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MAIN ARTICLE

Comparison of three diagnostic tests in detecting vestibular deficit in patients with peripheral vestibulopathy

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Abstract

Objectives: This study aimed to evaluate the results of the video head impulse test and of the caloric and rotatory chair tests in patients with dizziness. Agreement between test results was assessed and the best protocol for detecting peripheral vestibulopathy was identified.

Methods: Participants comprised 116 patients, 75 with a peripheral vestibulopathy and 41 with non-peripheral vestibulopathy. The main outcome measures were classified as normal or abnormal according to our laboratory data.

Results: Agreement between tests was low. Vestibulopathy testing that required all three results to be abnormal had a sensitivity of 0.547, a specificity of 0.878, and positive and negative predictive values of 0.891 and 0.514, respectively. Vestibulopathy testing that required just one result to be abnormal had a sensitivity of 0.933, a specificity of 0.292, and positive and negative predictive values of 0.701 and 0.705, respectively.

Conclusion: In peripheral vestibulopathy, there was weak concordance in the assessment of horizontal semicircular canal function among the different tests. However, the video head impulse test had sufficient statistical power to be recommended as the first-line test.

Key words: Vertigo; Head Thrust Test; Dizziness; Vestibulo-Ocular Reflex

Introduction

The main two goals of vestibular testing are to identify any degree of deficit and localise the specific end organ or central nervous system area affected. Usually, both goals can be accomplished using a combination of laboratory techniques. For some patients, the clinical data, bedside vestibular examination, ancillary otological and audiological examination provide sufficient indicators for diagnosis, with each test providing relevant information about the physiopathology.[1] However, information obtained at the initial examination can be inconclusive, and under these conditions vestibular tests are necessary to obtain a clear diagnosis.

Several laboratory vestibular tests are available, but two have stood the test of time: the bithermal caloric test (or caloric test) and the rotatory chair test. The response from each ear can be assessed independently in the caloric test, while both ears are tested simultaneously in the rotatory chair test. The caloric test stimulus is equivalent to a very low frequency sinusoidal rotation (0.001 Hz); this can be increased to 1 Hz in the rotatory chair test.[2] The caloric test is an artificial method of reproducing a sinusoidal stimulus in the ear, while stimulation in the rotatory chair test is computer-controlled to perform a true sinusoidal rotation or a step stimulation.[3] Test–re-test reliability is low for the caloric test but high for the rotatory chair test.[4] Both tests measure the function of the vestibular receptor in the ampullae of the horizontal semicircular canal, but they are time-consuming, require expensive equipment in suitably prepared rooms and cause irritating vestibular symptoms in patients during testing and for some time afterwards.[5] The response is mediated by the vestibulo-ocular reflex and influenced by other structures and functions at both the peripheral site and the central vestibular pathway, i.e. heat diffusion across the temporal bone, combined stimulation of other vestibular receptors, the velocity storage mechanism and the neural integrator, and central adaptation.

The recently introduced video head impulse test registers the eye response to sudden head impulses that acquire high velocity (over 150°/second) and frequency (1–16 Hz). This system mimics the performance of the

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scleral search coil in a magnetic field installation.[6,7] The response is restricted to the initial period after initiation of the brief stimulus (<100 milliseconds) and is mainly driven by the vestibulo-ocular reflex. The reflex gain is obtained by dividing the eye velocity by the head velocity, and it is possible to register the final refixation saccades.[8]

This study compared the results of the video head impulse test, the caloric test and the rotatory chair test in patients with dizziness with or without a clinical diagnosis of peripheral vestibulopathy. Previous investigations reported contradictory results regarding the sensitivity and specificity for diagnosing peripheral vestibulopathy of the rotatory chair and caloric tests.[3,9,10] Some differences were due to the protocols used for testing (either both tests were performed on all participants or testing ended after the first abnormal result) and to characteristics of the study population (predictive values for tests are mainly influenced by the prevalence of the pathology in the study cohort).

Materials and methods

Patients

This prospective study assessed the results of the three most common tests for evaluating horizontal semicircular canal function: the caloric test, the rotatory chair test and the video head impulse test. For a six-month period, patients were evaluated using all three techniques when vestibular function testing was needed. After a detailed explanation of the study aims was provided by one of the investigators (NPF) and informed consent was obtained, all three tests were carried out. The caloric and rotatory chair tests were administered by a highly experienced trained technician and the video head impulse test by one of the authors (NPF). The tests were performed consecutively in random order, with a 30-minute rest period between each test. The first 25 tests were used to quantify the test duration (after correct patient preparation). During the rest periods, patients filled in the disability questionnaires with the help of the vestibular test technician.

This study included 116 patients suffering from dizziness: 56 women (48.3 per cent) and 60 men (51.7 per cent). Patients were aged between 21 and 80 years (mean ± standard deviation (SD)), 54 ± 14 years).

Vestibular examination

Bithermal caloric test. The bithermal caloric test was performed according to the methods of Fitzgerald and Hallpike,[11] and left eye movements were recorded using a video-based system (Ulmer VNG software version 1.4; SYNAPSIS, Marseille, France). Each ear was irrigated with a constant flow of water alternately at 30°C and 44°C for 40 seconds each. The maximum slow phase velocity of nystagmus was calculated for each ear following irrigation, and the Jongkees formula was used to determine canal paresis and directional preponderance.[12] The result was considered abnormal if asymmetry between left and right ear responses was more than 20 per cent or if asymmetry between rightward and leftward induced nystagmus was more than 28 per cent.

Rotatory chair test. Rotatory chair test equipment (CHARTR RVT system; ICS Medical, Schaumburg, Illinois, USA) is housed in a structure that enables the test to be performed in the dark. For this test, the patient's head was positioned and restrained so that both horizontal semicircular canals were close to the plane of stimulus (i.e. at the gravitational horizontal) and the patient was maintained in alert state with light conversation. Eye movements were recorded by electro-oculography with the electrodes positioned to register horizontal nystagmus.

In the sinusoidal harmonic acceleration test, the patient undergoes sinusoidal oscillation about a yaw axis at various frequencies (0.01, 0.02, 0.04, 0.08, 0.16, 0.32 and 0.64 Hz) with a peak angular velocity of 50°/second. Three vestibulo-ocular reflex parameters were calculated from the chair velocity and slow phase velocity (phase, gain and symmetry), and a normal or pathological score was assigned. For this study, the limits of normality were set at the mean ± two SDs of results obtained in our laboratory for a group of normal participants. Phase, gain and symmetry were considered abnormal when results were abnormal for three adjacent frequencies.[13]

In the second test, the impulsive rotational test, the patient was subjected to velocity steps to the right and left. The velocity step involved the patient undergoing an angular acceleration of 100° per second for 1 second, rotation at a constant velocity for 60 seconds and a final deceleration to 0° per second within 1 second. The results were analysed in terms of rotation towards the right and left sides.

Vestibulo-ocular reflex test. The vestibulo-ocular reflex was evaluated using a video system (vHIT; GN Otometrics, Taastrup, Denmark). For this test, the patient wore a pair of lightweight, tight-fitting goggles on which were mounted a small video camera and a half-silvered mirror to reflect an image of the patient's right eye into the camera. The eye was illuminated by a low-level infra-red light-emitting diode. A small sensor on the goggles measured head movement. The whole goggle system weighed about 60 g and was tightly secured to the head to minimise slippage. Calibration was performed before starting the test. The clinician asked the patient to stare at a fixed target 90–100 cm in front, and then rotated the patient's head horizontally by small angles (about 10–20°) randomly to the left or right. The head movement speed was measured by the sensor in the goggles, and the image of the eye was captured by a high-speed camera (250 Hz) and processed to yield the eye velocity. At the end of each head rotation, the head-velocity stimulus and eye-velocity response were simultaneously displayed on the screen so that the

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clinician could quickly optimise the head impulse. In a full test, 20 impulses were randomly delivered in each direction. At the end of the test, all head-velocity stimuli and eye-velocity responses were displayed on the computer screen, along with a graph showing the calculated vestibulo-ocular reflex gain (ratio of eye velocity to head velocity) for each head rotation. In this system, the evaluation of head velocity and eye velocity does not rely on a single measurement but corresponds to the area under the curve for both velocities. The parameters evaluated were the vestibulo-ocular reflex mean gain (a normal result is defined by gain of more than 0.8) and refixation saccades (abnormal when found in at least 80 per cent of the recordings performed for head impulses in one or both directions and if the eye velocity was more than 50°/second). A video head impulse test was considered pathological when any of the findings was abnormal. A relative parameter was created and defined as gain asymmetry (G_s) from the higher gain (G_h) and lower gain (G_l) values using the formula: $G_s = [(G_h - G_l) / (G_h + G_l] \times 100$. Normal values in our laboratory were set at below 9 per cent.[14]

Disability and handicap assessment

The dizziness handicap inventory questionnaire was answered in a similar fashion to the original English version [15]: the patient had to answer 'yes', 'sometimes' or 'no' to each question and the responses were given values of 4, 2 and 0, respectively. The questionnaire has 25 items, so the total score ranged from 0 to 100. The vertigo symptom scale can provide a measure of vertigo severity and somatic anxiety.[16] It comprises 19 items that measure vertigo severity and 15 that measure somatic anxiety. The answers to each item range from 0 (never) to 4 (very often, i.e. on average more than once a week) and the total score for each section is 64 for anxiety and 72 for severity. A third test was the CIEV ('Cuestionario de impacto emocional del vértigo'), a questionnaire that measures the emotional impact of vertigo.[17] This makes it possible to establish whether the patient is of a psychological type that tends to develop pathological anxiety levels that might influence recovery. High scores (more than 15 points) on the questionnaire have been shown to correlate with the level of difficulty that patients have achieving a full recovery from the pathology after medical treatment.

Statistical analysis

All data were stored and analysed in IBM SPSS Statistics software version 19.0 (Armonk, New York, USA). Statistical analysis was performed using a two-tailed χ^2 test, Fisher's exact test, Student's *t*-test or Mann–Whitney test, as appropriate. All tests were two-tailed and *p* values less than 0.05 were considered significant. Patients were classified into two groups: those in which vestibulopathy was expected and those in which it was not. This study followed the recommendations of a similar study in which the clinical diagnosis was considered the 'gold standard'.[3] An assessment of the sensitivity, specificity, and positive and negative predictive values for each test was based on a clinical diagnosis or not of vestibulopathy.

Spearman's correlation coefficient (ρ) was calculated to assess the relationship between patients with and without vestibulopathy regarding gain asymmetry, canal paresis and rotation. Cohen's κ coefficient, overall agreement, and positive agreement and negative agreement (and 95 per cent confidence intervals (CIs)) were used to assess the agreement between different diagnostic methods.

Results

Vestibulopathy was diagnosed in 75 (64.6 per cent) and no vestibulopathy in 41 (35.3 per cent) patients. Table I shows relevant demographic and clinical data for both patient groups. The most frequent diagnosis in the peripheral vestibulopathy group was Ménière's disease. Benign positional paroxysmal vertigo patients with recurrent disease (more than three episodes) were included because their disease is recurrent (more than three episodes); these were seen mainly because of their chronic dizziness. Among the non-vestibular dizziness group, the most frequent diagnosis was vestibular migraine. Age and somatic anxiety level were different between groups. The mean time taken for each type of vestibular test in a patient subset was 35 ± 15 minutes for caloric testing, 48 ± 24 minutes for rotatory chair testing and 5 ± 2 minutes for video head impulse testing. These differences were significant ($p = 0.001$).

The caloric test was abnormal in 72 patients (62.1 per cent), of whom abnormal canal paresis was present in 67 (57.7 per cent). The rotatory chair was abnormal in 71 patients (61.2 per cent), the video head impulse test was abnormal in 73 (62.9 per cent) and gain asymmetry was abnormal in 46 patients (39.7 per cent). Some patients had two abnormal tests: caloric and rotatory chair tests were abnormal in 54 (46.6 per cent), caloric and video head impulse tests were abnormal in 55 (47.4 per cent), and rotatory chair and video head impulse tests were abnormal in 54 (46.6 per cent). All three tests were normal in 17 patients (14.7 per cent) and all three were abnormal in 46 (39.6 per cent). Results of the correlation study are shown in Table II.

Two different approaches were used to distinguish between vestibulopathy and no vestibulopathy: serial and in parallel. In the first, peripheral vestibulopathy was diagnosed when all three tests were abnormal: this approach had a sensitivity of 0.547, a specificity of 0.878, a positive predictive value of 0.891 and a negative predictive value of 0.514. In the second, peripheral vestibulopathy was diagnosed when only one test was abnormal: this approach had a sensitivity of 0.933, a specificity of 0.292, a positive predictive value of 0.701 and a negative predictive value of

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TABLE I
DEMOGRAPHICS AND DISABILITY LEVEL BY PATIENT GROUP

Variable	PV ($n = 75$)	No PV ($n = 41$)	p value*
Age (mean ± SD), years	56 ± 2	49 ± 4	0.001
Sex (male:female)	36:39	24:17	
Specific diagnosis	Definite Ménière's disease, 34; vestibular neuritis and sequelae, 12; BPPV sequelae, 11; otosclerosis, 5; vestibular schwannoma, 3; iatrogenic, 3; labyrinthitis, 3; cochlear implant, 1; probable Ménière's disease, 1; chronic otitis media, 1; immune-mediated syndrome, 1	Vestibular migraine, 15; chronic dizziness, 13; central vestibular, 4; anxiety-associated dizziness, 3; post-traumatic, 2; unidentified, 2; transient ischemic attacks, 2	
DHI (mean ± SD)	33 ± 4	36 ± 6	0.243
VSS anx (mean ± SD)	8 ± 1	11 ± 2	0.021
VSS sev (mean ± SD)	9 ± 1	10 ± 2	0.812
CIEV† (mean ± SD)	12 ± 1	13 ± 2	0.894

*Two-tailed chi-square test or Fisher exact test for categorical variables, two-tailed Mann–Whitney test for continuous variables. †Questionnaire for measuring the emotional impact of vertigo. PV = peripheral vestibulopathy; SD = standard deviation; DHI = dizziness handicap inventory test; VSS = vertigo symptom scale for anxiety symptoms and severity of symptoms; CIEV = cuestionario de impacto emocional del vértigo; anx = anxiety symptoms; sev = severity of symptoms

TABLE II
BETWEEN-TEST CORRELATIONS

Test correlation	Cohen's κ (95% CI)	Spearman's ρ	Po (%)	Po^+ (%)	Po^- (%)
CAL *vs* ROT	0.279* (0.105–0.456)	0.362*	69.8	60.7	75.5
CAL *vs* vHIT	0.356* (0.182–0.531)	0.356*	69.8	59.7	75.8
ROT *vs* vHIT	0.341* (0.166–0.517)	0.341*	68.9	59.1	75

*$p < 0.001$. CI = confidence interval; Po = overall agreement; Po^+ = positive agreement; Po^- = negative agreement; CAL = caloric test; ROT = rotatory chair test; vHIT = video head impulse test

0.705. Results of the different tests and evaluation methods are shown in Table III.

Discussion

Study participants were selected without bias regarding inclusion criteria other than the indication that a vestibular test should be performed (according to the criteria already described) and their willingness to undergo all three tests. It should be emphasised that because the study was performed in a tertiary centre and specialised otoneurology unit, there were differences in the most frequent diagnoses and other epidemiological data compared with other similar centres.[2,18,19] Moreover, in this study, the sex distribution differed somewhat from that described in others because it included more men than women. The study population comprised patients with a moderate level of disability and handicap, as measured by the dizziness handicap inventory total score and vertigo symptom scale questionnaire; the prognosis of all was considered good according to CIEV test results.

Two main conclusions of this study shall be discussed. Firstly, concordance among tests is weak.[20] This finding was expected because the tests clearly differ on two points: the stimulus frequency and the structures and processes involved in the response. However, it is notable that the κ coefficient is low and that agreement among positive (i.e. abnormal) and negative (i.e. normal) tests is high; this may be due to a low ability to detect abnormalities (vestibular deficit) or to significant disagreement among tests about what is considered normal or abnormal. The first possibility can be excluded because the number of patients with a single abnormal test is high (61–63 per cent, depending on the test) because of the selection criteria: canal paresis or directional preponderance in the caloric test, gain or refixation saccades in the video head impulse test, and vestibulo-ocular reflex asymmetry in the rotatory chair test. This may be explained by differences among tests in the definition of normal asymmetry after right and left ear stimulation: it is much higher for the caloric test (20 per cent for canal paresis and 28 per cent for directional preponderance) and the rotatory chair test than for the video head impulse test (normal gain symmetry is less than 9 per cent).

Previous reports indicated that data from the three tests are complementary. If the test data are of physiopathological interest, then we must determine the benefit of obtaining a large amount of information from a single patient. Previous work has shown that the video head impulse and rotatory chair tests track

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TABLE III
STATISTICAL CHARACTERISTICS OF EACH TEST

Test	Measure	PV (n = 75)	No PV (n = 41)	Spearman's ρ	Spearman's ρ (p value)	Sens	Spec	PPV	NPV
CAL	Canal paresis (mean ± SD), %	48 ± 35	20 ± 19	−0.416	<0.001	0.773	0.658	0.806	0.613
	Overall result (n (%))			−0.425	<0.001				
	– Normal	17 (22.7)	27 (65.8)						
	– Abnormal	58 (77.3)	14 (34.1)						
vHIT	G_s (mean ± SD), %	14 ± 17	5 ± 10	−0.207	0.026	0.747	0.585	0.761	0.558
	Overall result (n (%))			−0.329	<0.001				
	– Normal	19 (25.3)	24 (58.5)						
	– Abnormal	56 (74.6)	17 (36.6)						
ROT	TCrw (mean ± SD), sec	12.3 ± 11.8	14 ± 13.2	0.330	<0.001	0.747	0.634	0.788	0.558
	TClw (mean ± SD), sec	15.5 ± 13.7	17.1 ± 14.8	0.152	0.104				
	SHA overall result (n (%))			−0.374	<0.001				
	– Normal	19 (25.3)	26 (63.4)						
	– Abnormal	56 (74.7)	15 (36.6)						
Any test	Abnormal	70 (93.3)	29 (70.3)	−0.306	0.001	0.933	0.292	0.701	0.705
All three tests	Abnormal	41 (54.7)	5 (12.2)	−0.415	0.001	0.547	0.878	0.891	0.514

PV = peripheral vestibulopathy; Sens = sensitivity; Spec = specificity; PPV = positive predictive value; NPV = negative predictive value; CAL = caloric test; vHIT = video head impulse test; G_s = gain asymmetry; ROT = rotatory chair test; TCrw = time constant for rightward stimulation; sec = second; TClw = time constant for leftward stimulation; SHA = sinusoidal harmonic acceleration test

modest changes in the deficit side (compared with caloric testing) in patients who have suffered acute unilateral vestibulopathy; differences between the former tests are found when central compensation is evaluated.[21] For this reason, this study established sufficient criteria to consider the test abnormal when both the vestibular deficit and compensation were considered.

- **Several peripheral vestibular function tests measuring horizontal semicircular canal function are available**
- **Diagnostic agreement among tests is low**
- **The video head impulse test has sufficient statistical power to justify its use as the first-line test**

The second conclusion of this study is that for differential diagnosis, the test data should not be of physiopathological interest, and the best algorithm for detecting peripheral vestibulopathy should be identified. Data on the specificity, sensitivity, and positive and negative predictive values fit well with the type of patients who attend our out-patient clinic, including a high proportion of peripheral vestibulopathy patients. That is, the positive and negative predictive values are high and low, respectively. These patients have an unambiguous clinical history that makes them easily identifiable at a very early disease stage. Diagnosis is more problematic for patients with an ambiguous clinical history and for whom clinical data may be insufficient or of little assistance. In these patients, a test with the highest sensitivity or negative predictive value is more useful. In this study, one abnormal test was found to be sufficient for diagnosis because the sensitivity and negative predictive value were greater compared with conditions in which all tests must be abnormal for diagnosis. Moreover, results were very similar among tests and differences in statistical performance were low. The caloric test gave the best results but the second best test (the video head impulse test) was almost as good.

Although this was not a formal screening study, the Wilson–Jungner criteria for appraising the validity of a screening programme can help to decide which are the best measures to use for diagnosis. When deciding which test to use (other than sound characteristics), these researchers stated that the 'test should be acceptable to the population'.[22] The duration of the video head impulse test is much shorter compared with the caloric and rotatory chair tests, and the associated discomfort is lower for the video head impulse test, and comparable for the caloric and rotatory chair tests. Therefore, the video head impulse test may be more acceptable to patients. Recent reviews on screening programmes reported some additions to the Wilson–Jungner criteria such as the opportunity cost (including testing, diagnosis and treatment, administration, training and quality assurance) which should be balanced with expenditure on overall medical care.[23] A cost analysis of the tests used in this study was not performed, but costs associated with the rotatory chair and caloric tests are presumed to exceed those of the video head impulse test. Taken together, study data indicate that using the video head impulse test in the first out-patient evaluation fulfils the recommendations for differential diagnosis of vestibulopathy. The patient type and specific study aim(s) should determine which later tests should be performed.

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