Rotational chair testing in patients with unilateral peripheral vestibular disorders

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Objective
The aim of the study was to evaluate the rotational chair (RC) sinusoidal harmonic acceleration (SHA) test and the rotational velocity step (RVS) test in patients with unilateral peripheral vestibular disorders.

Study design
This study was retrospective in nature.

Setting
It was conducted in a clinical tertiary care vestibular function test center.

Patients
A total of 119 patients (63 men and 56 women) with documented unilateral peripheral vestibular lesions were evaluated with bithermal binaural caloric and sinusoidal and step velocity RC tests.

Intervention
Clinical, caloric, and RC tests were carried out.

Patients and methods
The study group was selected by including patients with a clinical diagnosis suggestive of peripheral vestibular lesions and with documented unilateral caloric weakness matching the clinical diagnosis, and by excluding patients with a clinical diagnosis suggestive of a peripheral vestibular lesion but not documented by unilateral caloric weakness, as well as patients with incomplete tests or uninterpretable data (due to poor recordings or eye movement artifacts). Caloric testing was performed using an infrared video-oculographic system and a Brookler–Grams closed-loop irrigation unit with standard bithermal irrigations of 30 and 44°C for 45 s each in the following order: L30°C, R30°C, R44°C, and L44°C. The RC testing paradigms used in this study were the rotational SHA test and the RVS test.

Results
When patients were classified on the basis of etiology, the most common cause of dizziness in the study group was found to be Ménière's disease (34.9%), followed by vestibular neuritis (31.1%). Seventy-two patients in the study group demonstrated right caloric weakness and 47 patients demonstrated left caloric weakness, whereas only 18 of 119 patients demonstrated directional preponderance. When the RC SHA test parameters (gain, phase, and symmetry) in the study group were compared with the manufacturer's normal values, statistically significant difference was seen in vestibulo-ocular reflex (VOR) gain at low frequencies (0.01–0.08 Hz), in VOR phase at all frequencies, and in VOR symmetry at low frequencies (0.01–0.04 Hz).

Conclusion
In summary, despite the encouraging results of the discriminating power of caloric testing, it should be emphasized that RC testing has its own unique capabilities, such as the following: (i) it is a physiologic stimulus whose frequency and amplitude can be varied precisely; (ii) the stimulus is unrelated to physical features of the external ear or temporal bone; (iii) it is useful in children who may not tolerate caloric testing; and (iv) it is very useful in assessing patients receiving vestibulotoxic drugs. Multiple stimuli of varying intensities can be applied to the vestibular system within a relatively short period of time.

Keywords:
asymmetry, caloric test, gain, phase, rotational chair test, time constant

Introduction

Balance is a complex sensorimotor task involving three steps:

(1) Accurate and redundant sensory input from the visual, vestibular, and proprioceptive systems;

(2) Central nervous system integration of the sensory signals and the generation of appropriate motor commands; and

(3) Adequate musculoskeletal capabilities to perform the motor tasks involved in oculomotor and posture control.

A defect in any one or more sensory integration and motor functions can lead to inappropriate muscle activity and imbalance [1].

Peripheral vestibular disorders are considered one of the most common causes of dizziness and vertigo. Peripheral vestibular deficit is defined as any disease process that results in damage, either partial or complete, to only one side or both sides of the peripheral vestibular system involving the vestibular end organs and/or the vestibular nerve [1]. The pathophysiology of peripheral vestibular disorders may be classified into the following:

(1) Abnormalities of coupling (conduction) of head motions to the canal or macular receptor hair cells;
(2) Abnormalities of the canal or macular hair cell receptors (sensory) and peripheral nerve supply (neural);
(3) Combination of the first two categories (mixed) [2].

The ability to evaluate the range of physiological functions using electronystagmography is limited, given that the use of caloric irrigation stimulates the system in a manner equivalent to a frequency between 0.002 and 0.004 Hz and accelerations of less than 10°/s. These values are below the level within which the vestibulo-ocular reflex (VOR) generally functions in daily activities [3]. Therefore, rotational chair (RC) testing has been used to expand the evaluation of the peripheral vestibular system as it can stimulate frequencies in the 0.01–1.28 Hz frequencies, which are considered more physiologic frequencies [4]. RC testing is a test in which sequences of sinusoidal angular velocity signals at several test frequencies are applied for evaluation of the VOR function [5].

Zee [6] reported that RC testing may provide valuable information for the diagnosis and subsequent management of patients with vestibular disorders. It completes the spectrum of tests necessary for diagnosing vestibular abnormalities, and assists in identification of peripheral vestibular deficits not detectable by other vestibular tests [6]. In contrast, Cass [7] mentioned that the major clinical advantage of computerized rotational testing is the ability to produce angular accelerations that can be precisely controlled and repeated. Multiple stimuli of varying intensities can be applied to the vestibular system within a relatively short period of time [7].

RC testing is ideal in the assessment of patients suffering from peripheral vestibular disorders because, unlike caloric testing, higher frequencies are also tested and both labyrinths are stimulated simultaneously. This allows for accurate determination of the remaining vestibular function. Thus, it can differentiate central from peripheral and compensated from uncompensated vestibular disorders through abnormalities detected in gain, phase, symmetry, and time constants [8]. The aim of this study was to demonstrate the RC sinusoidal harmonic acceleration (SHA) test and the rotational velocity step (RVS) test in patients with unilateral peripheral vestibular disorders.

Patients and methods

After obtaining approval from the institutional review board, 250 charts of patients with complaints of dizziness and balance problems were randomly selected for retrospective review; all patients were referred for caloric and RC testing. A total of 119 charts were selected out of the 250 patient charts on the basis of the following criteria:

(1) Clinical diagnosis suggestive of peripheral vestibular lesions.
(2) Documented unilateral caloric weakness matching the clinical diagnosis.
(3) Exclusion of patients with a clinical diagnosis suggestive of peripheral vestibular lesion but not documented by unilateral caloric weakness, as well as patients with incomplete tests or uninterpretable data (due to poor recordings or eye movement artifacts).

The clinical diagnosis was made independently of the caloric and RC test results on the basis of a combination of detailed history taking, physical examination, bedside neuro-otologic examination, audiologic evaluation, and radiologic studies as clinically indicated. The entire study group was subjected to the following tests.

Caloric stimulation

Caloric testing was performed using an infrared video-oculographic system (Micromedical Technologies, Chatham, Illinois, USA) and a Brookler–Grams closed-loop irrigation unit with standard bithermal irrigations of 30 and 44°C for 45 s each in the following order: L30°C, R30°C, R44°C, and L44°C.

The caloric test variables used in this study were the percentage of caloric weakness (CW) as calculated using the Jongkees Index formula.

Rotational stimulation

RC testing was performed using Micromedical Technologies System 2000 with the standard commercially available software (4 Channel Spectrum S1.0.3, Micromedical Technologies , Inc., 10 Kemp

Drive, Chatham, Illinois 62629, USA) for test analysis. The patient was positioned and secured to the RC housed in a darkened booth with the patient's head restrained and adjusted so that both lateral semicircular canals were close to the plane of stimulus. During rotation, the patient was instructed to keep his/her eyes open and was given appropriate mental alerting tasks.

First, the SHA test of the VOR was performed. The derived parameters were the VOR gain (ratio of the amplitude of peak slow-component eye velocity vs. head velocity), phase (time between eye and head movement), and symmetry (comparison of eye velocity during rightward vs. leftward rotation), which were measured at 0.01, 0.02, 0.04, 0.08, 0.16, 0.32, and 0.64 Hz, with a peak angular velocity of 60°/s.

After SHA testing, the RVS test was performed using100°/s velocity to the right (clockwise) and left (counter-clockwise). The entire procedure was performed with both clockwise and counter-clockwise initial rotation. There were two bursts of nystagmus for each per-rotatory:

(1) Prerotatory nystagmus, which starts with the initial acceleration of the chair; and
(2) Postrotatory nystagmus, which starts with the complete stop of the chair.

The derived parameter is the time constant (Tc), which represents the time in seconds for the nystagmus slow-component velocity to decay to 37% of its peak value. Overall, four time constants were identified for each patient.

Statistical analysis
SPSS (version 13.0; SPSS Inc., Chicago, Illinois, USA) for Windows was used. Results are presented as percentage, mean, and SD. The paired t-test was used to compare results between the study group and the manufacturer's normal values. Level of significance was set at P-values less than or equal to 0.05.

Results
Table 1 demonstrates the demographic characteristics of the study group (119 patients): the age range was 22–79 years, and there were 63 men and 56 women. When patients were categorized according to etiology, the most common cause of dizziness in the study group was found to be Ménière's disease (34.9%), followed by vestibular neuritis (31.1%) (Fig. 1).

Table 2 shows that 72 patients in the study group had right caloric weakness and 47 patients had left caloric weakness, whereas only 18 of 119 patients demonstrated directional preponderance.

Table 3 shows the comparison of the RC SHA test parameters (gain, phase, and symmetry) in the study group with the manufacturer's normal values. Statistically significant difference was seen in VOR gain at low frequencies (0.01–0.08 Hz), in VOR phase at all frequencies, and in VOR symmetry at low frequencies (0.01–0.04 Hz).

Table 1 Descriptive demographic features of the study group

Features	Study group
Age (years)	
Range	22–79
Mean ± SD	58.23 ± 15.13
Sex	
Men	63
Women	56
Total	119

Table 2 Mean (X) and SD for the caloric test parameters (unilateral weakness and directional preponderance) in the study group
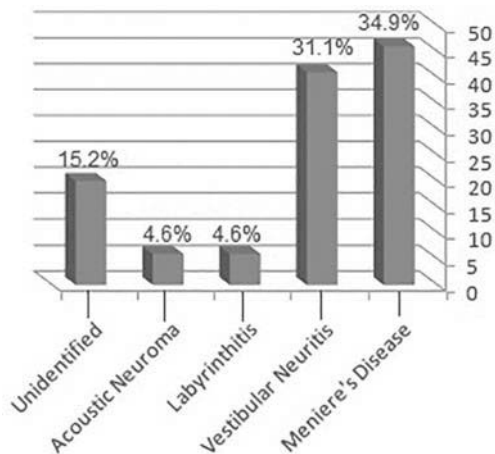
Caloric test parameters	N (%)	X	SD	Range Minimum	Range Maximum
Unilateral weakness					
Right	72 (60)	42.85	10.88	25	68
Left	47 (40)	39.14	9.21	27	54
Directional preponderance	18 (15)	29.44	3.26	24	38

Table 3 Mean (X), SD, t-values, and P-values of vestibulo-ocular reflex gain, phase, and symmetry for the study group compared with the manufacturer's normal values

SHA tests	Manufacturer X	Manufacturer SD	Study group X	Study group SD	t-Value	P-value
Gain						
0.01	0.51	0.04	0.29	0.06	6.78	<0.05
0.02	0.57	0.09	0.39	0.18	5.75	<0.05
0.04	0.59	0.08	0.42	0.25	4.21	<0.05
0.08	0.66	0.05	0.54	0.22	3.27	<0.05
0.16	0.65	0.09	0.62	0.07	1.44	>0.05
0.32	0.67	0.04	0.64	0.32	0.14	>0.05
0.64	0.67	0.05	0.47	0.08	0.23	>0.05
Phase						
0.01	-40.33	10.12	-55.62	13.89	2.78	<0.05
0.02	–21.78	6.67	–33.46	8.32	3.22	<0.05
0.04	–12.87	2.21	–18.56	6.86	3.22	<0.05
0.08	-4.67	2.14	-9.76	4.46	3.77	<0.05
0.16	-6.04	1.98	-6.88	5.22	1.56	<0.05
0.32	0.92	3.31	–2.34	5.33	3.15	<0.05
0.64	6.33	2.35	0.67	2.22	5.26	<0.05
Symmetry						
0.01	5.99	3.98	11.32	9.44	2.67	<0.05
0.02	4.72	2.96	9.87	8.78	1.95	<0.05
0.04	4.27	2.77	8.64	8.53	3.15	<0.05
0.08	4.95	4.22	6.43	7.32	2.11	>0.05
0.16	5.6	3.99	7.88	7.01	2.31	>0.05
0.32	6.03	4.46	7.22	6.25	0.88	>0.05
0.64	3.78	3.97	5.43	3.97	2.32	>0.05

SHA, sinusoidal harmonic acceleration.

Figure 1

Pie chart showing distribution of the study group according to the suspected cause of dizziness.

Tables 4 and 5 show the correlation between the side of caloric weakness and the clockwise and counter-clockwise stimulation of the step velocity test.

When RC step velocity test parameters (gain and time constant) in patients with right caloric weakness were compared with the manufacturer's normal values we found a statistically significant reduction in the gain and time constants of the clockwise prerotatory and counter-clockwise postrotatory parts of the step velocity test (Table 4).

When RC step velocity test parameters (gain and time constants) in patients with left caloric weakness were compared with the manufacturer's normal values we found a statistically significant reduction in the gain and time constants of the clockwise postrotatory and counter-clockwise prerotatory parts of the step velocity test (Table 5).

Table 6 shows the following findings:

(1) The highest sensitivity of the RVS time constant is with phase.
(2) The highest specificity of the RVS time constant is with gain.
(3) The highest positive predictive value of the RVS time constant is with phase.
(4) The highest negative predictive value of the RVS time constant is with symmetry.

Discussion

The present study was conducted on 119 patients with definite unilateral peripheral vestibular lesions, suspected on clinical diagnosis and documented by

Table 4 Mean (*X*), SD, *t*-values, and *P*-values of the rotatory chair velocity step test in the study group with right caloric weakness as compared with the manufacturer's normal values

Rotatory velocity step tests	Manufacture		Study group (right CW)		*t*-Value	*P*-value
	X	SD	*X*	SD		
Clockwise						
Prerotatory						
Gain	0.55	0.11	0.34	0.05	6.67	<0.05
TC	14.8	3.21	10.41	2.22	6.9	<0.05
Postrotatory						
Gain	0.57	0.19	0.51	0.06	3.22	>0.05
TC	15.5	2.99	15.1	1.56	1.38	>0.05
Counter-clockwise						
Prerotatory						
Gain	0.49	0.47	0.55	0.08	2.11	>0.05
TC	14.5	3.24	15.2	2.64	1.98	>0.05
Postrotatory						
Gain	0.52	0.14	0.35	0.08	5.22	<0.05
TC	15.3	2.51	11.1	1.22	8.11	<0.05

Table 5 Mean (*X*), SD, *t*-values, and *P*-values of the rotatory velocity step test for both the study group with left caloric weakness and the manufacturer's normal values

Rotatory velocity step tests	Manufacturer		Study group (left CW)		*t*-Value	*P*-value
	X	SD	*X*	SD		
Clockwise						
Prerotatory						
Gain	0.55	0.11	0.57	0.05	1.66	<0.05
TC	14.8	3.21	14.7	2.31	1.77	<0.05
Postrotatory						
Gain	0.57	0.19	0.29	0.09	5.99	>0.05
TC	15.5	2.99	10.5	1.9	4.88	>0.05
Counter-clockwise						
Prerotatory						
Gain	0.49	0.47	0.34	0.02	5.01	>0.05
TC	14.5	3.24	8.5	2.6	6.47	>0.05
Postrotatory						
Gain	0.52	0.14	0.55	0.04	0.88	<0.05
TC	15.3	2.51	15.9	1.66	1.33	<0.05

Table 6 Sensitivity, specificity, and positive and negative predictive values for the rotatory velocity step test (time constant) as compared with the caloric test and the sinusoidal harmonic acceleration test

Reference tests	Rotatory velocity step test (time constant)			
	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Caloric test				
Caloric weakness	68.3	28.6	75.6	56.7
SHA test				
Gain	79.9	44.5	79.4	34.2
Phase	95.6	42.6	91.3	43.5
Symmetry	74.8	28.2	57.2	69.2

SHA, sinusoidal harmonic acceleration; PPV, positive predictive value, NPV, negative predictive value.

unilateral caloric weakness. The mean age of the study group was 58.23 ± 15.13 years. The sex distribution was

tilted toward men (53% of men vs. 47% of women) (Table 1). Kamal et al. [9,10] noticed light increase in peripheral vestibular disorders among men. However, Stahle and Arenberg [11] and Tokumaso et al. [12] reported that peripheral vestibular disorders are more common in women than in men.

The present study demonstrated that the most common cause of peripheral vestibular disorders in the study group was Ménière's disease (34.9%), followed by vestibular neuritis (31.1%) (Fig. 1). El-Gohary et al. [13] reported another observation in a similar study on patients with peripheral vestibular disorders in which the most common was benign paroxysmal positional vertigo (35%), followed by vestibular neuritis (30%), ototoxicity (20%), and Ménière's disease (15%). This discrepancy between the two studies could be attributed to the selection criteria of the study group [13].

In this study, one of the selection criteria was presence of unilateral caloric weakness; therefore, 100% of the study group had unilateral caloric weakness, 60% had right caloric weakness, and 40% had left caloric weakness. Unilateral caloric weakness was considered when the difference in the mean maximum slow-phase velocity exceeded 20%. In contrast, other studies demonstrated normal caloric response in patients with peripheral vestibular lesions. For example, Haid et al.[14] reported abnormal caloric test results in only 54% of patients with peripheral vestibular lesions, similar to the report of Stahle [15]. Diagnosis of peripheral vestibular lesions with normal caloric response and abnormal RC testing in terms of reduced time constant, low gain, and asymmetrical responses to the rotational stimuli was also reported by Shepard and Telian [17] and Takahashi et al. [16], who reported such an observation in 10 of 47 dizzy patients with normal caloric responses.

The observation of normal caloric response and abnormal RC testing in patients with suspected peripheral vestibular lesions could be attributed to the fact that the caloric test assesses the integrity of the peripheral vestibular system through stimulation of the horizontal semicircular canals. The stimulus of warm, cool, or ice water is equivalent to rotational stimulation at a frequency of 0.002–0.004 Hz. These levels of stimulation are significantly lower than those experienced by the VOR system on a daily basis and may not identify dysfunction at higher frequencies in the 0.01–1.28 Hz range, which are considered more higher and physiological frequencies [4].

In this study, 18 (15%) patients showed directional preponderance (Table 2).

Fourteen of those 18 patients showed asymmetry in RC testing. Such consistent association of directional preponderance (caloric testing) and asymmetry of the SHA test was noticed by Shepard and Telian [17]. This observation could be explained by the presence of response bias within the system, favoring larger slow-component velocities in one direction versus the other. A bias usually results from a peripheral lesion with incomplete dynamic compensation in the central nervous system [17].

Jacobson et al. [18] stated that directional preponderance exists when the nystagmus response to horizontal semicircular canal stimulation is stronger in one direction than in the other. This is particularly apparent in patients with acute uncompensated unilateral peripheral vestibular lesions [18]. Black [2] reported that directional preponderance tended to be directed toward the unimpaired ear in patients with a history of short duration vestibular deficits. Directional preponderance is clinically diagnosed when there is a 25% or greater difference in intensity of maximum slow-phase velocity between right beating and left beating responses [19].

The SHA test was conducted at frequencies of 0.01–0.64 Hz. It revealed reduced gain limited to low frequencies (0.01–0.08 Hz) (Table 3), which agreed with the findings of El-Gohary et al. [13]. There was also phase lead at all frequencies and asymmetry was limited mainly to the low frequencies (0.01–0.04 Hz). The reduction in VOR gain could be considered as reduced vestibular response due to reduction in the input/output function between eye and chair velocities [This reflects that chair velocity (stimulus) was higher than eye velocity (response)] [20]. Koizuka et al. [21] reported that the abnormal VOR gain in peripheral vestibular disorders is due to loss of velocity storage mechanism, which normally functions to maintain the vestibular response.

The RVS test revealed reduced gain and time constants for rotation toward the side of the lesion in the study group (Tables 4 and 5). Similar findings were reported by Baloh et al. [22], who examined 48 patients with unilateral significant reduction in gain and time constants for rotation toward the side of the lesion. In this study, as shown in Tables 4 and 5, there was consistent association between the side of the lesion on caloric testing and the RVS test in which patients with right caloric weakness showed statistically significant reduction in the gain and time constants of the clockwise prerotatory and counter-clockwise postrotatory parts, and patients with left caloric weakness showed statistically significant reduction in the gain and time constants of the clockwise postrotatory and counter-clockwise prerotatory parts [22].

Shepard [4] stated that, although both ears are involved in responses to rotatory stimuli, the right periphery (horizontal semicircular canal and superior vestibular nerve) is primarily responsible for responding to accelerations to the right or to decelerations from fixed velocity rotation leftward. The reverse is true for the left labyrinth. Therefore, prerotatory and postrotatory step tests also allow comparison of the time constant for dominant stimulation to one peripheral system.

Table 6 demonstrates the sensitivity, specificity, and positive and negative predictive values of the RVS time constant in relation to the caloric test and the gain, phase, and asymmetry of the SHA test. The highest sensitivity was between the RVS time constant and phase (95.6%), whereas the highest specificity was with gain (44.5%). Ideally, the RVS test and the SHA test can be employed in parallel to increase the accuracy of estimates of the system time constant and identification of the abnormally functioning system.

Palomar-Asenjo et al. [23] studied the caloric and RC tests in 100 patients with unilateral Ménière's disease and reported that the caloric test was fairly specific for patients with unilateral peripheral vestibulopathy, whereas the RC test was more sensitive. They attributed these findings to the fact that the time constant of the VOR is more stable than the canal paresis of the caloric test in test–retest reliability studies [23].

Conclusion

The combination of caloric test and RC testing produced the strongest predictive capabilities for identifying peripheral vestibular injury. This finding reinforces the common belief that the caloric and RC tests are complementary tests in evaluating dizzy patients. One explanation for this finding may be that caloric stimulation is equivalent to a very low-frequency rotation of 0.002–0.004 Hz, which falls substantially below the lowest frequency of the RC test (0.01–1.0 Hz) [4]. Therefore, RC testing has been used to expand the evaluation of the peripheral vestibular system.

Despite the encouraging results of the discriminating power of caloric testing, it should be emphasized that RC testing has its own unique capabilities, such as the following:

(1) It is a physiologic stimulus whose frequency and amplitude can be varied precisely;

(2) The stimulus is unrelated to physical features of the external ear or temporal bone;
(3) It is useful in children who may not tolerate caloric testing; and
(4) It is very useful in assessing patients receiving vestibulotoxic drugs [4].

Recommendations

On the basis of the current study, we recommend studying the RC test in patients with bilateral peripheral vestibular disorders and in patients with central vestibular disorders and using the RC test as an objective measure of the outcome of vestibular rehabilitation therapy in these patients.

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