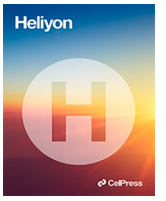
Heliyon 10 (2024) e38532

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

R-cVR, a two-step bedside algorithm for the differential diagnosis of acute dizziness and vertigo

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ARTICLE INFO

Keywords:
Acute dizziness or vertigo
Postural balance
Bedside examination
Differential diagnosis
R-cVR algorithm

ABSTRACT

Background: The ability to quickly and accurately differentiate between peripheral and central dizziness or vertigo is vital. We developed the R-cVR algorithm for the early identification of central-type dizziness or vertigo.

Methods: In this single-center, retrospective cohort study, we assessed patients with isolated dizziness or vertigo between December 10, 2023, and February 28, 2024. Classification into central or peripheral types was based on magnetic resonance imaging (MRI)-diffusion-weighted imaging (DWI) results. We reevaluated the diagnostic value of the Romberg test for acute dizziness or vertigo by quantifying the duration of standing and created the R-cVR algorithm. The algorithm's accuracy was subsequently validated against the MRI-DWI results.

Results: After screening, 109 patients were recruited and divided into central ($n = 25$) and peripheral ($n = 84$) groups. The central group had a high incidence of cerebral infarction (88.0 %), whereas the peripheral group included patients with vestibular neuronitis, benign paroxysmal positional vertigo, and Meniere's disease (96.4 %). Significant disparities in the incidence of balance disorders were noted between the groups (92.0 % vs. 15.5 %, $p < 0.001$). Multivariate logistic regression revealed an odds ratio of 61.82 for balance disorders ($p < 0.001$). The R-cVR algorithm, which integrates the Romberg test and the V-shaped stance with closed-eyes protocol, was tested against MRI-DWI and yielded high diagnostic agreement (kappa = 0.80), with a sensitivity and specificity of 88.0 % and 94.0 %, respectively. There was no significant difference in the diagnostic efficacy of this algorithm for acute dizziness or vertigo with or without nystagmus.

Conclusion: The R-cVR algorithm effectively identifies central-type dizziness or vertigo and is simple for general practitioners to use without specialized equipment, which may be valuable in various clinical settings.

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https://doi.org/10.1016/j.heliyon.2024.e38532
Received 11 March 2024; Received in revised form 23 August 2024; Accepted 25 September 2024
Available online 26 September 2024

1. Introduction

Acute dizziness or vertigo is a common complaint among patients in the emergency department (ED) [1,2]. Approximately 2.1 %–3.6 % of ED patients exhibit symptoms of vertigo [1,3,4]. Diagnosing dizziness or vertigo can be a complex task due to its diverse underlying causes, which complicate accurate identification [5]. Benign conditions such as benign paroxysmal positional vertigo (BPPV) or vestibular neuronitis (VN) are frequently responsible for dizziness or vertigo, accounting for 24–43 % of cases [2,6]. However, recognizing the potential presence of potentially dangerous brain diseases, such as acute cerebral infarction, is essential [2,7,8]. Approximately 5 % of stroke patients can present with symptoms resembling BPPV, and 25 % of patients can present with symptoms mimicking VN [9–12]. For patients with accompanying focal neurological signs (such as hemiplegia and hemisensory disturbances), diagnosing central lesions is not difficult; the challenge arises when diagnosing isolated dizziness or vertigo. Prompt and precise identification and management of central-type dizziness or vertigo are imperative for preventing severe outcomes.

In recent years, several bedside diagnostic methods that can effectively distinguish between peripheral-type and central-type vertigo have emerged, providing clinical doctors with new diagnostic approaches [13,14]. The head impulse test, nystagmus assessment, test of skew, and hearing assessment (HINTS+) and the spontaneous nystagmus, direction, head impulse test, and standing (STANDING) protocols are bedside examination methods that deserve attention [2,14]. The findings of these protocols suggest that distinguishing central-type dizziness or vertigo through physical examination is feasible. However, both approaches were also found to be less effective in identifying patients without nystagmus.

Through our observation of the diagnosis and management of patients with isolated dizziness or vertigo, we noted that patients often exhibit a spectrum of postural instability. Many previous studies have reported a correlation between trunk/gait ataxia and central vertigo [14–17]. Gait ataxia is present in up to 95.6 % of patients with posterior circulation strokes [18], indicating the potential diagnostic value of assessing postural instability in the diagnosis of central-type dizziness or vertigo. However, the efficacy of truncal ataxia in diagnosing vertigo disorders using a hierarchical stratification scheme is low [15]. Considering the simplicity and accessibility of this type of test protocol, improving the efficacy of these tests would be more useful for emergency physicians treating patients with dizziness or vertigo. Therefore, we reevaluated the Romberg test in a quantitative manner, and we subsequently designed a new algorithm to improve the test's diagnostic value and aid in the early identification of central dizziness or vertigo.

2. Materials and methods

2.1. Study participants

This investigation was a single-center, retrospective cohort study meticulously executed by the research team. This study was observational in nature and did not involve any intervention in the patients' routine diagnostic or treatment activities. Based on the

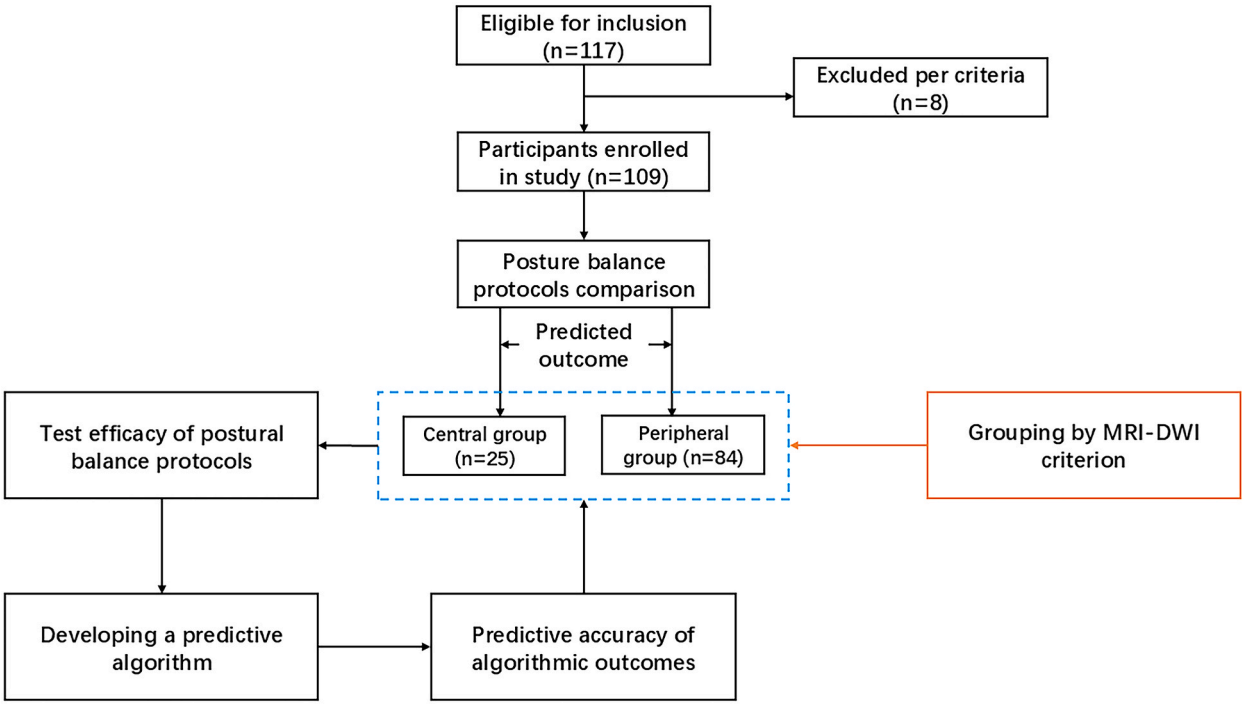

Fig. 1. Flowchart. Abbreviations: MRI-DWI = magnetic resonance imaging-diffusion-weighted imaging.

sample size of the HINTS study [19], we planned to enroll no fewer than 100 patients. We searched our Dizziness Center database for patients with isolated dizziness or vertigo admitted between December 10, 2023, and February 28, 2024. "Isolated dizziness or vertigo" was defined by the criteria of Edlow et al. (2023) [3]: dizziness or vertigo with no focal symptoms other than those related to vestibular dysfunction, such as malaise, nausea, vomiting, nystagmus, and postural instability. The inclusion criterion was patients with isolated dizziness or vertigo who were admitted within one week of symptom onset. The exclusion criteria were as follows: 1. patients with acute critical conditions other than dizziness or vertigo; 2. patients with a history of limb weakness, inability to stand, or advanced systemic chronic illnesses or complications (e.g., chronic kidney disease with a glomerular filtration rate [GFR] less than 30 ml/min; diabetes with a hemoglobin A1c [HbA1c] level greater than 7 %; and hematologic disorders indicated by abnormal counts of red blood cells, platelets, and white blood cells in routine blood tests); 3. patients with dizziness or vertigo that may also be caused by other diseases (such as anemia, hyperthyroidism, fever, or hypotension); and 4. patients who did not have magnetic resonance imaging-diffusion-weighted imaging (MRI-DWI) results or who were unable to cooperate with physical examinations. The enrollment process is depicted in Fig. 1.

2.2. Management strategies

Patients presenting with acute dizziness or vertigo at the Dizziness Center are routinely subjected to a comprehensive evaluation, encompassing a thorough anamnesis, a specialist neurological examination, a postural balance assessment, MRI-DWI and cerebral arterial imaging, vestibular function tests, ophthalmoscopic electromyography, routine blood biochemistry, and other relevant assessments.

To reduce information bias, the data in our database were obtained from exams conducted by a designated neurologist with the rank of associate chief. Additionally, an independent assessment of the outcomes was performed by another neurologist of the same rank. Disagreements were resolved by a senior neurologist. For patients with hearing loss or related symptoms, an otolaryngologist was consulted. Patients were categorized into central and peripheral groups on the basis of their MRI-DWI results. These evaluations did not disrupt patients' standard diagnostic and treatment routines.

2.3. Assessment of standing posture

We designed the following posture balance protocols based on the Romberg test (standing with both feet together) [20]. The tests included the Romberg test with open eyes (RO) and closed eyes (RC) and standing with heels together and toes slightly apart, forming a "V" shape, with open eyes (VO) and closed eyes (VC). For each protocol, the participants were observed for 10 s, and the longest standing maintenance time for each protocol was recorded. Patients who demonstrated standing stability for more than 10 s were recorded as 10 s and considered to have adequate balance. If the patient was unable to stand, the standing time was recorded as 0 s. These protocols were carefully filtered and restructured to create a novel algorithm, which was subsequently evaluated for its diagnostic accuracy against the results obtained from MRI-DWI.

2.4. Neuroimaging

All study participants underwent a brain MRI scan within 72 h after admission. The hospital's standard MRI protocol, conducted with a 1.5-T General Electric Superconductive Magnet, included T1- and T2-weighted, fluid-attenuated inversion recovery (FLAIR), and DWI sequences (Philips, Netherlands).

2.5. Statistical analysis

First, the Shapiro–Wilk test was used to evaluate the distribution of continuous variables. The findings are reported as the mean (± standard deviation [SD]) for normally distributed data or the median (interquartile range [IQR]) for nonnormally distributed data. Comparative analyses were conducted using Student's *t*-test for normally distributed variables and the Wilcoxon test for nonnormally distributed variables, as appropriate. Categorical variables are represented as frequencies (%), and comparisons were performed using the chi-square test or Fisher's exact test, as dictated by the data's distribution and expected frequencies. To determine whether postural balance serves as an independent predictor of central-type dizziness or vertigo, a multivariate logistic regression model was constructed that incorporated all variables that were found to be statistically significant ($p < 0.05$) in the univariate analysis and could affect central-type dizziness or vertigo. The diagnostic efficacy of the predictive model was gauged through the receiver operating characteristic (ROC) curve, with the area under the ROC curve (AUC) serving as a quantitative measure. Cohen's kappa value was used to evaluate the accuracy of the diagnostic algorithm for predicting patient outcome. All the statistical analyses were conducted using SPSS software version 26 for Windows (SPSS, IBM, Inc., USA), and graphical representations of the statistical data were generated with GraphPad Prism version 10 for Windows (GraphPad Software, LLC, USA).

3. Results

3.1. Overview of the clinical characteristics of patients with dizziness or vertigo

Upon querying our database, we identified 117 patients who met our inclusion criteria (Fig. 1). Initial screening led to the exclusion

of 8 patients for the following reasons: chronic leukemia (1), immune thrombocytopenia (1), uremia (1), chronic pineal tumor with hydrocephalus (1), noncooperation during physical examination (2), fever (1), or left lower limb pain (1). A total of 109 patients were eligible for enrollment in the study. MRI-DWI results facilitated the classification of patients into two groups: central (n = 25) and peripheral (n = 84).

A summary of the general clinical characteristics of the patients is presented in Table 1. We focused particularly on the influence of common stroke risk factors such as hypertension, diabetes status, heart disease status, and smoking status, among others [21], on central-type dizziness or vertigo, as well as disparities in primary clinical symptoms between the central and peripheral groups. Significant differences were observed between the central and peripheral groups for several variables, including average age, hypertension status, diabetes status, balance disorders, and average hospital stay ($p < 0.05$). The central group primarily included cerebral infarction patients (88.0 %). Among these patients, 63.6 % of infarctions were confined to the posterior circulation blood supply region, 22.7 % were confined to the anterior circulation blood supply region, and 13.6 % had multiple sites of involvement. In the

Table 1
General clinical characteristics of the enrolled patients.

	All patients (n = 109)	Central group (n = 25)	Peripheral group (n = 84)	*p* value*
General characteristics				
Age (years)	62.4 (±13.0)	68.0 (±11.2)	60.7 (±13.1)	0.013
Sex, female (n%)	64 (58.7)	14 (56.0)	50 (59.5)	0.753
Patient history				
Hypertension	44 (40.4)	18 (72.0)	26 (31.0)	<0.001
Coronary heart disease	13 (11.9)	3 (12.0)	10 (11.9)	1.000
Atrial fibrillation	6 (5.5)	3 (12.0)	3 (3.6)	0.262
Diabetes	23 (21.1)	10 (40.0)	13 (15.5)	0.008
Smoking	15 (13.8)	5 (20.0)	10 (11.9)	0.483
Alcoholism	4 (3.7)	1 (4.0)	3 (3.6)	1.000
Onset to exam (days)[a]	3.0 (1.0–6.5)	4.0 (2.0–7.0)	3.0 (1.0–5.5)	0.094
Clinical symptoms				
Headache	7 (6.4)	2 (8.0)	5 (6.0)	1.000
Neck pain	2 (1.8)	1 (4.0)	1 (1.2)	0.408
Visual spinning	46 (42.2)	11 (44.0)	35 (41.7)	0.836
Nausea	50 (45.9)	10 (40.0)	40 (47.6)	0.502
Vomiting	39 (35.8)	7 (28.0)	32 (38.1)	0.355
Hearing loss	4 (3.7)	0 (0.0)	4 (4.8)	0.572
Tinnitus	15 (13.8)	4 (16.0)	11 (13.1)	0.969
Balance disorder[b]	36 (33.0)	23 (92.0)	13 (15.5)	<0.001
Spontaneous nystagmus	42 (38.5)	11 (44.0)	31 (36.9)	0.522
Induced nystagmus	13 (11.9)	0 (0.0)	13 (15.5)	0.081
Auxiliary examination				
Systolic BP upon admission (mmHg)	142.1 (±21.7)	146.68 (±14.3)	140.71 (±23.2)	0.124
Diastolic BP upon admission (mmHg)	82.4 (±10.7)	84.5 (±10.7)	81.8 (±10.7)	0.264
Carotid ultrasound plaque thickness (mm)[a]	2.0 (1.4–2.8)	2.3 (1.5–2.8)	2.0 (1.1–2.8)	0.359
Diagnosis				
Cerebral infarction		22 (88.0)		
Cerebral tumor		1 (4.0)		
Cerebral trauma		1 (4.0)		
Cerebellum atrophy		1 (4.0)		
VN			48 (57.1)	
BPPV			13 (15.5)	
Meniere's disease			20 (23.8)	
Sudden deafness			2 (2.4)	
Subjective dizziness			1 (1.2)	
Stroke location (n = 22)				
SCA		1 (4.5)		
AICA		1 (4.5)		
PICA		8 (36.4)		
MCA		2 (9.1)		
PCA		4 (18.2)		
ACA		3 (13.6)		
Multiple infarct locations		3 (13.6)		
Hospital stay (days)[a]	7.0 (4.0–9.0)	9.0 (7.0–11.0)	6.0 (3.5–8.0)	<0.001

Note: The data are presented as counts (%), means (±SD), or medians (IQRs). *p* values for dichotomous variables were calculated using chi-square tests or Fisher's exact tests. *p* values for continuous variables were computed using the Wilcoxon rank-sum test or Student's *t*-test.
Abbreviations: BP = blood pressure; BPPV = benign paroxysmal positional vertigo; VN = vestibular neuritis; MRI = magnetic resonance imaging; SD = standard deviation; IQR = interquartile range. SCA = superior cerebellar artery; AICA = anterior inferior cerebellar artery; PICA = posterior inferior cerebellar artery; MCA = middle cerebral artery; PCA = posterior cerebral artery; ACA = anterior choroidal artery.
**p* value for the central group vs. the peripheral group.
[a] The data were subjected to the Shapiro–Wilk test for normality, and the results were nonnormally distributed.
[b] A balance disorder was defined as the inability to stand for 10 s.

peripheral group, the predominant conditions were VN, BPPV and Meniere's disease (96.4 %), which are also common reasons for hospitalization in patients presenting with dizziness or vertigo.

3.2. Balance disorder as a predictor

The indicators significantly associated with an increased risk of developing central dizziness or vertigo according to univariate analyses were included in a multifactorial logistic regression analysis, as was the indicator of balance disorder (Table 2). The odds ratio (OR) for balance disorders was 61.82 (95 % confidence interval [CI]: 11.02–346.83), with a p value < 0.001, indicating that patients with balance disorders were approximately 61.82 times more likely to have central dizziness or vertigo than patients without balance disorders were. These results suggested that balance disorders are an independent predictor of central dizziness or vertigo.

3.3. Investigation of postural balance assessment protocols

The diagnostic utility of various postural balance protocols for differentiating central from peripheral dizziness or vertigo was investigated through ROC curve analysis (Fig. 2A) and the corresponding AUC values (Table 3). All postural assessment protocols were effective at differentiating between central and peripheral dizziness or vertigo, with a significance level of $p < 0.001$. The RO protocol had the largest AUC (0.91), which suggested that this protocol had the highest diagnostic efficacy among these protocols.

After further assessment of the predictive value of the RO protocol for identifying center-type dizziness or vertigo (Table 4), the highest diagnostic efficacy was achieved when the Youden index was 0.765. This peak efficacy corresponded to a standing maintenance time of 9.5 s, with a sensitivity of 92.0 % and a specificity of 84.5 %. As the duration of standing maintenance decreased, the specificity of the test protocol gradually increased, whereas the sensitivity gradually decreased. When the standing maintenance time was less than 3.5 s, the specificity was greater than 95 %.

For patients with a standing maintenance time of 3.5–9.5 s, we determined that additional examination methods were needed to compensate for the insufficient diagnostic specificity of the RO protocol. The data of patients who had stood for 3.5–9.5 s in the RO protocol ($n = 19$) were collected for re-evaluation (Fig. 2B). Within this time range, the RO protocol predicted central dizziness or vertigo with an AUC of only 0.58, indicating that this time frame is inefficient for the diagnosis of dizziness or vertigo in individuals with balance disorders. A comparative analysis was conducted to evaluate the differences in standing maintenance time for several protocols associated with the RO protocol, including the RO-RC, RO-VC, and VC-RC protocols. The VC-RC protocol had the largest AUC (0.81) and therefore the greatest potential for diagnostic efficacy. The greatest efficacy in diagnosing central dizziness or vertigo was achieved at a Youden index of 0.689 and a difference in standing maintenance time of 1.5 s as the cutoff value, with a sensitivity of 88.9 % and specificity of 80.0 %. The smaller the difference in maintenance time between the protocols, the greater the specificity of the diagnosis for central dizziness or vertigo was (Table 4).

3.4. R-cVR algorithm

By combining the RO protocol with the VC-RC protocol, we designed a prediction algorithm, as shown in Fig. 3. The algorithm is briefly termed the 'R-cVR algorithm', with 'R' denoting the *Romberg* test with open eyes and 'cVR' denoting the difference in maintenance time in the eyes *closed* state between the *'V'*-shaped stance and the *Romberg* test, i.e., the VC-RC protocol.

The R-cVR algorithm process is as follows: Before starting the examination, the patient was asked to remain seated for at least 30 s (1) First, the RO protocol was evaluated. A standing maintenance time of less than 3.5 s indicated the possible presence of central dizziness or vertigo. On the other hand, a standing stability greater than 9.5 s indicated possible peripheral dizziness or vertigo. (2) If the standing maintenance time was between 3.5 and 9.5 s, the VC-RC protocol was performed. A difference in standing maintenance time between the two protocols of less than 1.5 s indicated possible central dizziness or vertigo. Conversely, a difference greater than 1.5 s suggested possible peripheral dizziness or vertigo.

3.5. Verification of the accuracy of the R-cVR algorithm

A comparison of the R-cVR algorithm results with the MRI-DWI findings revealed a sensitivity of 88.0 % and a specificity of 94.0 %. The kappa value was 0.80, suggesting good overall concordance with the diagnostic results of MRI-DWI (Table 5).

Table 2
Multivariate logistic regression validates balance disorder as an independent predictor.

	Regression coefficient	OR (95 % CI)	p value
Age	0.021	1.02 (0.97–1.08)	0.454
Hypertension	1.497	4.47 (1.12–17.83)	0.034
Diabetes	−0.533	0.59 (0.13–2.63)	0.486
Balance disorder	4.124	61.82 (11.02–346.83)	<0.001
Constant	−5.590	0.004	0.006

Abbreviations: CI = confidence interval; OR = odds ratio.

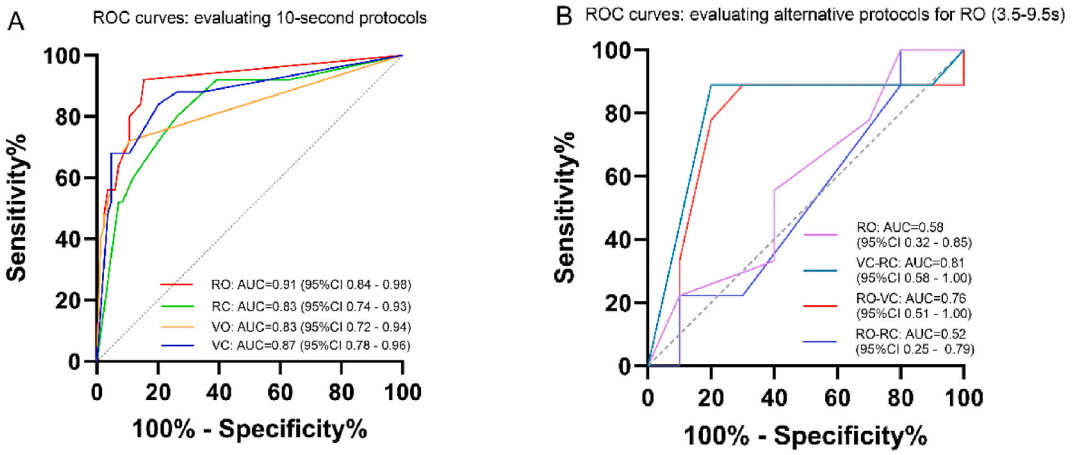

Fig. 2. (A) Summary of ROC curves generated using postural balance protocols (10 s of observation) to predict central dizziness or vertigo. (B) Summary comparisons of ROC curves evaluated by alternative protocols when the patient presented with a balance disorder within the time range assessed by the RO protocol (3.5–9.5 s). Abbreviations: ROC = receiver operating characteristic; AUC = area under the ROC curve; CI = confidence interval; RO = Romberg test with open eyes; RC = Romberg test with closed eyes; VO = V-shaped stance with open eyes; VC = V-shaped stance with closed eyes. Note: The symbol "-" represents the difference in standing maintenance time, e.g., VC-RC, which is the difference between the VC protocol standing maintenance time and the RC protocol standing maintenance time; similar conventions apply to other abbreviations.

Table 3
Comparison of posture balance protocols.

Protocols	Central group*	Peripheral group*	*p* value	AUC
RO	3.0 (0.0–7.0)	10.0 (10.0–10.0)	<0.001	0.91 (95 % CI 0.84–0.98)
RC	0.0 (0.0–4.0)	7.5 (4.0–10.0)	<0.001	0.83 (95 % CI 0.74–0.93)
VO	4.0 (0.0–10.0)	10.0 (10.0–10.0)	<0.001	0.83 (95 % CI 0.72–0.94)
VC	1.0 (0.0–5.0)	10.0 (6.0–10)	<0.001	0.87 (95 % CI 0.78–0.96)

Abbreviations: RO = Romberg test with open eyes; RC = Romberg test with closed eyes; VO = V-shaped stance with open eyes; VC = V-shaped stance with closed eyes; AUC = area under the ROC curve; IQR = interquartile range.
*Note: The data, representing the duration of standing in seconds for different protocols, are presented as medians (IQRs).

Table 4
Stratification of diagnostic values for the RO and VC-RC protocols.

Protocols	Time (s)*	Sensitivity	Specificity	Youden's Index
RO	−1.0	0.000	1.000	0.000
	0.5	0.400	0.988	0.388
	1.5	0.440	0.976	0.416
	2.5	0.480	0.976	0.456
	3.5	0.560	0.964	0.524
	4.5	0.560	0.940	0.500
	5.5	0.640	0.929	0.569
	6.5	0.720	0.893	0.613
	7.5	0.800	0.893	0.693
	8.5	0.840	0.857	0.697
	9.5	0.920	0.845	0.765
	11.0	1.000	0.000	0.000
VC-RC	−1.0	0.000	1.000	0.000
	0.5	0.444	0.900	0.344
	1.5	0.889	0.800	0.689
	3.0	0.889	0.600	0.489
	4.5	0.889	0.200	0.089
	6.5	0.889	0.100	−0.011
	9.0	1.000	0.000	0.000

Abbreviations: RO = Romberg test with open eyes; RC = Romberg test with closed eyes; VC = V-shaped stance with closed eyes; VC-RC = difference in standing maintenance time between the VC and RC protocols.
*Note: Within the RO protocol, a shorter stance maintenance duration suggests increased specificity for central-type dizziness or vertigo. When a patient presented with a balance disorder within the time range assessed by the RO protocol (3.5–9.5 s), the VC-RC protocol was used for further observation. A smaller difference between the protocols indicates greater specificity for central-type dizziness or vertigo.

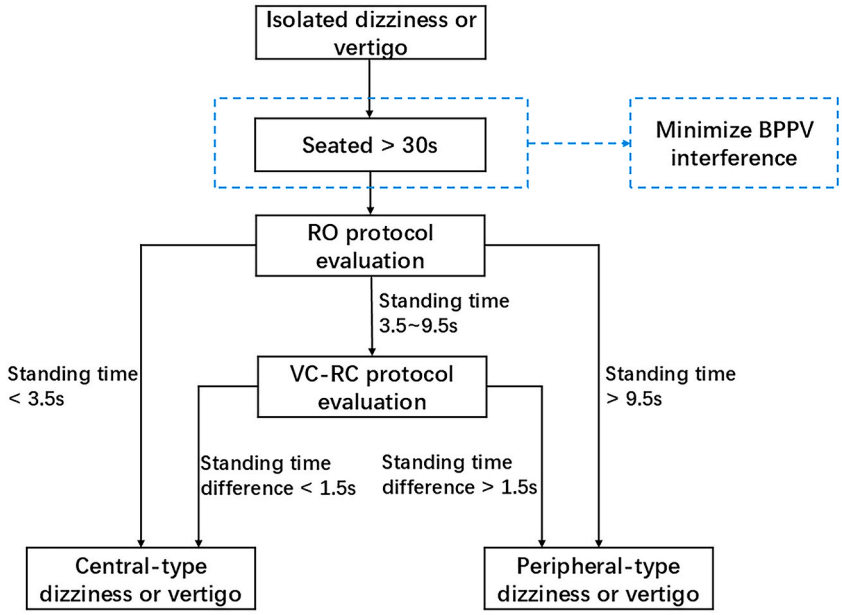

Fig. 3. Flowchart of the R-cVR algorithm. Abbreviations: BPPV = benign paroxysmal positional vertigo; RO = Romberg test with open eyes; RC = Romberg test with closed eyes; VC = V-shaped stance with closed eyes; VC-RC = difference in standing maintenance time between the VC and RC protocols.

Table 5
Predictive efficacy of the R-cVR algorithm.

	All patients, n = 109	With nystagmus*, n = 24	Without nystagmus*, n = 33
Sensitivity (%)	88.0	80.0	85.7
Specificity (%)	94.0	94.7	88.5
PPV (%)	81.5	80.0	66.7
NPV (%)	96.3	94.7	95.8
LR+	14.8	15.2	7.4
LR-	0.128	0.21	0.16
Kappa value	0.80	0.75	0.67

Abbreviations: LR+, positive likelihood ratio; LR–, negative likelihood ratio; NPV, negative predictive value; PPV, positive predictive value.
*Note: Data grouped by nystagmus status are restricted to patients with acute dizziness or vertigo within 3 days of onset and excluding BPPV.

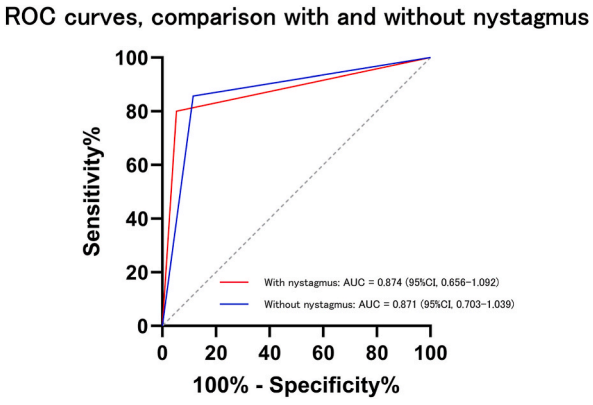

Fig. 4. ROC curves with and without nystagmus.

3.6. Subgroup analysis

Patients with acute dizziness or vertigo (n = 57) within 3 days of onset and excluded from BPPV were screened for subgroup analysis and divided into nystagmus (n = 24) and without nystagmus (n = 33) groups. The diagnostic efficacy is shown in Table 5. The sensitivity/specificity of the algorithm in the nystagmus group was 80.0 %/94.7 %, with a kappa value of 0.75. The sensitivity/specificity of the algorithm in the group without nystagmus was 85.7 %/88.5 %, with a kappa value of 0.67. A comparison of the two diagnostic efficacy ROC curves is shown in Fig. 4. The difference in the AUC was not statistically significant ($p = 0.984 > 0.05$).

4. Discussion

4.1. Significance of the research

In emergency patients, accurate identification of potentially dangerous central dizziness or vertigo to provide prompt and effective treatment is highly important for ensuring patient prognosis. This problem is particularly important in patients with acute cerebral infarction [22]. However, this process is not easy. The third Guideline for Reasonable and Appropriate Care in the Emergency Department (GRACE-3) recommends that the management of patients with vestibular syndrome (VS) begin with categorization according to the timing and triggers of symptom onset [3]. Although this classification scheme helps to clarify the diagnosis and treatment of VS, it is not always effective in clinical practice for patients with acute dizziness or vertigo. For example, it is unclear whether patients with previous spontaneous episodic vestibular syndrome (s-EVS) should be diagnosed with a new acute event or recurrent s-EVS. This classification scheme also does not effectively identify patients with acute cerebral infarction. Therefore, a more effective identification scheme is needed to assist clinicians in diagnosis and treatment.

4.2. Research design and interpretation of results

Vestibular dizziness and postural balance share a common anatomical basis, both of which depend on an intact vestibular system to maintain normal function [23]. Damage to different parts of the vestibular pathway can lead to VS and balance disorders of different degrees [24,25]. Our study revealed a significant difference in the severity of balance disorders caused by peripheral and central vestibular lesions.

Previous studies have suggested that the Romberg test, categorized by rank, is helpful in differentiating central from peripheral dizziness or vertigo, but its diagnostic efficacy is not satisfactory [15]. We expected to quantify the degree of postural instability through observations of standing maintenance time and attempted to fine-tune postural balance by adjusting upper extremity posture (Table S1) to observe the ability of the Romberg test to predict dizziness or vertigo. The results showed that the AUCs of the Romberg tests for various upper limb postures were similar (Fig. S1), and all of them were capable of distinguishing between central and peripheral dizziness or vertigo (Table S2, $p < 0.001$). These findings suggest that alterations in upper limb posture do not significantly affect the results of the Romberg test. Ultimately, we chose the Romberg test with both hands extended forward as the basis for our algorithm because of its relatively large AUC.

The R-cVR algorithm was designed as follows: (1) Patients remained seated for more than 30 s to stabilize their anxiety and reduce their subjective feelings of fear. Moreover, this practice helped minimize postural balance disturbances caused by BPPV; sudden head position changes may cause otoliths to roll in the semicircular canals of BPPV patients, leading to secondary balance disturbances [26]. (2) If the standing maintenance time using the RO protocol was less than 3.5 s, its specificity for predicting central dizziness or vertigo was greater than 95 %. This finding indicates that a satisfactory misdiagnosis rate can be achieved using this cutoff time. Therefore, 3.5 s was set as the first observation point for the R-cVR algorithm. However, a missed diagnosis of central dizziness or vertigo may lead to serious consequences; therefore, the sensitivity of the protocol needed to be improved, which would result in a reduced specificity. By calculating the Youden index using the ROC curve, it was found that the diagnostic efficacy reached its maximum when the standing maintenance time was 9.5 s, which corresponded to a sensitivity of 92 %. Therefore, we set 9.5 s as the second observation point for the algorithm. (3) Results of the RO protocol within the range of 3.5–9.5 s are insufficient to distinguish between central and peripheral dizziness or vertigo. Therefore, to improve the accuracy of the algorithm, an alternative is needed. We speculated that central dizziness or vertigo typically leads to unsteady standing due to significant trunk ataxia and does not significantly increase standing duration as a result of minor postural changes, which may differ from the effects of peripheral dizziness or vertigo. Therefore, we designed a bipedal V-shaped stance to slightly increase standing stability in the Romberg test. Calculations revealed that the likelihood of central dizziness or vertigo is high when the difference in the duration of the V-shaped stance with the eyes closed is less than 1.5 s compared with that of the closed-eyes Romberg test stance. Certainly, within this time range, the VC-RC protocol is not the only alternative protocol available.

4.3. Comparison of existing diagnostic approaches

Currently, the most commonly used auxiliary imaging methods for identifying central lesions in patients are computed tomography (CT) and MRI [27]. In cases of acute ischemic stroke, brain CT usually fails to detect lesions until 24 h after the patient becomes symptomatic and is even less sensitive for identifying posterior circulation cerebral infarctions (PCIs) (only 28.5 %) [28,29]. Although brain MRI-DWI is often used as a standard diagnostic imaging method, early MRI-DWI may also produce false-negative results within 48 h of onset in patients at high risk for stroke (12%–14 %) [19,30]. This proportion is even greater in patients with minor stroke [31].

In addition, MRI-DWI is not always feasible in emergency situations because of the need for specialized equipment and longer waiting times. Therefore, MRI is not an ideal screening method.

Compared with anterior circulation strokes, acute PCIs are more complex and variable [32], which makes their diagnosis more challenging. A survey conducted in EDs revealed that patients who presented with symptoms of dizziness, an imbalance in stroke or transient ischemic attack (TIA) had a risk of misdiagnosis in up to 35 % of the patients [33]. The Face Arm and Speech Test (FAST) is a simple protocol for predicting anterior circulation strokes but lacks sensitivity in identifying PCIs [34,35]. With its modified version, BE-FAST (Balance, Eyes, Face, Arm, Speech, Time), the misdiagnosis rate for infarcts confined to the basilar artery feed zone remains low at 43 % [36]. The POST-National Institutes of Health Stroke Scale (POST-NIHSS) can be used for prognostic assessment of posterior circulation stroke. However, studies have not explored its diagnostic predictive value for PCIs [37]. Another assessment tool, the ABCD2 (age, blood pressure, clinical features, duration of symptoms, and diabetes) score, has a cutoff value of $\geq$4 and a sensitivity and specificity of approximately 55.7 % and 81.8 %, respectively [9]. The PCI score has a sensitivity and specificity of approximately 94.1 % and 41.4 %, respectively [38]. In addition, the TriAGe+ (No triggers, Atrial fibrillation, Gender +) score, with a cutoff value of 10, had a sensitivity and specificity of 77.5 % and 72.1 %, respectively [39]. These protocols do not have sufficiently high diagnostic value to limit their utility in practice.

At present, the HINTS+ and STANDING algorithms are considered to have greater diagnostic value than other methods [14]. The HINTS + protocol has a sensitivity of 97.2 % and a specificity of 92.4 % [13], whereas the STANDING protocol has a sensitivity ranging from 93.4 % to 100 % and a specificity ranging from 71.8 % to 94.3 % [40]. However, there are several difficulties with both protocols in clinical practice. First, importantly, the guidelines state that in both the HINTS+ and STANDING protocols, evaluating nystagmus in patients requires the use of Frenzel lenses [3,16]. This requirement greatly limits the use of these evaluation protocols, as non-specialists are often unequipped with these devices. Second, accurately judging a patient's diagnosis according to the results of the nystagmus test can be challenging for an untrained physician [3,40,41]. In addition, in practice, many patients with acute dizziness or vertigo do not experience significant spontaneous nystagmus [42,43]. All of these conditions limit the clinical application of protocols that rely on nystagmus examination [44]. Third, our clinical observations revealed that some patients with acute dizziness or vertigo had difficulty cooperating with the head-pulse test (particularly elderly patients), which is a critical process in evaluating the HINTS + or STANDING protocols.

It has been proposed that central acute dizziness or vertigo can be predicted by categorizing different levels of gait and trunk instability [15,30,45]. This assessment strategy does not rely on nystagmus examination. These studies agree that the more severe the gait or trunk ataxia is, the more accurate the prediction of central dizziness or vertigo is [16]. However, the diagnostic value of this grading-based prediction method is not ideal [14]. In the study by Carmona et al., trunk ataxia was categorized into three grades, and a grade of 2 (inability to walk without support) or 3 (falls while standing) was considered positive. This study revealed that using a combined assessment of grade 2 or 3 trunk ataxia as a diagnostic criterion for identifying anterior/posterior circulation strokes in patients with acute dizziness or vertigo resulted in a high sensitivity of 92.9 % but a low specificity of 61.1 % [15]. Notably, when grade 2 trunk ataxia was independently assessed in the identification of central lesions, the sensitivity decreased to only 26.2 %, whereas the specificity remained at 61.1 % [15]. These findings suggest that the "inability to walk without support" (grade 2 trunk ataxia) may not be an appropriate predictor. In clinical practice, the combined definition of grade 2 or 3 trunk ataxia as a joint positive predictor is inappropriate because this combination can significantly increase the risk of misdiagnosis.

In our study, we quantified the standing maintenance time of postural balance protocols and found that redesigning the R-cVR algorithm significantly improved the diagnostic efficacy of these protocols according to the timeframe in which its diagnostic efficacy was ineffective. According to our database, cerebral infarction is a major cause of central dizziness or vertigo, so this algorithm can be used to distinguish cerebral infarction from acute dizziness or vertigo. Although the sensitivity and specificity of the R-cVR algorithm for detecting acute stroke may be slightly lower than those of the HINTS+ and STANDING protocols, the R-cVR algorithm is simpler to use than the other algorithms and does not require special equipment. This simplicity makes it particularly useful for nonspecialists, thus providing broad clinical utility. In addition, the R-cVR algorithm does not conflict with existing diagnostic protocols, such as STANDING, BE-FAST, and trunk ataxias, and can be integrated with these protocols to improve their diagnostic accuracy. Furthermore, while existing studies often rely on comprehensive assessments involving nystagmus, limb function, and biochemical markers [9,14,38,39], these protocols are significantly less effective in patients with isolated dizziness or vertigo without significant neurologic symptoms, especially when nystagmus is absent. Our R-cVR algorithm addresses this diagnostic gap.

4.4. Results discussion and subgroup analysis

In this retrospective study, all the included patients underwent a thorough head MRI-DWI. Patients who did not undergo head MRI-DWI were excluded. Therefore, the types of diseases and proportions of patients with dizziness or vertigo included in this study differ from the actual distributions in the real world. In addition, some patients with nystagmus-typical peripheral dizziness or vertigo, such as those with VN, do not require hospitalization. This situation may have contributed to the high proportion of dizziness or vertigo patients in our database who lacked nystagmus, which is different from the findings of previous studies [42,43]. According to our data, patients with both anterior and posterior circulation strokes can present with dizziness or vertigo symptoms, with the highest percentage observed in patients with strokes in the posterior circulation of the region supplied by the posterior inferior cerebellar artery. This finding is consistent with those of previous studies [42,43].

The efficacy of the R-cVR algorithm in identifying acute dizziness or vertigo with a short onset and without nystagmus is a question of interest in medical practice. Since BPPV is easy for specialists to identify through positional testing, we further screened patients with onset within three days and excluded BPPV patients from the subgroup analysis. Overall, the algorithm was effective in

identifying acute dizziness or vertigo in patients both with and without nystagmus. The AUC difference between the two groups was 0.003 ($p = 0.984 > 0.05$), indicating that there was no significant difference in diagnostic efficacy (Fig. 4). When the results of the algorithm were compared with the MRI-DWI diagnostic results, the kappa value for the group without nystagmus was slightly lower than that for the group with nystagmus. Owing to the small amount of data from the subgroup analysis, future extended studies are needed to further validate these results.

The initial aim of our study was to design a simple and universal algorithm that could improve the ability of nonspecialist physicians (especially emergency physicians) to identify first-visit acute dizziness or vertigo. This application scenario is different from algorithms such as HINTS+ and STANDING, which require specialist physicians to assess nystagmus status with the aid of specialized equipment. Thus, our algorithm cannot be directly compared with these algorithms. Overall, the sensitivity and specificity of the R-cVR algorithm are slightly lower than those of the HINTS+ and STANDING algorithms [2,19]. However, for patients experiencing dizziness or vertigo without nystagmus, the HINTS + algorithm may not be an ideal protocol, in which case the R-cVR algorithm can be used as a complementary tool. Additionally, the posture assessment process in the STANDING algorithm can be enhanced by incorporating the R-cVR algorithm, potentially improving the overall diagnostic efficacy of the original algorithm.

4.5. Analysis of misdiagnosed patients

The application of the R-cVR algorithm to cases from the original database yielded 8 misjudgments out of a total of 109 cases (Table S3). Misdiagnosis in the elderly population warrants particular attention. Among the 5 patients with misdiagnosed peripheral-type dizziness or vertigo, 4 were 68 years and older. This trend may be attributable to the natural decline in postural coordination abilities in the aging population, which can lead to varying degrees of balance disorders [46]. This finding also implies that when the algorithm is employed for diagnosing elderly patients with dizziness or vertigo, and the result suggests a central lesion, further confirmation through MRI-DWI examination is necessary. The fourth patient had BPPV and had not remained seated for the required period (>30 s) before the examination; therefore, we suggest that it is necessary for patients to sit quietly for a sufficient period before beginning the examination. The three instances of central-type dizziness or vertigo that went undetected were characterized by minimal infarctions that did not affect the key regions integral to equilibrium. These patients had low modified Rankin scale (mRS) scores, indicating that the infarcts had no significant impact on their daily living ability, and were discharged.

4.6. Limitations and prospects of the study

This study has several limitations. 1. Patients without MRI-DWI data were excluded from this study, which may have introduced a degree of selection bias. In addition, grouping patients according to MRI-DWI outcomes has its own limitations. False-negative results or undetectable central lesions (e.g., TIA) may have affected the accuracy of the results of the R-cVR algorithm. However, MRI remains the most important technique for identifying central lesions. Previous similar studies, such as those of the HINTS and STANDING protocols, used MRI-DWI as the diagnostic grouping criterion [2,19]. Therefore, we continued to use MRI-DWI as the grouping criterion in this study. 2. Our preliminary observations indicate that patients who can stand and maintain stability for more than 10 s are highly likely to continue doing so for extended periods, with a minimal incidence of falls. Under these circumstances, the likelihood of central-type dizziness or vertigo is exceedingly low. Thus, our initial criterion that standing for more than 10 s is indicative of adequate balance capacity may have led to the exclusion of data from individuals who were able to withstand more than this threshold. 3. Overall, the number of available patients enrolled in this study was low, and the sample size was even smaller for the 3.5–9.5 s interval of low diagnostic efficacy of the RO protocol. Therefore, additional patients need to be included in the future to further refine our study.

Future prospects include the following: 1. This study was a single-center study, and the findings may have been influenced by the specific setting and sample characteristics of the center, which may limit the generalizability of the results. Future research could aim to expand the sample size and replicate this study at multiple research centers. 2. The onset time of the enrolled patients was further reduced. In our database, the number of patients in the acute phase was limited; therefore, we used a relatively generous time window for the inclusion of patients based on symptom onset. 3. To ensure accuracy, the data for this study were collected by associate chief neurologists. In future scaled-up studies, this step could be performed by emergency physicians to increase the applicability of the results to daily practice.

5. Conclusion

Although postural balance tests are easy to perform, previous studies have shown that their accuracy in diagnosing central dizziness or vertigo is not satisfactory. In this study, we identified important time intervals in which the diagnostic efficacy of postural balance schemes is limited. Additionally, we designed a new R-cVR algorithm, which provides new ideas for future studies to improve postural balance schemes. The R-cVR algorithm can effectively identify central-type dizziness or vertigo under certain conditions. The algorithm is simple and can be easily grasped by nonspecialists, does not require any diagnostic tools and has wider applicability than the HINTS + or STANDING algorithms. For physicians unfamiliar with the HINTS + or STANDING protocols, the R-cVR algorithm can serve as a simple supplemental diagnostic tool; therefore, it is worthwhile to promote and learn.

Funding

No funding was received to support this work.

Declaration of informed consent

Written informed consent was obtained from the patients. Informed consent, along with the patients' medical records, will be securely stored in our hospital.

Ethics and informed consent

Approval for the study was obtained from the Ethics Committee of Hunan University of Medicine General Hospital in China (Approval No. KY-2023120501, dated December 5, 2023), and written informed consent was obtained from all participants in accordance with the Helsinki Declaration of 1964. Written informed consent was obtained from all individual participants included in the study.

Consent to publish

The authors affirm that the human research participants provided informed consent for publication of the images in the figures and videos of this manuscript.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Mingxia Li: Writing – original draft, Methodology, Funding acquisition, Data curation. **Bichun Tan:** Validation, Resources, Investigation. **Qingnan Wu:** Software, Investigation, Data curation. **Shuangxi Liu:** Supervision, Resources. **Jun Zhou:** Supervision, Formal analysis. **Liqian Xiao:** Methodology, Investigation. **Meng Nie:** Resources. **Fengyu Ming:** Methodology. **Jing Zhou:** Supervision, Project administration. **Xing Luo:** Supervision, Project administration. **Junjie Yin:** Writing – review & editing, Validation, Software, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e38532.

References

[1] D.E. Newman-Toker, Y.H. Hsieh, C.A. Camargo Jr., A.J. Pelletier, G.T. Butchy, J.A. Edlow, Spectrum of dizziness visits to US emergency departments: cross-sectional analysis from a nationally representative sample, Mayo Clin. Proc. 83 (2008) 765–775.
[2] S. Vanni, R. Pecci, C. Casati, F. Moroni, M. Risso, M. Ottaviani, P. Nazerian, S. Grifoni, P. Vannucchi, STANDING, a four-step bedside algorithm for differential diagnosis of acute vertigo in the Emergency Department, Acta Otorhinolaryngol. Ital. 34 (2014) 419–426.
[3] J.A. Edlow, C. Carpenter, M. Akhter, D. Khoujah, E. Marcolini, W.J. Meurer, D. Morrill, J.G. Naples, R. Ohle, R. Omron, S. Sharif, M. Siket, S. Upadhye, E.S. Loj, E. Sundberg, K. Tartt, S. Vanni, D.E. Newman-Toker, F. Bellolio, Guidelines for reasonable and appropriate care in the emergency department 3 (GRACE-3): acute dizziness and vertigo in the emergency department, Acad. Emerg. Med. 30 (2023) 442–486.
[4] A.S. Saber Tehrani, D. Coughlan, Y.H. Hsieh, G. Mantokoudis, F.K. Korley, K.A. Kerber, K.D. Frick, D.E. Newman-Toker, Rising annual costs of dizziness presentations to U.S. emergency departments, Acad. Emerg. Med. 20 (2013) 689–696.
[5] L.E. Walther, Current diagnostic procedures for diagnosing vertigo and dizziness, GMS Curr. Top. Otorhinolaryngol., Head Neck Surg. 16 (2017) Doc02.
[6] R.D. Herr, L. Zun, J.J. Mathews, A directed approach to the dizzy patient, Ann. Emerg. Med. 18 (1989) 664–672.
[7] E. Armato, E. Ferri, A. Pinzani, E. Ulmer, Cerebellar haemorrhage mimicking acute peripheral vestibulopathy: the role of the video head impulse test in differential diagnosis, Acta Otorhinolaryngol. Ital. 34 (2014) 288–291.
[8] A.P. Casani, I. Dallan, N. Cerchiai, R. Lenzi, M. Cosottini, S. Sellari-Franceschini, Cerebellar infarctions mimicking acute peripheral vertigo: how to avoid misdiagnosis? Otolaryngol. Head Neck Surg. 148 (2013) 475–481.
[9] C. Gerlier, M. Hoarau, A. Fels, H. Vitaux, C. Mousset, W. Farhat, M. Firmin, V. Pouyet, A. Paoli, G. Chatellier, O. Ganansia, Differentiating central from peripheral causes of acute vertigo in an emergency setting with the HINTS, STANDING, and ABCD2 tests: a diagnostic cohort study, Acad. Emerg. Med. 28 (2021) 1368–1378.

[10] A.A. Tarnutzer, S.H. Lee, K.A. Robinson, Z. Wang, J.A. Edlow, D.E. Newman-Toker, ED misdiagnosis of cerebrovascular events in the era of modern neuroimaging: a meta-analysis, Neurology 88 (2017) 1468–1477.
[11] D.E. Newman-Toker, J.A. Edlow, TiTrATE: a novel, evidence-based approach to diagnosing acute dizziness and vertigo, Neurol. Clin. 33 (2015) 577–599, viii.
[12] C.A. Blum, S.E. Kasner, Transient ischemic attacks presenting with dizziness or vertigo, Neurol. Clin. 33 (2015) 629–642, ix.
[13] A.A. Tarnutzer, D. Gold, Z. Wang, K.A. Robinson, J.C. Kattah, G. Mantokoudis, A.S. Saber Tehrani, D.S. Zee, J.A. Edlow, D.E. Newman-Toker, Impact of clinician training background and stroke location on bedside diagnostic test accuracy in the acute vestibular syndrome - a meta-analysis, Ann. Neurol. 94 (2023) 295–308.
[14] A.A. Tarnutzer, J.A. Edlow, Bedside testing in acute vestibular syndrome-evaluating HINTS plus and beyond-A critical review, Audiol Res 13 (2023) 670–685.
[15] S. Carmona, C. Martinez, G. Zalazar, M. Moro, A. Batuecas-Caletrio, L. Luis, C. Gordon, The diagnostic accuracy of truncal ataxia and HINTS as cardinal signs for acute vestibular syndrome, Front. Neurol. 7 (2016) 125.
[16] V.P. Shah, J.E.S.L. Oliveira, W. Farah, M.O. Seisa, A.K. Balla, A. Christensen, M. Farah, B. Hasan, F. Bellolio, M.H. Murad, Diagnostic accuracy of the physical examination in emergency department patients with acute vertigo or dizziness: a systematic review and meta-analysis for GRACE-3, Acad. Emerg. Med. 30 (2023) 552–578.
[17] Z. Calic, C. Cappelen-Smith, C.S. Anderson, W. Xuan, D.J. Cordato, Cerebellar infarction and factors associated with delayed presentation and misdiagnosis, Cerebrovasc. Dis. 42 (2016) 476–484.
[18] C. Deluca, G. Moretto, A. Di Matteo, M. Cappellari, A. Basile, D.M. Bonifati, T. Mesiano, C. Baracchini, G. Meneghetti, S. Mazzucco, M. Ottina, P. Lochner, A. Tonon, M.A. Bonometti, A. De Boni, E. Turinese, N. Freddi, A. Adami, F. Pizzini, G. Defazio, G. Tomelleri, P. Bovi, A. Fiaschi, M. Tinazzi, Ataxia in posterior circulation stroke: clinical-MRI correlations, J. Neurol. Sci. 300 (2011) 39–46.
[19] J.C. Kattah, A.V. Talkad, D.Z. Wang, Y.H. Hsieh, D.E. Newman-Toker, HINTS to diagnose stroke in the acute vestibular syndrome: three-step bedside oculomotor examination more sensitive than early MRI diffusion-weighted imaging, Stroke 40 (2009) 3504–3510.
[20] J. Forbes, S. Munakomi, H. Cronovich. Romberg test, StatPearls, Treasure Island (FL) ineligible companies, DisClosure: Sunil Munakomi declares no relevant financial relationships with ineligible companies. Disclosure: Heather Cronovich declares no relevant financial relationships with ineligible companies, 2023. Available from: https://www.ncbi.nlm.nih.gov/books/NBK563187/.
[21] A.K. Boehme, C. Esenwa, M.S. Elkind, Stroke risk factors, genetics, and prevention, Circ. Res. 120 (2017) 472–495.
[22] E. Berge, W. Whiteley, H. Audebert, G.M. De Marchis, A.C. Fonseca, C. Padiglioni, N.P. de la Ossa, D. Strbian, G. Tsivgoulis, G. Turc, European Stroke Organisation (ESO) guidelines on intravenous thrombolysis for acute ischaemic stroke, Eur Stroke J 6 (2021) I–LXII.
[23] T. Brandt, M. Dieterich, M. Strupp, Vertigo and Dizziness, 2005.
[24] D. Eibling, Balance disorders in older adults, Clin. Geriatr. Med. 34 (2018) 175–181.
[25] O.J. Surgent, O.I. Dadalko, K.A. Pickett, B.G. Travers, Balance and the brain: a review of structural brain correlates of postural balance and balance training in humans, Gait Posture 71 (2019) 245–252.
[26] J.A. Edlow, K. Kerber, Benign paroxysmal positional vertigo: a practical approach for emergency physicians, Acad. Emerg. Med. 30 (2023) 579–588.
[27] C. Gerlier, A. Fels, H. Vitaux, C. Mousset, A. Perugini, G. Chatellier, O. Ganansia, Effectiveness and reliability of the four-step STANDING algorithm performed by interns and senior emergency physicians for predicting central causes of vertigo, Acad. Emerg. Med. 30 (2023) 487–500.
[28] V.P. Shah, J.E.S.L. Oliveira, W. Farah, M. Seisa, A. Kara Balla, A. Christensen, M. Farah, B. Hasan, F. Bellolio, M.H. Murad, Diagnostic accuracy of neuroimaging in emergency department patients with acute vertigo or dizziness: a systematic review and meta-analysis for the guidelines for reasonable and appropriate care in the emergency department, Acad. Emerg. Med. 30 (2023) 517–530.
[29] J. Edlow, A negative non-contrast CT is insufficient to exclude a cerebellar infarct, Emerg. Med. J. 39 (2022) 564–565.
[30] D.E. Newman-Toker, K.A. Kerber, Y.H. Hsieh, J.H. Pula, R. Omron, A.S. Saber Tehrani, G. Mantokoudis, D.F. Hanley, D.S. Zee, J.C. Kattah, HINTS outperforms ABCD2 to screen for stroke in acute continuous vertigo and dizziness, Acad. Emerg. Med. 20 (2013) 986–996.
[31] A.S. Saber Tehrani, J.C. Kattah, G. Mantokoudis, J.H. Pula, D. Nair, A. Blitz, S. Ying, D.F. Hanley, D.S. Zee, D.E. Newman-Toker, Small strokes causing severe vertigo: frequency of false-negative MRIs and nonlacunar mechanisms, Neurology 83 (2014) 169–173.
[32] A.A. Tarnutzer, A.L. Berkowitz, K.A. Robinson, Y.H. Hsieh, D.E. Newman-Toker, Does my dizzy patient have a stroke? A systematic review of bedside diagnosis in acute vestibular syndrome, CMAJ (Can. Med. Assoc. J.) 183 (2011) E571–E592.
[33] K.A. Kerber, D.L. Brown, L.D. Lisabeth, M.A. Smith, L.B. Morgenstern, Stroke among patients with dizziness, vertigo, and imbalance in the emergency department: a population-based study, Stroke 37 (2006) 2484–2487.
[34] K. Krishnan, K. Bassilious, E. Eriksen, P.M. Bath, N. Sprigg, S.K. Brækken, H. Ihle-Hansen, M.A. Horn, E.C. Sandset, Posterior circulation stroke diagnosis using HINTS in patients presenting with acute vestibular syndrome: a systematic review, European Stroke Journal 4 (2019) 233–239.
[35] G. Banerjee, S.P. Stone, D.J. Werring, Posterior circulation ischaemic stroke, BMJ 361 (2018) k1185.
[36] S. Aroor, R. Singh, L.B. Goldstein, BE-FAST (balance, eyes, Face, arm, Speech, time): reducing the proportion of strokes missed using the FAST mnemonic, Stroke 48 (2017) 479–481.
[37] F. Alemseged, A. Rocco, F. Arba, J.P. Schwabova, T. Wu, L. Cavicchia, F. Ng, J.L. Ng, H. Zhao, C. Williams, F. Sallustio, A.H. Balabanski, A. Tomek, M.W. Parson, P.J. Mitchell, M. Diomedi, N. Yassi, L. Churilov, S.M. Davis, B.C.V. Campbell, T. Basilar Artery, I. Management Collaboration, Posterior National Institutes of Health stroke scale improves prognostic accuracy in posterior circulation stroke, Stroke 53 (2022) 1247–1255.
[38] S. Vanni, R. Pecci, J.A. Edlow, P. Nazerian, R. Santimone, G. Pepe, M. Moretti, A. Pavellini, C. Caviglioli, C. Casula, S. Bigiarini, P. Vannucchi, S. Grifoni, Differential diagnosis of vertigo in the emergency department: a prospective validation study of the standing algorithm, Front. Neurol. 8 (2017) 590.
[39] R. Kuroda, T. Nakada, T. Ojima, M. Serizawa, N. Imai, N. Yagi, A. Tasaki, M. Aoki, T. Oiwa, T. Ogane, K. Mochizuki, M. Kobari, H. Miyajima, The TriAGe+ score for vertigo or dizziness: a diagnostic model for stroke in the emergency department, J. Stroke Cerebrovasc. Dis. 26 (2017) 1144–1153.
[40] C. Dmitriew, A. Regis, O. Bodunde, R. Lepage, Z. Turgeon, S. McIsaac, R. Ohle, Diagnostic accuracy of the HINTS exam in an emergency department: a retrospective chart review, Acad. Emerg. Med. 28 (2021) 387–393.
[41] A.E. Quimby, E.S.H. Kwok, D. Lelli, P. Johns, D. Tse, Usage of the HINTS exam and neuroimaging in the assessment of peripheral vertigo in the emergency department, J Otolaryngol Head Neck Surg 47 (2018) 54.
[42] F. Nikles, H. Kerkeni, E. Zamaro, A. Korda, F. Wagner, T.C. Sauter, R. Kalla, M. Morrison, G. Mantokoudis, Do monosymptomatic stroke patients with dizziness present a vestibular syndrome without nystagmus? An underestimated entity, Eur. J. Neurol. 31 (2024) e16066.
[43] S. Carmona, C. Martinez, G. Zalazar, N. Koohi, D. Kaski, Acute truncal ataxia without nystagmus in patients with acute vertigo, Eur. J. Neurol. 30 (2023) 1785–1790.
[44] S. Carmona, C. Martínez, G. Zalazar, N. Koohi, D. Kaski, Acute truncal ataxia without nystagmus, Eur. J. Neurol. 31 (4) (2024 Apr) e16185, https://doi.org/10.1111/ene.16185. Epub 2023 Dec 21. PMID: 38127109; PMCID: PMC11235698.
[45] L. Chen, W. Lee, B.R. Chambers, H.M. Dewey, Diagnostic accuracy of acute vestibular syndrome at the bedside in a stroke unit, J. Neurol. 258 (2011) 855–861.
[46] K. Jahn, The aging vestibular system: dizziness and imbalance in the elderly, Adv. Oto-Rhino-Laryngol. 82 (2019) 143–149.