeeSched/.
97. Chalela JA, Kidwell CS, Nentwich LM, et al. . Magnetic resonance imaging and computed tomography in emergency assessment of patients with suspected acute stroke: a prospective comparison. Lancet. 2007;369(9558):293–298. [PubMed: 17258669]
98. Hwang DY, Silva GS, Furie KL, Greer DM. Comparative Sensitivity of Computed Tomography vs. Magnetic Resonance Imaging for Detecting Acute Posterior Fossa Infarct. J Emerg Med. May 2012;42(5):559–565. [PubMed: 22305149]
99. Ozono Y, Kitahara T, Fukushima M, et al. . Differential diagnosis of vertigo and dizziness in the emergency department. Acta Otolaryngol. Feb 2014;134(2):140–5. [PubMed: 24308666]
100. Kabra R, Robbie H, Connor SE. Diagnostic yield and impact of MRI for acute ischaemic stroke in patients presenting with dizziness and vertigo. Clin Radiol. Jul 2015;70(7):736–42.
101. Kerber KA, Schweigler L, West BT, Fendrick AM, Morgenstern LB. Value of computed tomography scans in ED dizziness visits: analysis from a nationally representative sample. Am J Emerg Med. Nov 2010;28(9):1030–1036. [PubMed: 20825765]
102. Smith-Bindman R, Lipson J, Marcus R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Int Med. Dec 14 2009;169(22):2078–2086. [PubMed: 20008690]
103. Mortele KJ, Oliva MR, Ondategui S, Ros PR, Silverman SG. Universal use of nonionic iodinated contrast medium for CT: evaluation of safety in a large urban teaching hospital. AJR Am J Roentgenol. Jan 2005;184(1):31–34. [PubMed: 15615946]

104. Josephson SA, Dillon WP, Smith WS. Incidence of contrast nephropathy from cerebral CT angiography and CT perfusion imaging. Neurology. May 24 2005;64(10):1805–1806.
105. 2012 Medicare Hospital Outpatient Prospective Payment Schedule Rates: Computed Tomography Procedures: Siemens Medical Solutions USA, Inc; 2012. Available from http://www.medical.siemens.com/siemens/en_US/rg_marcom_FBAs/files/Reimburseme nt/CT_2012_Final_HOPPS_Payment_Rates.pdf.
106. Preventing accidents and injuries in the MRI suite: The Joint Commission; 2008. Available from http://www.jointcommission.org/sentinel_event_alert_issue_38_preventing_accidents_and_injuries_in_the_mri_suite/.
107. Shellock FG, Spinazzi A. MRI safety update 2008: part 1, MRI contrast agents and nephrogenic systemic fibrosis. AJR Am J Roentgenol. Oct 2008;191(4):1129–1139. [PubMed: 18806155]
108. 2012 Medicare Hospital Outpatient Prospective Payment Schedule Rates: Magnetic Resonance Imaging: Siemens Medical Solutions USA, Inc; 2012. Available from http://www.medical.siemens.com/siemens/en_US/rg_marcom_FBAs/files/Reimburseme nt/MR_2012_Final_HOPPS_Payment_Rates.pdf.
109. Kamalian S, Atkinson WL, Florin LA, Pomerantz SR, Lev MH, Romero JM. Emergency department CT screening of patients with nontraumatic neurological symptoms referred to the posterior fossa: comparison of thin versus thick slice images. Emerg Radiol. Jun 2014;21(3):251–256. [PubMed: 24469596]
110. Newman-Toker DE, Edlow JA. High-stakes diagnostic decision rules for serious disorders: the Ottawa subarachnoid hemorrhage rule. JAMA. Sep 25 2013;310(12):1237–1239. [PubMed: 24065009]
111. Axer H, Grassel D, Bramer D, et al. Time course of diffusion imaging in acute brainstem infarcts. J Magn Reson Imaging. Oct 2007;26(4):905–912. [PubMed: 17896361]
112. Laupacis A, Sekar N, Stiell IG. Clinical prediction rules. A review and suggested modifications of methodological standards. JAMA. 1997;277(6):488–494. [PubMed: 9020274]
113. Stiell IG, Bennett C. Implementation of clinical decision rules in the emergency department. Acad Emerg Med. Nov 2007;14(11):955–959. [PubMed: 17923717]
114. Stiell IG, Greenberg GH, McKnight RD, et al. Decision rules for the use of radiography in acute ankle injuries. Refinement and prospective validation. JAMA. 1993;269(9):1127–1132. [PubMed: 8433468]
115. Perry JJ, Stiell IG, Sivilotti ML, et al. Clinical decision rules to rule out subarachnoid hemorrhage for acute headache. JAMA. Sep 25 2013;310(12):1248–1255. [PubMed: 24065011]
116. Robinson DA. A method of measuring eye movement using a scleral search coil in a magnetic field. IEEE Trans Biomed Elect. 1963;10:137–145.
117. MacDougall HG, Weber KP, McGarvie LA, Halmagyi GM, Curthoys IS. The video head impulse test: diagnostic accuracy in peripheral vestibulopathy. Neurology. 2009;73(14):1134–1141. [PubMed: 19805730]
118. Luis L, Costa J, Vaz Garcia F, Valls-Sole J, Brandt T, Schneider E. Spontaneous Plugging of the Horizontal Semicircular Canal With Reversible Canal Dysfunction and Recovery of Vestibular Evoked Myogenic Potentials. Otol Neurotol. Apr 29 2013.
119. Hirvonen TP, Aalto H, Jutila T. Labyrinthine function after semicircular canal surgery on seventeen patients with cholesteatoma. Clin Otolaryngol. Apr 30 2015.
120. Kim HA, Lee H. Isolated vestibular nucleus infarction mimicking acute peripheral vestibulopathy. Stroke. Jul 2010;41(7):1558–1560. [PubMed: 20489171]
121. Tohgi H, Takahashi S, Chiba K, Hirata Y. Cerebellar infarction. Clinical and neuroimaging analysis in 293 patients. The Tohoku Cerebellar Infarction Study Group. Stroke. 1993;24(11):1697–1701. [PubMed: 8236346]
122. Chen L, Todd M, Halmagyi GM, Aw S. Head impulse gain and saccade analysis in pontine-cerebellar stroke and vestibular neuritis. Neurology. Oct 21 2014;83(17):1513–1522. [PubMed: 25253747]
123. Robinson DA, Zee DS, Hain TC, Holmes A, Rosenberg LF. Alexander's law: its behavior and origin in the human vestibulo-ocular reflex. Ann Neurol. Dec 1984;16(6):714–722.

124. Lin CY, Young YH. Clinical significance of rebound nystagmus. Laryngoscope. Nov 1999;109(11):1803–1805.
125. Lee SU, Kim HJ, Kim JS. Pseudo-spontaneous and head-shaking nystagmus in horizontal canal benign paroxysmal positional vertigo. Otol Neurotol. Mar 2014;35(3):495–500.
126. Kim HJ, Lee SH, Park JH, Choi JY, Kim JS. Isolated vestibular nuclear infarction: report of two cases and review of the literature. J Neurol. Oct 27 2013.
127. Brodsky MC, Donahue SP, Vaphiades M, Brandt T. Skew deviation revisited. Surv Ophthalmol. 2006;51(2):105–128. [PubMed: 16500212]
128. Zee DS. Considerations on the mechanisms of alternating skew deviation in patients with cerebellar lesions. J Vestib Res. 1996;6(6):395–401. [PubMed: 8968967]
129. Halmagyi GM, Brandt T, Dieterich M, Curthoys IS, Stark RJ, Hoyt WF. Tonic contraversive ocular tilt reaction due to unilateral meso-diencephalic lesion. Neurology. 1990;40(10):1503–1509. [PubMed: 2215939]
130. Brandt T, Dieterich M. Pathological eye-head coordination in roll: tonic ocular tilt reaction in mesencephalic and medullary lesions. Brain. 1987;110 (Pt 3):649–666. [PubMed: 3495315]
131. Dieterich M, Brandt T. Wallenberg's syndrome: lateropulsion, cyclorotation, and subjective visual vertical in thirty-six patients. Ann Neurol. 1992;31(4):399–408. [PubMed: 1586141]
132. Dieterich M, Brandt T. Thalamic infarctions: differential effects on vestibular function in the roll plane (35 patients). Neurology. 1993;43(9):1732–1740. [PubMed: 8414023]
133. Brandt T, Dieterich M. Skew deviation with ocular torsion: a vestibular brainstem sign of topographic diagnostic value. Ann Neurol. 1993;33(5):528–534. [PubMed: 8498829]
134. Brandt T, Dieterich M. Vestibular syndromes in the roll plane: topographic diagnosis from brainstem to cortex. Ann Neurol. 1994;36(3):337–347. [PubMed: 8080241]
135. Mossman S, Halmagyi GM. Partial ocular tilt reaction due to unilateral cerebellar lesion. Neurology. 1997;49(2):491–493. [PubMed: 9270583]
136. Chen CM, Lin SH. Ipsiversive partial ocular tilt reaction in a patient with acute paramedian thalamic infarctions. Acta Neurol Taiwan. 2006;15(1):29–33. [PubMed: 16599282]
137. Zwergal A, Cnyrim C, Arbusow V, et al. Unilateral INO is associated with ocular tilt reaction in pontomesencephalic lesions: INO plus. Neurology. Aug 19 2008;71(8):590–593. [PubMed: 18711113]
138. Halmagyi GM, Gresty MA, Gibson WP. Ocular tilt reaction with peripheral vestibular lesion. Ann Neurol. 1979;6(1):80–83. [PubMed: 315752]
139. Wolfe GI, Taylor CL, Flamm ES, Gray LG, Raps EC, Galetta SL. Ocular tilt reaction resulting from vestibuloacoustic nerve surgery. Neurosurgery. 1993;32(3):417–420. [PubMed: 8455767]
140. Safran AB, Vibert D, Issoua D, Hausler R. Skew deviation after vestibular neuritis. Am J Ophthalmol. 1994;118(2):238–245. [PubMed: 8053470]
141. Vibert D, Hausler R, Safran AB, Koerner F. Ocular tilt reaction associated with a sudden idiopathic unilateral peripheral cochleovestibular loss. ORL J Otorhinolaryngol Relat Spec. 1995;57(6):310–315. [PubMed: 8789479]
142. Vibert D, Hausler R, Safran AB, Koerner F. Diplopia from skew deviation in unilateral peripheral vestibular lesions. Acta Otolaryngol. 1996;116(2):170–176. [PubMed: 8725507]
143. Cosetti MK, Tawfik K, Fouladvand M, Roland JT, Jr., Lalwani AK. Diplopia due to skew deviation following neurotologic procedures. Otol Neurotol. Jul 2012;33(5):840–842. [PubMed: 22699992]
144. Wong AM, Tweed D, Sharpe JA. Vertical misalignment in unilateral sixth nerve palsy. Ophthalmology. Jul 2002;109(7):1315–1325. [PubMed: 12093657]
145. Weber KP, MacDougall HG, Halmagyi GM, Curthoys IS. Impulsive testing of semicircular-canal function using video-oculography. Ann N Y Acad Sci. 2009;1164:486–491. [PubMed: 19645955]
146. Macdougall HG, McGarvie LA, Halmagyi GM, Curthoys IS, Weber KP. The Video Head Impulse Test (vHIT) Detects Vertical Semicircular Canal Dysfunction. PLoS One. 2013;8(4):e61488.

147. MacDougall HG, McGarvie LA, Halmagyi GM, Curthoys IS, Weber KP. Application of the video head impulse test to detect vertical semicircular canal dysfunction. Otol Neurotol. Aug 2013;34(6):974–979. [PubMed: 23714711]

148. Manzari L, Burgess AM, MacDougall HG, Bradshaw AP, Curthoys IS. Rapid fluctuations in dynamic semicircular canal function in early Meniere's disease. Eur Arch Otorhinolaryngol. Apr 2011;268(4):637–639. [PubMed: 21153901]

149. Manzari L, Burgess AM, Curthoys IS. Vestibular function in Lermoyez syndrome at attack. Eur Arch Otorhinolaryngol. Feb 2012;269(2):685–691. [PubMed: 21681570]

150. Manzari L, Macdougall HG, Burgess AM, Curthoys IS. New, fast, clinical vestibular tests identify whether a vertigo attack is due to early Meniere's disease or vestibular neuritis. Laryngoscope. Aug 2 2012.

151. Mantokoudis G, Saber Tehrani AS, Kattah JC, et al. Quantifying the vestibulo-ocular reflex with video-oculography: nature and frequency of artifacts. Audiol Neurotol. 2015;20(1):39–50.

152. Edlow JA, Newman-Toker DE, Savitz SI. Diagnosis and initial management of cerebellar infarction. Lancet Neurol. Oct 2008;7(10):951–964. [PubMed: 18848314]

153. Paul NL, Simoni M, Rothwell PM. Transient isolated brainstem symptoms preceding posterior circulation stroke: a population-based study. Lancet Neurol. Jan 2013;12(1):6571.

154. Martin-Schild S, Albright KC, Tanksley J, et al. Zero on the NIHSS Does Not Equal the Absence of Stroke. Ann Emerg Med. Jan 2011;57(1):42–45. [PubMed: 20828876]

155. Oppenheim C, Stanescu R, Dormont D, et al. False-negative diffusion-weighted MR findings in acute ischemic stroke. AJNR Am J Neuroradiol. 2000;21(8):1434–1440. [PubMed: 11003275]

156. Kim AS, Sidney S, Klingman JG, Johnston SC. Practice variation in neuroimaging to evaluate dizziness in the ED. Am J Emerg Med. Jun 2012;30(5):665–672. [PubMed: 21570240]

157. Caplan LR, Adelman L. Neurologic education. West J Med. Sep 1994;161(3):319–322. [PubMed: 7975574]

158. Newman-Toker DE, Perry JJ. Acute diagnostic neurology: challenges and opportunities. Acad Emerg Med. Mar 2015;22(3):357–361. [PubMed: 25716296]

159. Cutfield NJ, Seemungal BM, Millington H, Bronstein AM. Diagnosis of acute vertigo in the emergency department. Emerg Med J. Mar 12 2011.

160. Vanni S, Pecci R, Casati C, et al. . STANDING, a four-step bedside algorithm for differential diagnosis of acute vertigo in the Emergency Department. Acta Otorhinolaryngol Ital. Dec 2014;34(6):419–426. [PubMed: 25762835]

161. Bartl K, Lehnen N, Kohlbecher S, Schneider E. Head impulse testing using video-oculography. Ann N Y Acad Sci. May 2009;1164:331–333. [PubMed: 19645921]

162. ICS Impulse. http://icsimpulse.com/. Accessed June 15, 2015.

163. Eye See Cam. http://www.interacoustics.us/eyeseecam. Accessed June 15, 2015.

164. Newman-Toker DE. AVERT Phase II Trial: Acute Video-oculography for Vertigo in Emergency Rooms for Rapid Triage. Johns Hopkins University: National Institute on Deafness and Other Communication Disorders (NIDCD 1U01DC013778–01A1); 2014.

165. Nelson RE, Saltzman GM, Skalabrin EJ, Demaerschalk BM, Majersik JJ. The cost-effectiveness of telestroke in the treatment of acute ischemic stroke. Neurology. Oct 25 2011;77(17):1590–1598. [PubMed: 21917781]

166. Audebert HJ, Boy S, Jankovits R, et al. Is mobile teleconsulting equivalent to hospital-based telestroke services? Stroke. Dec 2008;39(12):3427–3430. [PubMed: 18787198]

167. Omron R, Saber-Tehrani AS, Duval-Arnold J, et al. The participation in a vertigo day resulted in better resident comfort with discharging patients without receiving a CT scan in patients with vestibular neuritis [abstract]. Society for Academic Emergency Medicine Annual Meeting. Chicago, IL 2012.

168. Daudelin DH, Selker HP. Medical error prevention in ED triage for ACS: use of cardiac care decision support and quality improvement feedback. Cardiol Clin. 2005;23(4):601–614, ix. [PubMed: 16278128]

169. Newman-Toker DE, Edlow JA. TiTrATE: a novel approach to diagnosing acute dizziness and vertigo. Neurol Clin. 2015 (in press).

170. Singh H, Giardina TD, Meyer AN, Forjuoh SN, Reis MD, Thomas EJ. Types and origins of diagnostic errors in primary care settings. JAMA Intern Med. Mar 25 2013;173(6):418–425. [PubMed: 23440149]

171. Berwick DM. Making good on ACOs' promise--the final rule for the Medicare shared savings program. N Engl J Med. Nov 10 2011;365(19):1753–1756. [PubMed: 22013899]

172. Gold D, Newman-Toker DE, Sharfstein JM. Neurology and the Affordable Care Act. JAMA Neurol. Apr 20 2015.

173. Newman-Toker DE, Hsieh YH, Camargo CA, Jr., Pelletier AJ, Butchy GT, Edlow JA. Spectrum of dizziness visits to US emergency departments: cross-sectional analysis from a nationally representative sample. Mayo Clin Proc. Jul 2008;83(7):765–775. [PubMed: 18613993]

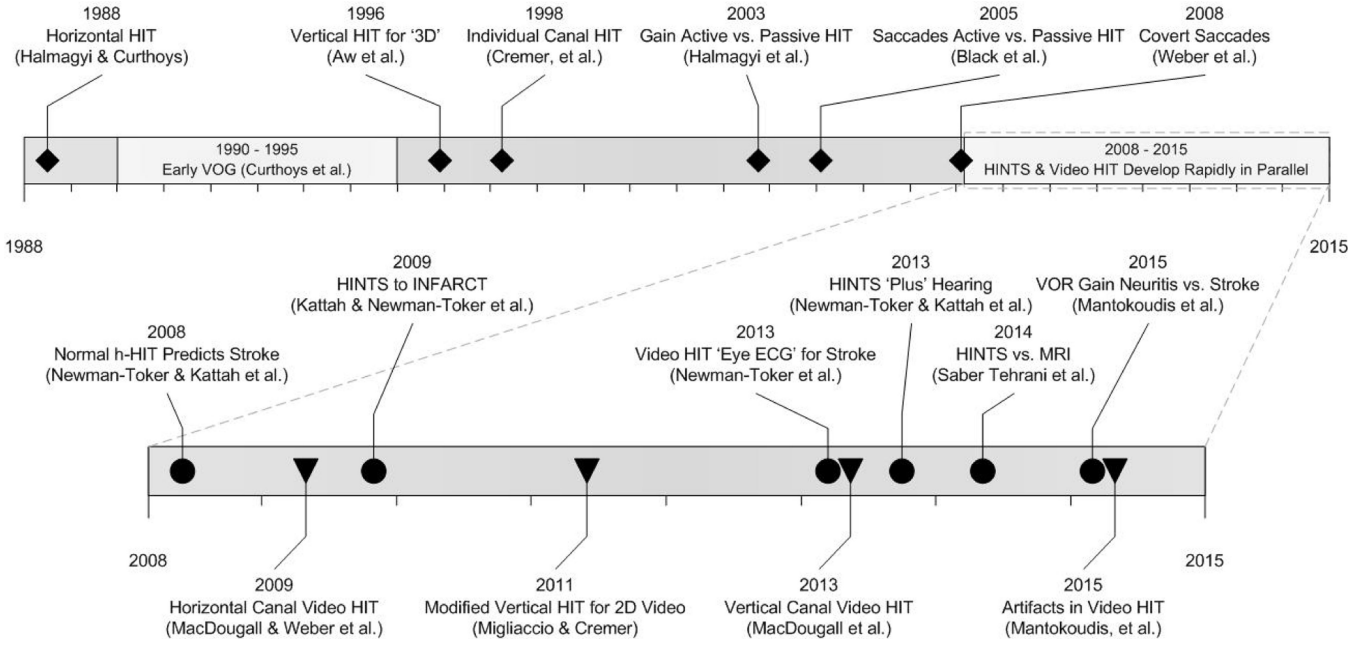

Figure 1. Timeline showing major milestones in the development of HIT, HINTS, and VOG-HINTS testing

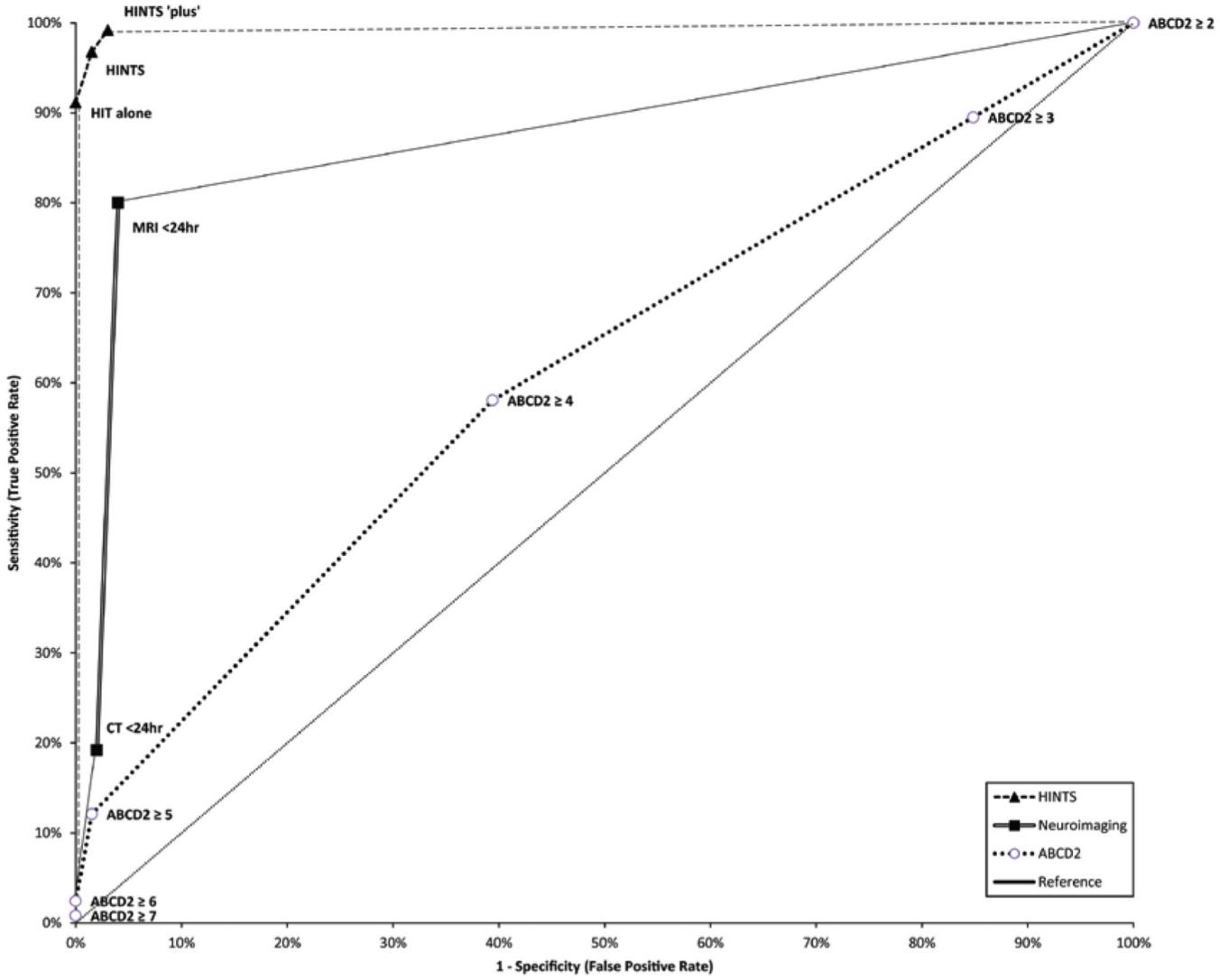

Figure 2. Receiver operating characteristic curve analysis for the 'HINTS family' compared to neuroimaging (CT or MRI) and vascular risk stratification by ABCD^2 score for detecting stroke in patients presenting the acute vestibular syndrome.

Receiver operating characteristic (ROC) curves shown for three different diagnostic approaches to diagnosing stroke in the acute vestibular syndrome. The reference diagonal line indicates a hypothetical useless diagnostic test with a likelihood ratio of 1.0 at all threshold cutoffs. Such a test provides no additional information about the underlying diagnosis. A perfect test or decision rule has threshold cutoffs in the upper left corner (100% sensitivity, 100% specificity) and an area under the curve (AUC) of 1.0. The AUC for the HINTS family of tests is estimated to be 0.995 in this patient population.[23] Note that the horizontal HIT alone outperforms MRI for diagnosing stroke in the first 24–48 hours after the onset of acute, continuous vertigo.

Abbreviations: ABCD2 – age, blood pressure, clinical features, duration of symptoms, diabetes; CT – computed tomography; HINTS – head impulse, nystagmus, test of skew; HINTS "plus" – HINTS plus new hearing loss detected by finger rubbing; HIT – head impulse test; MRI – magnetic resonance imaging

Adapted from Newman-Toker, et al., Academic Emergency Medicine, 2013[23]

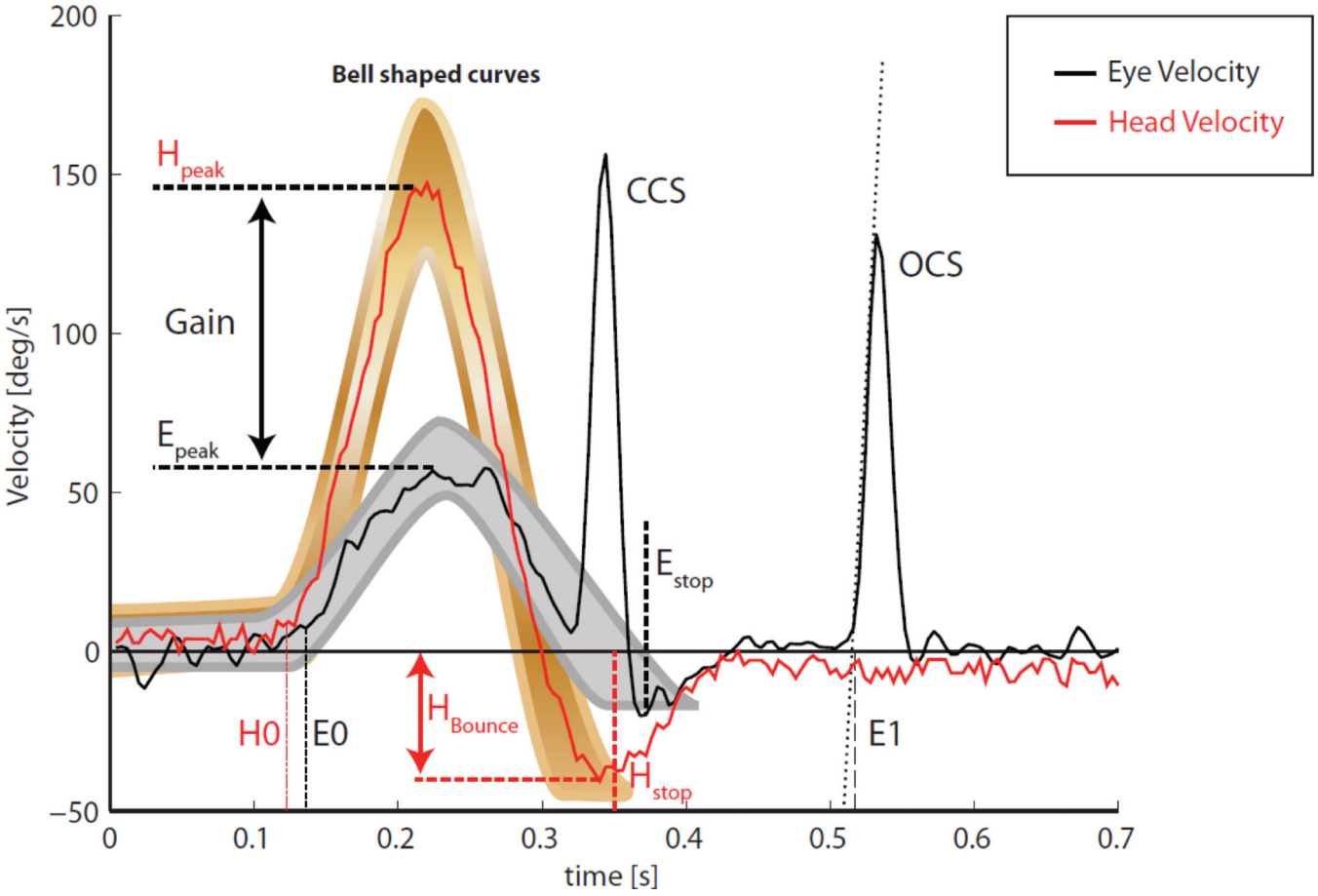

Figure 3. Physiologic attributes and parameter definitions for a single, typical, abnormal h-HIT trace.

Head velocity traces are shown in red, eye velocity in black. Note that eye movements are in the opposite direction to head movements, but are displayed graphically as superimposed to make visual assessment of VOR gain (eye movements relative to head movements) clearer. H0 = Head velocity onset; E0 = eye velocity onset; H_{peak} = peak head velocity; E_{peak} = peak eye velocity; H_{bounce} = head velocity crosses baseline with head reversal following deceleration (bounce); H_{stop} = head movement stops; E_{stop} = eye movement stops; CCS = covert corrective saccade (during head movement); OCS = overt corrective saccade (after head movement) with dotted line (slope = saccade acceleration) to identify E1 saccade onset; VOR latency = E0 – H0; VOR gain = eye velocity divided by head velocity at a specific time during the HIT (generally E_{peak}/H_{peak}) or across a range of times (E_{times}/H_{times}) (generally the ratio of the areas under the two curves over the entire HIT duration); saccade latency = E1 – E0.

Reproduced with permission from Mantokoudis, et al. Audiology & Neuro-otology, 2015[151]

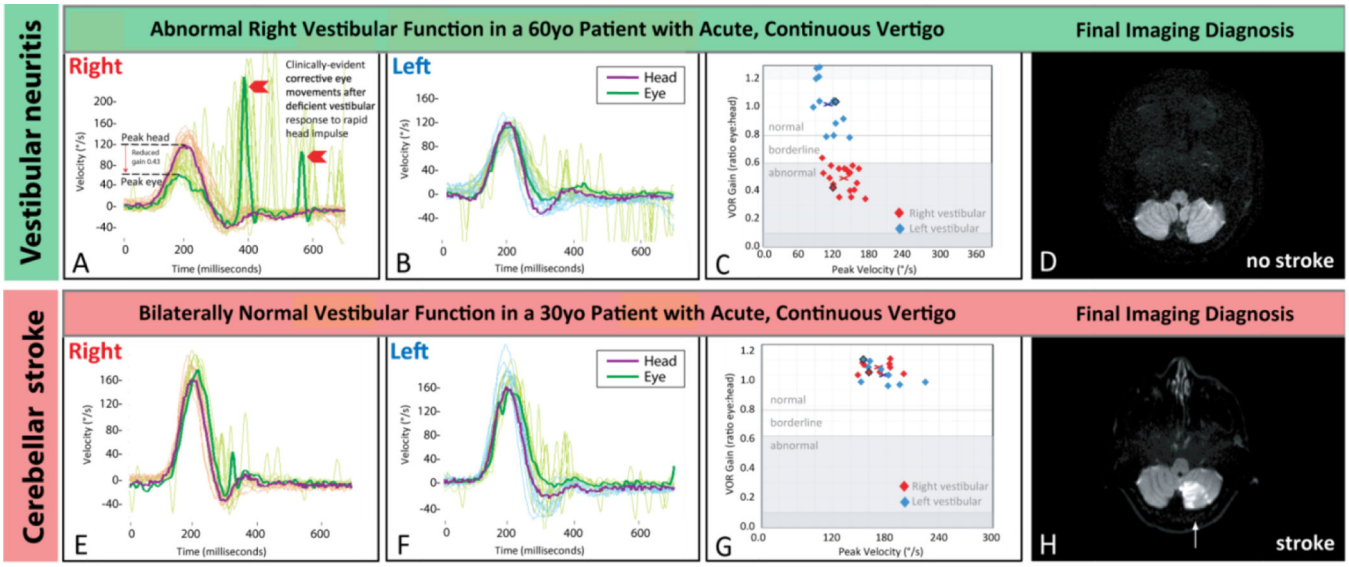

Figure 4. Physiologic (VOG) diagnosis of neuritis vs. stroke in two acute vertigo patients in the ED.[28]

Clinical features were the same for both patients (vertigo, nausea, and gait disturbance without neurologic or auditory symptoms or signs). Both had unidirectional nystagmus (first degree in light with visual fixation) without skew deviation. Shown are physiologic tracings from high-speed video recordings of multiple rightward (A;E) and leftward (B;F) h-HIT maneuvers temporally superimposed with a single maneuver bolded. The abnormal h-HIT (A) has both a quantitative abnormality (reduced VOR gain during the head movement, *downward red arrow*) and a qualitative, clinically-evident abnormality (fast, corrective eye movements to realign the eye on the target after the head stops moving, *red chevrons*). Each h-HIT result is mapped in the corresponding VOR gain plot (C;G) where the central 'x' denotes the mean right- or left-sided VOR gain across h-HIT trials. Representative axial MRI-DWI images through the inferior cerebellum show no stroke in the older vestibular neuritis patient (D) and a large acute, left posterior inferior cerebellar artery territory infarction in the younger stroke patient (H, *arrow*). The 60 year old is the typical patient who would most likely undergo an unnecessary $10,000 stroke workup and admission; the 30 year old, whose stroke spanned 8 axial slices (lesion 3.0×5.0×4.4 cm), is the typical patient who may be missed and sent home as a 'peripheral' and whose stroke may swell, causing hydrocephalus, herniation, and death.[152]

Abbreviations: h-HIT – horizontal head impulse test; MRI-DWI – magnetic resonance imaging with diffusion weighted imaging; VOR – vestibulo-ocular reflex; °/s – degrees per second; yo – year old

Adapted from Newman-Toker et al., Stroke 2013[28]

Video 1.
Demonstration of the HINTS examination in a normal subject.

Video 2.

(A, normal speed; B, slow motion) Patient with a normal rightward h-HIT and abnormal leftward h-HIT with an overt refixation saccade, indicating a left VOR deficit. The refixation is overt (after the HIT) and thus is readily detected clinically. (C, normal speed; D, slow motion) Patient with a normal rightward h-HIT and abnormal leftward h-HIT with a covert refixation saccade, indicating a left VOR deficit. The refixation is covert (during the HIT) and thus is hidden clinically and only readily detected using quantitative eye movement recordings. It is even difficult to see using slow-motion video playback.

Video 3.

Patient with a spontaneous, left-beating vestibular nystagmus obeying Alexander's law. In this case, the nystagmus was due to a peripheral vestibular lesion.

Video 4.

Patient with a mixed vestibular and gaze-holding nystagmus defying Alexander's law. In this case, the nystagmus was due to a central lesion (ischemic stroke in the anterior inferior cerebellar artery territory).

Video 5.

Skew deviation (left hypertropia by alternate cover test) in a patient with a central lesion (ischemic stroke in the posterior inferior cerebellar artery territory).

Table 1.

Ocular motor and auditory features of acute peripheral and central vestibulopathies

Clinical Disorder	Head Impulse	Nystagmus with Right Lesion	Skew Deviation	Hearing Loss
Vestibular neuritis (VN) Labyrinthitis or cochlea-vestibular neuritis (CVN)	Unilateral decrease	Contralesional-beating, direction-fixed, obeys Alexander's law	Rare [22,60] *	VN: absent † CVN: present † (mild to severe [34])
VN or CVN complete (AC, HC, PC, utricle, saccule)	AC, HC, PC	H: left (major) V: none T: left ear beating (minor)	As above	As above
VN or CVN superior branch (AC, HC, utricle)	AC, HC	H: left (major) V: upbeat (minor) T: left ear beating (minor)	As above	As above
VN or CVN inferior branch (PC, saccule)	PC	H: none V: downbeat (major) T: left-ear beat (minor)	None [35]	As above (n=3/9 [35])
AICA Stroke	Unilateral decrease ~50% [22,34]; occasional bilateral asymmetric decrease [25,36]	50% direction-changing, gaze-evoked nystagmus [34]	28% [34]	Present in 56% [34] (mild to severe [34])
PICA or SCA Stroke	99% clinically normal bilaterally [22]	38% direction-changing, gaze-evoked nystagmus [22]	30% [22]	Rare [37,38]

* Skew deviation is well known in vestibular neurectomy, but rarely found in vestibular neuritis or labyrinthitis (2%, n=2/91[22,34,35]). This may be because small skew deviations (<2–4 prism diopters) are not easily identified at the bedside by alternate cover testing.

† Standard terminology suggests that, by definition, hearing loss is absent in vestibular neuritis and present in labyrinthitis.[39] However, these terms are used inconsistently in clinical practice and the medical literature. As yet, there is no way to reliably determine whether a lesion is located in the vestibular nerve or the labyrinth in the majority of acute cases.

Abbreviations: AC – anterior canal; AICA – anterior inferior cerebellar artery; CVN – cochleo-vestibular neuritis (i.e., labyrinthitis); H – horizontal; HC – horizontal canal; PC – posterior canal; PICA – posterior inferior cerebellar artery; SCA – superior cerebellar artery; T – torsional; V – vertical; VN – vestibular neuritis

Table 2.

Test properties of widely available and new methods to assess for stroke in the acute vestibular syndrome

Test for Stroke in Acute Vertigo	Estimated Sensitivity	Estimated Specificity	Total Time Added	Side Effects & Risks	Approximate Cost
Detailed bedside neurologic exam	19%[21]	~95%	10–20 min	possible increase in dizziness while testing	$0 plus ED doctor time or $132–242[96] consult
Brain CT +/− contrast CTA	7–42%[97–100]	98%[97] (for all acute strokes)	40–77 min[101]	radiation;[102] contrast allergy,[103] nephropathy[104]	$233–396[105]
Stroke-protocol MRI with DWI, MRA +/− contrast	80% (<24hrs)[22] 86% (<72hrs)[23] 99% (>72hrs)[23]	96%[97] (for all acute strokes)	60 min up to 6 hrs or longer	projectiles, burns;[106] contrast toxicity (systemic sclerosis)[107]	$1204–$1638[108]
Eye movements HINTS[21]-VOG[28]	99% *[23]	97% *[23]	10–20 min[28]	possible increase in dizziness while testing	$30–101† plus ED technician time

Abbreviations: CT – computed tomography; CTA – CT angiography; DWI – diffusion-weighted imaging; ED – emergency department; HINTS – head impulse, nystagmus, test of skew; hrs – hours; min – minutes; MRA – magnetic resonance angiography; MRI – magnetic resonance imaging; VOG – video-oculography

* Sensitivity and specificity of HINTS for central dizziness or vertigo, including non-stroke

† Based on average Medicare reimbursements for a partial or complete vestibular function test battery

Table 3.

Pre-test and post-test probabilities of stroke using different tests to 'rule out' stroke in acute vestibular syndrome

	Post-Test probability of Stroke after a Negative Test Obtained within 24 Hours			
Pre-Test Probability of Stroke (vascular risk profile)	General Neuro Exam (Sn 18.8%,[21] Sp 95%, NLR 0.85)	CT Brain (Sn 19.2%, * Sp 98%,[97] NLR 0.84)	MRI-DWI Brain (Sn 80.0%,[22] Sp 96.0%,[97] NLR 0.21)	HINTS+ Battery (Sn 99.2%,[23] Sp 97.0%, NLR 0.01)
10% (low)	8.7%	8.4%	2.3%	0.1%
25% (average[22])	22.2%	21.6%	6.5%	0.3%
50% (high)	46.1%	45.2%	17.2%	0.8%
75% (very high)	71.9%	73.7%	38.5%	2.4%

* Sensitivity of CT brain for ischemic stroke is aggregated from four available studies (19.2%, n=88/459): Chalela et al. (16.0%, n=57/356, prospective),[97], Hwang et al. (41.8%, n=28/67, retrospective),[98] Ozono et al. (6.7%, n=1/15, prospective),[99] Kabra et al. (9.5%, n=2/21, retrospective).[100] The largest study by Chalela et al. included both supratentorial and infratentorial strokes. CT is less sensitive for identifying soft tissue lesions in the posterior cranial fossa for anatomical reasons, including beam hardening artifacts from the adjacent heavy bone of the skull base.[109] Therefore, the measured sensitivity in the Chalela study (16.0%[97]) is likely an overestimate. The study by Hwang et al. with the highest measured sensitivity (41.8%[98]) was likely an overestimate due to its retrospective nature, in which the decision to proceed to MRI was non-uniform, and only cases with MRI were considered.

Abbreviations: CT – computed tomography; HINTS+ – head impulse, nystagmus, test of skew, plus hearing; MRI-DWI – magnetic resonance imaging with diffusion weighted imaging; NLR – negative likelihood ratio; Sn – sensitivity; Sp – specificity

Table 4.

Current resource utilization for dizziness in US emergency departments and projected with routine VOG use

Resource Utilization for All, Unselected ED Dizziness and Vertigo	Current (2015 US National[1,173])	Projection with ED VOG Use
All ED Dizziness CT Rate	46.6%	4.7%
All ED Dizziness MRI Rate	2.7%	6.8%
All ED Dizziness Admission Rate	18.8%	17.2%
Total ED/Hospital Workup Costs	**$9,809,454,038**	**$8,735,803,281**
Annual US Healthcare Savings	-	**$1,073,650,757**

Abbreviations: ED – emergency department; US – United States; VOG – video-oculography

Adapted from Newman-Toker, et al., BMJ Quality & Safety, 2013[2]