Usability of the head impulse test in routine clinical practice in the emergency department to differentiate vestibular neuritis from stroke

Björn Machner1 | Kira Erber2 | Jin Hee Choi1 | Peter Trillenberg1 | Andreas Sprenger1 | Christoph Helmchen1

1Department of Neurology, University Hospitals Schleswig-Holstein, Campus Lübeck, Lübeck, Germany
2Department of Anesthesiology and Intensive Care, University Hospitals Schleswig-Holstein, Campus Lübeck, Lübeck, Germany

Correspondence
Björn Machner, Department of Neurology, University Hospitals Schleswig-Holstein, Campus Lübeck, Ratzeburger Allee 160, 23538 Lübeck, Germany.
Email: Bjoern.Machner@neuro.uniluebeck.de

Abstract

Background and purpose: The bedside head impulse test (bHIT) is used to differentiate vestibular neuritis (VN) from posterior circulation stroke (PCS) in patients presenting with acute vestibular syndrome (AVS). If assessed by neuro-otological experts, diagnostic accuracy is high. We report on its diagnostic accuracy when applied by nonexperts during routine clinical practice in the emergency department (ED), its impact on patient management, and the potential diagnostic yield of the video-oculography–supported head impulse test (vHIT).

Methods: Medical chart review of 38 AVS patients presenting to our university medical center’s ED, assessed by neurology residents. We collected bHIT results (abnormal/peripheral or normal/central) and whether patients were admitted to the stroke unit or general neurological ward. Final diagnosis (VN, n = 24; PCS, n = 14) was determined by clinical course, magnetic resonance imaging, and vHIT.

Results: The bHIT’s accuracy was only 58%. Its sensitivity for VN was high (88%), but due to many false-abnormal bHITs in PCS (36%), the specificity was low (64%). The vHIT yielded excellent specificity (100%) and moderate sensitivity (67%). The decision on the patient’s further care was almost arbitrary and independent from the bHIT: 58% of VN and 57% of PCS patients were admitted to the stroke unit.

Conclusions: The bHIT, applied by nonexperts during routine practice in the ED, has low accuracy, is too often mistaken as abnormal/peripheral, and is not consistently used for patients’ in-hospital triage. As false-abnormal bHITs can lead to misdiagnosis/mistreatment of stroke patients, we recommend that bHIT applied by nonexperts should be reassessed by a neuro-otological expert or preferably quantitative vHIT in the ED.

Keywords
dizziness, HINTS, stroke, vertigo, vestibulopathy

Abbreviations: AICA, anterior inferior cerebellar artery; AVS, acute vestibular syndrome; bHIT, bedside head impulse test; CI, confidence interval; DWI, diffusion-weighted imaging; ECG, electrocardiography; ED, emergency department; HINTS, head impulse, nystagmus, and test-of-skew; HIT, head impulse test; MRI, magnetic resonance imaging; PCS, posterior circulation stroke; vHIT, video-oculography–based head impulse test; VN, vestibular neuritis; VOR, vestibular ocular reflex.

See editorial by C. Froment Tilkietke on page 1437

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

© 2020 The Authors. European Journal of Neurology published by John Wiley & Sons Ltd on behalf of European Academy of Neurology
INTRODUCTION

Patients presenting to the emergency department (ED) with an acute vestibular syndrome (AVS), defined by sudden onset of vertigo or dizziness, nausea/vomiting, gait instability, and nystagmus, most often suffer from a peripheral unilateral vestibulopathy (e.g., vestibular neuritis [VNI]) [1]. However, about 25% of AVS cases are caused by a posterior circulation stroke (PCS) [2–6]. The diagnosis of PCS in AVS can be challenging [7], especially because early magnetic resonance imaging (MRI) can miss about 20% to 50% of posterior fossa infarctions [2,8]. In the first 24 to 48 h, the combined test of three eye-movement signs at the bedside (head impulse, nystagmus, and test-of-skew [HINTS]) even outperforms the MRI in differentiating peripheral from central causes of AVS [1]. Among these tests, the bedside head impulse test (bHIT) is the single best predictor for a stroke in AVS [2]. A bilaterally intact vestibular ocular reflex (VOR) without corrective saccades is found in 80% to 100% of AVS patients with PCS, if they are assessed by neuro-otological experts [9–11]. Vice versa, an abnormal bHIT result (i.e., reduced ipsilesional VOR with subsequent corrective saccade) usually indicates peripheral unilateral vestibulopathy and is found in 83% to 100% of acute VN patients [9–12]. Posterior circulation stroke only rarely causes a VOR deficit leading to abnormal bHIT, particularly if the anterior inferior cerebellar artery (AICA) is affected [4,13,14]. On the other hand, a mild peripheral vestibulopathy can be missed by the bHIT, because clinical detection depends on the severity of the VOR gain reduction and presence of overt large-amplitude corrective saccades [13,15].

If the bHIT is used in an emergency setting to distinguish VN from PCS in AVS patients, a general problem of clinical bedside tests arises; the reliability of the test depends on the individual skills of the examiner. The bHIT is technically demanding to perform, and its interpretation varies significantly with the expertise of the assessor, as previously reported for vestibular patients in a nonemergency setting [16–18]. Neuro-otological experts were shown to have lower sensitivity but higher specificity than nonexperts when stating an abnormal (peripheral) bHIT, mainly because they tend to rate borderline results as normal to avoid missing central pathology [16] This is in line with the high predictive value of a normal bHIT for PCS, if AVS patients are assessed by neuro-otological experts under controlled study conditions [1,9–12].

However, AVS patients present to the ED under real-life conditions (i.e., 24/7), during routine clinical practice, encountering different doctors at varying levels of clinical experience. In many healthcare systems, ED physicians decide on the management of AVS patients, and even if neurology or otolaryngology residents are present in the ED, they are usually not highly trained neuro-otological experts. Taking this into account, many questions arise. First, does the bHIT, when performed and interpreted by nonexperts during routine workup in the ED, still hold its diagnostic accuracy for differentiating VN from PCS in AVS patients? Second, do ED doctors rely on their bHIT result and use it for time-critical decisions on the patient’s further management? To specify, will AVS patients who reveal a normal bHIT in the ED correctly be suspected of PCS and consequently admitted to a stroke unit, and will those with an abnormal bHIT instead be classified as VN and sent to a usual-care ward? Whether an AVS patient is admitted (triaged) to the stroke unit or a general neurological ward, is medically (monitoring, thrombolytic, or antithrombotic therapy) and economically (costs, resources) relevant. Third, could an immediate video-oculography-based head impulse test (vHIT) improve diagnostic accuracy in the ED and thereby change the patient management? Some argue that a vHIT, which is able to quantify the VOR gain and uncover covert corrective saccades [19], could increase the sensitivity and specificity of the bHIT [17], whereas others doubt an additional diagnostic value [11].

In this retrospective study, we searched our in-house register [6] of 610 dizzy patients presenting to our university medical center’s ED for those who revealed AVS. We extracted the bHIT results obtained by neurology residents, analyzed the bHIT’s accuracy (in reference to the corresponding vHIT), its sensitivity, and specificity (in relation to the final diagnosis of VN or PCS), and the impact on patients’ in-hospital triage (i.e., whether they were admitted to the stroke unit or usual-care ward). We expected nonexperts in the ED to be less accurate and to misinterpret the bHIT too often as abnormal, going along with a reduced specificity for PCS due to false-abnormal peripheral bHITs in PCS patients. On the other hand, ED doctors trained to avoid missing a stroke might have a tendency to classify AVS patients as PCS and to ignore/distrust their own bHIT result, thereby causing unnecessary admissions of VN patients to the stroke unit. Given that, we expected the vHIT to have higher diagnostic accuracy than the bHIT and the potential to improve the in-hospital triage of AVS patients (electrocardiography for the eyes [17]).

METHODS

Study design and setting

Data were derived from an in-house register, originally compiled by reviewing medical charts of adult patients who presented with dizziness, vertigo, or imbalance to the ED at the University Medical Center in Lübeck, Germany between 1 January 2016 and 31 December 2018, and receiving neurological workup [6]. The ED at this tertiary-care university hospital encounters about 42,000 patients per year. It is staffed 24/7 with resident and attending internal medicine physicians as well as a neurology resident.

The study was approved by the ethics committee of the University of Lübeck (18-146A) and has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Due to the retrospective design and use of anonymized data, individual written informed consent was not needed.

Study population

Within the register, we searched for patients who met the following criteria defining an AVS: (i) new and persistent vertigo or dizziness,
(ii) instability of gait, and (iii) spontaneous nystagmus. We excluded patients (i) with onset of symptoms >72 h before admission to the ED, (ii) whose symptoms remitted in less than 24 h after admission, (iii) who did not undergo magnetic resonance brain imaging or video-based head impulse testing to confirm final diagnosis (to avoid misdiagnosis), (iv) with diagnosis of an inflammatory disease of the central nervous system, because focus was on PCS as the most common central cause of AVS, and (v) patients with an unclear AVS who did not meet the diagnostic criteria of VN or PCS (see Diagnostic Classification section).

**Bedside head impulse test and other clinical measures**

The bHIT result was extracted from the documentation of the resident’s neurological examination in the ED. It was operationalized as either abnormal (peripheral) or normal (central). We also extracted information on the other two HINTS signs, namely, whether the nystagmus’ fast phase alternated with gaze (bilateral gaze-evoked nystagmus) and whether a skew deviation (vertical misalignment of bulbi) was observed. Finally, we collected information on any focal neurological abnormality such as dysarthria, Horner’s syndrome, unilateral facial weakness, limb ataxia, or sensory impairments. Notably, major deficits such as aphasia/anarthria or hemiparesis were exclusion criteria during the compilation.

**Video-oculography device, performance, and analysis of vHIT**

The vHIT was recorded using the EyeSeeCam HIT System (Autronics, Hamburg, Germany), a head-mounted video-oculography device [20]. The patient was seated on a chair and fixated on a laser target at a distance of 100 cm. After calibration, a medical-technical assistant standing behind the patient delivered repetitive passive and rapid head rotations (peak velocity: 200–250°/s, amplitude: 10–15°) in the plane of the horizontal semicircular canals. HITs were unpredictable for direction and onset. The device recorded head and eye velocity traces and immediately calculated and plotted the VOR gain ratio for each head impulse test (HIT) trial.

Although grossly invalid HIT trials were already rejected by the device’s software during recording, all vHITs were reassessed offline by three neuro-otological experts (B.M., P.T., C.H.). They classified each vHIT as either interpretable or uninterpretable due to severe disruptive artifacts. Only interpretable vHITs were included in the further analyses.

From the device’s software we exported the patient’s mean VOR gain across all trials for each side (ipsilesional, contralesional) at a specific time interval (60 ms after HIT onset) [20,21]. We calculated the left-right asymmetry of the VOR gain using a previously suggested formula [9,17]: (higher gain–lower gain)/higher gain * 100.

Finally, one algorithm-based vHIT result (abnormal or normal) was obtained for each patient. The algorithm judged the VOR as abnormal if the ipsilesional VOR gain was equal to or below 0.7 and as normal if both VOR gain values were above this threshold. This simple cutoff criterion of a pathological VOR gain was based on previous calculations of mean VOR gains in healthy subjects [19,22], it was shown to correctly distinguish 80% to 90% of PCS from VN patients and has good overlap with vHIT judgements by neuro-otological experts [9,17].

**Imaging parameters**

All patients included in the final analysis underwent magnetic resonance brain imaging, including diffusion-weighted imaging (DWI) sequences. The results of the studies, either a DWI lesion in the cerebellum or brainstem (medulla oblongata, pons, mesencephalon) or no DWI lesion, were abstracted from the official neuroradiological reports and double-checked by a clinical neurologist and stroke expert (B.M.).

**Diagnostic classification**

Diagnosis of VN required the following criteria: (i) presence of spontaneous nystagmus, (ii) abnormal clinical bHIT and/or vHIT, (iii) normal MRI-DWI, and (iv) no skew deviation or clear focal neurological abnormality. Diagnosis of PCS required an acute ischemic lesion in the brainstem or cerebellum as confirmed by MRI-DWI.

**Statistical analysis**

Statistical analyses were performed using SPSS 22.0.0.2 (IBM, Armonk, NY, USA). Descriptive statistics were calculated for all variables of interest, and data are presented as counts and percentages. Differences between the groups (VN, PCS) were statistically compared using t tests for quantitative variables or Pearson χ² test for categorical variables. Comparisons of sensitivity/specificity between the two HIT methods were performed using McNemar test for paired samples, applying Yates continuity correction [23]. The significance level was set at p < 0.05.

**RESULTS**

**Selection and clinical characteristics (including bHIT) of VN and PCS patients**

Of 610 patients, 193 met the inclusion criteria defining AVS (Figure 1). After exclusion of 155 patients due to predefined criteria (see Methods section), 38 patients went into the final analysis, 24 of whom had VN and 14 PCS.
The individual clinical characteristics for each patient are provided in Table S1. The between-group comparisons (Table 1) revealed that VN patients were slightly older than PCS patients ($d = 10 \pm 4$ years, $p = 0.034$). PCS patients more often exhibited a normal bHIT, positive HINTS, and focal neurological abnormalities (Table 1). The percentage of patients admitted to the stroke unit due to suspected stroke did not differ between VN (58%) and PCS (57%).

The majority (11 of 14) of VN patients, who were misdiagnosed as PCS and admitted to the stroke unit, showed an abnormal (peripheral) bHIT result in the ED. Only two of them exhibited mild focal abnormalities (facial hypesthesia, discrete ataxia on pointing). Five of the six PCS patients, who were initially misdiagnosed as VN and not admitted to the stroke unit, exhibited a normal bHIT in the ED.

Mean VOR gains and accuracy of clinical bHIT in relation to the vHIT

The vHIT was usually performed within 24 h after admission (median = 1 day, 95% confidence interval [CI]: 0–3 days). The vHIT was interpretable in all of the included subjects (i.e., 24 VN and 14 PCS patients). Mean VOR gain values differed significantly between VN and PCS patients (Table 2). Both ipsilesional and contralesional mean VOR gain values were lower in VN than in PCS, but the difference was particularly prominent for the ipsilesional VOR gain ($d = 0.43 \pm 0.09$; vs. $d = 0.21 \pm 0.06$ for contralesional VOR gain). The gain asymmetry was greater in VN than in PCS ($d = 24 \pm 7\%$, $p = 0.001$).

Regarding the accuracy of the bHIT, we compared the bHIT result from the examination in the ED to the corresponding vHIT result, independent of the final clinical diagnosis. Taking the vHIT as reference is adequate because vHIT-derived VOR results are highly congruent to VOR measurements with scleral search coils defining the technical gold standard [19].

The bHIT and vHIT were congruent in 22 of 38 patients (58%), and both revealed an equally abnormal ($n = 13$) or normal ($n = 9$) result. In 16 patients (42%), the bHIT differed from the vHIT, with $n = 3$ (8%) having a normal bHIT but abnormal vHIT and $n = 13$ (34%) having an abnormal bHIT but normal vHIT.

A within-group analysis revealed that all the PCS patients with an abnormal bHIT ($n = 5$) eventually had a normal vHIT.

Sensitivity and specificity of bHIT versus vHIT for distinguishing VN and PCS

We related the individual result from (i) the bHIT assessment in the ED and (ii) the algorithm-based vHIT judgement to the patient’s final
diagnosis (VN or PCS). Each test’s sensitivity was determined by calculating the percentage of VN patients with an abnormal/peripheral HIT result among all VN patients. The specificity was determined by analyzing the percentage of PCS patients with a normal HIT result among all PCS patients.

Sensitivity was 88% (n = 21 of 24; 95% CI: 73%–100%) for the bHIT and 67% (n = 16 of 24; 95% CI: 46%–85%) for the vHIT (Figure 2). Specificity was 64% (n = 9 of 14; 95% CI: 39%–88%) for the bHIT and 100% (n = 14 of 14; 95% CI: 100%–100%) for the vHIT. The sensitivity did not differ between bHIT and vHIT (p = 0.227). However, the vHIT had higher specificity than the bHIT (p = 0.044).

**DISCUSSION**

**Accuracy of nonexperts’ bHIT in the ED**

The accuracy of the bHIT, when performed by nonexperts during routine clinical practice in the ED, is by far not as high as when it is assessed by neuro-otological experts under controlled conditions [9–11]. Only 58% of the bHIT results could be confirmed in the subsequent quantitative vHIT. This finding has important implications, especially with regard to the relatively high number (36%) of false-positive bHITs in PCS patients. Assigning an abnormal bHIT to a patient with normal vHIT represents a false-positive result that can lead to a dangerous false-benign misdiagnosis (VN in a patient with PCS). Moreover, the bHIT is the most important compound of the HINTS triad, which usually detects 96% to 100% of strokes in AVS patients, given that they are assessed by neuro-otological experts [1,24]. If the bHIT is erroneously rated as abnormal, the HINTS may falsely be counted as negative, and their sensitivity for stroke decreases. This is underlined by the lower percentage (79%) of HINTS-positive PCS patients in our study.

That nonexperts have the tendency to rate the bHIT as abnormal, especially if VOR gains are at borderline values that experts
would still assess as normal, is in line with previous findings in non-
acute vestibular outpatients [16]. Similar to the latter study, nonex-
perats revealed high sensitivity (88%) for VN but at the cost of low
specificity (64%), reflected by many false-abnormal bHITs in PCS.
Although this may constitute only a minor problem in an elective
outpatient visit, it represents a major fault in the emergency setting
where a stroke must not be missed, as early treatment and monitor-
ing is mandatory [25,26].

The examiner’s level of experience may be one reason for re-
duced bHIT accuracy [16]. Furthermore, a strong spontaneous
nystagmus in the acute stage of an AVS may hamper correct bHIT as-
essment [19]. Nonetheless, 36% of PCS patients in our study were
falsely assigned an abnormal bHIT in the ED, which provided the
grounds for misdiagnosis. Surprisingly, nearly all the PCS patients,
who were initially misdiagnosed as VN and not admitted to the
stroke unit, revealed a normal bHIT in the ED, and thereby positive
HINTS, which usually should have been recognized as a red flag for
central pathology. This leads us to the question whether ED doctors
actually rely on their own bHIT result and how this influences the
further patient management in the hospital.

Reliance on the bHIT for clinical decision making

Our data indicate that doctors in the ED did not rely on their own
bHIT result. In 14 VN patients, who were initially misdiagnosed
as PCS and admitted to the stroke unit, 11 had an abnormal (pe-
ipheral) bHIT result in the ED. Only two of these VN patients had
mild focal symptoms that could potentially be regarded as central
signs indicating PCS. Hence, the majority of VN patients admitted
to the stroke unit clinically presented with an isolated peripheral
AVS that did not justify monitoring on a stroke unit. As mentioned
above, five of six PCS patients, who were falsely suspected of VN
and admitted to the general neurological ward, revealed a normal
(central) bHIT result in the ED. Thus, residents in the ED did not
take their own bHIT result into account when deciding on the pa-
tient’s in-hospital triage. This may be due to distrust in their own
clinical skills, lack of knowledge about peripheral/central signs in
AVS, or a systematic bias in the ED to suspect stroke in AVS. The
latter may also be related to time pressure in the ED, economic
reimbursement considerations, and the fear of making a misdiag-
nosis (i.e., missing a stroke) with harmful consequences. However,
that 58% of AVS patients were admitted to the stroke unit is in
clear contrast to the 37% of patients having PCS and to the fact
that the majority of AVS patients usually have a benign unilateral
peripheral vestibulopathy [2,4,5,9,11].

Interestingly, if residents in the ED would have completely re-
lied on their own—though sometimes inaccurate—bHIT result, their
diagnostic assignment and patient management would have been
better than their actual performance. If applying the bHIT as a sin-
gle classifier, only 36% instead of 43% of PCS patients would have
been misdiagnosed, and only 12% versus 58% of VN patients would
have been unnecessarily monitored in the stroke unit. We admit that
such an approach would misclassify PCS patients with a truly ab-
normal bHIT, that is, AICA strokes that collaterally damage the inner
ear due to occlusion of the labyrinthine artery causing a mixed cen-
tral-peripheral pathology [4,13,14]. However, these cases are gen-
erally rare, and none of the 14 PCS patients in our study exhibited
a severe ipsilesional VOR deficit that would have led to diagnostic
misclassification.

Diagnostic value of vHIT devices

Could a vHIT device, allowing quantitative VOR gain assessment,
 improve diagnosis and management of AVS patients in the ED?
This is currently under investigation in two prospective clinical tri-
als (NCT02483429 by Newman-Toker and collaborators; U1111-
1172-8719 [27]). Data of our retrospective study suggest that an
immediate vHIT could support the diagnostic distinction between
VN and PCS [9,17] and also improve patient management (e.g., in-
hospital triage of AVS patients). Particularly, the vHIT’s specific-
itly was excellent (100%) and significantly higher than the bHIT’s.
For the ED setting, the specificity is certainly the more relevant
parameter because it describes the percentage of PCS patients
correctly identified by the test (normal HIT). Even not taking the
remaining HINTS, central oculomotor disorders, and focal abnor-
malities into account, our simple algorithm-based vHIT correctly
identified 100% of PCS patients and 67% of VN patients. In an-
other study that used a different video-oculography device but
comparable algorithm, the vHIT correctly classified 88% of PCS
and 92% of VN patients [9].

Hence, if a vHIT would be immediately available in the ED, such
as ECG [17], to support the clinician’s decision, 88% to 100% of PCS
patients could be correctly identified and adequately treated on the
stroke unit, whereas only 8% to 33% of VN patients would be falsely
classified as PCS and unnecessarily admitted to the stroke unit. This
points to an additional diagnostic value of the vHIT, compared to the
bHIT, that is usually assessed by doctors with limited neuro-otologi-
cal expertise in the ED. Hence, implementation of a vHIT in the ED is
likely to reduce the number of missed strokes and the number of VN
patients who are unnecessarily admitted to stroke units. Moreover,
the vHIT could help to teach and reassure nonexpert residents in
the ED to improve their bHIT’s accuracy and learn to rely on their
clinical skills. Only in expert centers, the clinical bHIT may be as sim-
ilarly reliable and precise as the vHIT in differentiating PCS from VN
[9,10,17], and in those situations a vHIT may not have additional di-
agnostic yield [11].

CONCLUSION

Our findings indicate that under routine conditions in the ED, the
bHIT in AVS patients has low accuracy, is too often interpreted as
abnormal, and only of limited impact on further patient management
(e.g., stroke unit admission). We recommend that an abnormal bHIT
in the ED should be carefully reassessed by a neuro-otological expert, or preferably by vHIT, before making the diagnosis of a unilateral peripheral vestibulopathy and potentially missing a stroke. In addition to an improvement in diagnosis and the patient’s in-hospital triage, this could also help to increase ED the physician’s skills and trust in the clinical bHIT. Even if neuro-otological expertise is limited, we encourage ED clinicians to perform the bHIT and use it for diagnosis and clinical decision making in AVS patients, as we could show that taking a less accurate bHIT into account is better than completely ignoring it.

CONFLICT OF INTEREST
The authors declare that they have no conflicts of interest.

AUTHOR CONTRIBUTIONS
Björn Machner: conceptualization (lead), data curation (lead), formal analysis (lead), funding acquisition (lead), investigation (lead), methodology (lead), project administration (lead), resources (equal), software (equal), visualization (equal), writing original draft (lead). Kira Erber: data curation (equal), formal analysis (equal), visualization (equal), writing review editing (supporting). Jin Hee Choi: data curation (equal), formal analysis (supporting), project administration (supporting), writing review editing (supporting). Peter Trillenberg: conceptualization (supporting), methodology (supporting), writing review editing (supporting). Andreas Sprenger: data curation (equal), formal analysis (equal), software (equal), visualization (equal), writing review editing (equal). Christoph Helmchen: conceptualization (equal), methodology (equal), resources (equal), supervision (lead), writing review editing (lead).

ETHICAL APPROVAL
The study was approved by the ethics committee of the University of Lübeck (18-146A) and has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID
Björn Machner https://orcid.org/0000-0001-7981-2906
Peter Trillenberg https://orcid.org/0000-0002-3434-0295

REFERENCES
1. 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. 2008;83:765-775.
2. Lee SH, Kim JS. Acute diagnosis and management of stroke presenting dizziness or Vertigo. Neurol Clin. 2015;33:687-698, xi.
3. Choi JH, Park MG, Choi SY, et al. Acute transient vestibular syndrome: prevalence of stroke and efficacy of bedside evaluation. Stroke. 2017;48:556-562.
4. Machner B, Choi JH, Trillenberg P, Heide W, Helmchen C. Risk of acute brain lesions in dizzy patients presenting to the emergency room: who needs imaging and who does not? J Neurol. 2020;267:126–135.
5. Royl G, Ploner CJ, Leithner C. Dizziness in the emergency room: diagnoses and misdiagnoses. Eur Neurol. 2011;66:256-263.
6. Saber Tehrani AS, Kattah JC, Mantokoudis G, et al. Small strokes causing severe vertigo: frequency of false-negative MRIs and non-lacunar mechanisms. Neurology. 2014;83:169-173.
7. Mantokoudis G, Tehrani ASS, Wozniak A, et al. VOR gain by head impulse video-oculography differentiates acute vestibular neuritis from stroke. Otol Neurotol. 2015;36:457-465.
8. Newman-Toker DE, Kattah JC, Alvernia JE, Wang DZ. Normal head impulse test differentiates acute cerebellar strokes from vestibular neuritis. Neurology. 2008;70:2378-2385.
9. Guler A, Karbek Akarca F, Eraslan C, et al. Clinical and video head impulse test in the diagnosis of posterior circulation stroke presenting as acute vestibular syndrome in the emergency department. J Vestib Res. 2017;27:233-242.
10. Cnyrim CD, Newman-Toker D, Karch C, Brandt T, Strupp M. Bedside differentiation of vestibular neuritis from central ‘vestibular pseudoneuritis’. J Neuro Neurosurg Psychiatry. 2008;79:458-460.
11. Chen L, Todd M, Halmagyi GM, Aw S. Head impulse gain and saccade analysis in pontine-cerebellar stroke and vestibular neuritis. Neurology. 2014;83:1513-1522.
12. Choi SY, Kee HJ, Park JH, Kim HJ, Kim JS. Combined peripheral and central vestibulopathy. J Vestib Res. 2014;24:443-451.
13. Yip CW, Glaser M, Frenzel C, Bayer O, Strupp M. Comparison of the bedside head-impulse test with the video head-impulse test in a clinical practice setting: a prospective study of 500 outpatients. Front Neurol. 2016;7:58.
14. Jorns-Haderli M, Straumann D, Palla A. Accuracy of the bedside head impulse test in detecting vestibular hypofunction. J Neurol Neurosurg Psychiatry. 2007;78:1113-1118.
15. 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. 2013;44:1158-1161.
16. Helmchen C, Knauss J, Trillenberg P, Brendl A, Sprenger A. Role of the patient’s history of vestibular symptoms in the clinical evaluation of the bedside head-impulse test. Front Neurol. 2017;8:51.
17. MacDougall HG, Weber KP, McGarvie LA, Halmagyi GM, Curthoys IS. The video head impulse test: diagnostic accuracy in peripheral vestibulopathy. Neurology. 2009;73:1134-1141.
18. Bartl K, Lehnen N, Kohlbecher S, Schneider E. Head impulse testing using video-oculography. Ann Acad Med. 2009;1164:331-333.
19. Zamaro E, Tehrani AS, Kattah JC, et al. VOR gain calculation methods in video head impulse recordings. J Vestib Res. 2020;30(4):225-234.
20. McGarvie LA, MacDougall HG, Halmagyi GM, Burgess AM, Weber KP, Curthoys IS. The video head impulse test (vHIT) of semicircular canal function - age-dependent normative values of VOR gain in healthy subjects. Front Neurol. 2015;6:154.
21. Yates F. Contingency tables involving small numbers and the χ2 test. Suppl J Roy Stat Soc. 1934;1:217-235.
22. 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. 2013;20:986-996.
23. Machner B, Choi JH, Neumann A, Trillenberg P, Helmchen C. What guides decision-making on intravenous thrombolysis in acute vestibular
syndrome and suspected ischemic stroke in the posterior circulation? *J Neurol.* 2020. https://doi.org/10.1007/s00415-020-10134-9

26. Newman-Toker DE. Missed stroke in acute vertigo and dizziness: it is time for action, not debate. *Ann Neurol.* 2016;79:27-31.

27. Mohwald K, Bardins S, Muller HH, Jahn K, Zwergal A. Protocol for a prospective interventional trial to develop a diagnostic index test for stroke as a cause of vertigo, dizziness and imbalance in the emergency room (EMVERT study). *BMJ Open.* 2017;7:e019073.

**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section.