

ORIGINAL ARTICLE

Dynamic visual acuity during head-thrust test in canal planes in healthy subjects and patients with vestibular neuritis

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Abstract

Conclusions: Dynamic visual acuity (DVA) during the head-thrust test (htDVA) is reliable in normal subjects, having a high specificity for the horizontal canal, so it may be useful to monitor vestibular rehabilitation in patients with vestibular neuritis (VN). **Objective:** To obtain reference values for htDVA in healthy individuals and to investigate the potential application in subjects with unilateral VN. **Methods:** A total of 73 healthy individuals and 50 patients with unilateral VN were included. The DVA test was performed by adjusting a sensor on the subject's head to measure head velocity. During head thrust, the optotype flashed if the head velocity reached 150°/s, as previously defined, and a DVA score was obtained for each canal. **Results:** The htDVA was reliable in normal subjects (intra-class correlation coefficient (ICC) = 0.44–0.71; $p = 0.001–0.007$). The htDVA score showed an age-dependent increase for all canals ($p < 0.0001$). The 95th percentile of htDVA was used as the criterion to consider htDVA as abnormal in patients with VN. In all, 44%, 30%, and 16% of patients had an increase in htDVA score for one, two or all three canals on the affected side. The sensitivity and specificity of the htDVA test for the horizontal canal were 22% and 85%, respectively.

Keywords: Vestibular rehabilitation, vestibular testing, vestibular system, angular vestibulo-ocular reflex

Introduction

The angular vestibulo-ocular reflex (aVOR) stabilizes the images on the retina during angular head accelerations. Visual acuity during head rotations in the horizontal plane can be used as a clinical test to monitor the horizontal canal aVOR in individuals with vestibular hypofunction. Moreover, the change from static visual acuity to visual acuity during head rotation movements can be quantified using the dynamic visual acuity (DVA) test, in which a subject's visual acuity during head rotations is measured using optotype characters presented only while the head is moving at known head velocities [1]. DVA has been evaluated using self-generated sinusoidal head rotations in the horizontal plane [1] and during sinusoidal pitch head movements [2]; however, vertical self-generated head rotations have a low sensitivity for diagnosis of unilateral vestibular

hypofunction [2], and this limits its utility to horizontal canal in clinical practice.

The head-thrust (ht) test is a passive, unpredictable, manual head rotation with a low amplitude of 20–30°, velocity of 150°/s and high acceleration of 3000°/s² that is routinely used as a sign of horizontal canal hypofunction [3]. The patient is instructed to keep looking straight ahead and the test is considered positive when refixation saccadic movements to the original fixation point are observed in the opposite direction to the horizontal canal stimulated and indicates an impairment of the aVOR. The specificity of the ht for identifying patients with unilateral vestibular hypofunction is 95–100% [3,4], but the sensitivity is variable [5]. By using 3D scleral coils and a diagonal impulse, these observations were also extended to posterior and anterior canals, suggesting that the ht test in canal planes could be used to detect loss

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(Received 8 February 2010; accepted 15 March 2010)

ISSN 0001-6489 print/ISSN 1651-2251 online © 2010 Informa UK Ltd. (Informa Healthcare, Taylor & Francis AS)
DOI: 10.3109/00016481003785994

of individual canal function in patients following vestibular neurectomy [6], and in individuals with superior and inferior vestibular neuritis (VN) [7].

Passive and unpredictable ht in canal planes can be used as a reliable stimulus to measure individual canal aVOR. DVA has been used to estimate the individual canal function of semicircular canals using the ht (htDVA) in the direction of maximum sensitivity of each canal in a sample of 19 healthy controls, in 5 patients after plugging the superior canal for treatment of superior canal dehiscence, and in 2 subjects after vestibular neurectomy [8]. This approach could be useful to monitor DVA in patients with vestibular hypofunction.

The aim of the study was to use ht in canal planes to obtain reference values of DVA in healthy subjects and to explore their potential utility in the evaluation of patients with unilateral VN.

Material and methods

Subjects

We studied a series of 73 individuals without clinical history of vertigo or hearing loss (control group) from January 2008 to June 2009 by the htDVA. In addition, 50 consecutive patients with acute unilateral VN were prospectively evaluated (25 left, 25 right VN). All patients met the clinical diagnostic criteria for VN: 1) an episode of sudden onset of prolonged vertigo (more than 24 h) with vestibular hypofunction (unidirectional spontaneous horizontal-torsional nystagmus, contralateral deviation of vestibulo-spinal reflexes, and reduced or absent caloric response); 2) absence of other auditory or neurological findings, and 3) no previous history of neuro-otologic disease. Physical examination included examination of the ears, Rinne and Weber test, pure tone audiometry, and a basic neuro-otologic examination including the horizontal canal ht test [3]. The diagnostic protocol included an MRI scan of the brain to exclude other causes of neuro-otological disorders mimicking peripheral vestibulopathy.

Individuals with sensorineural hearing loss were excluded to avoid the inclusion of patients with a first episode of Meniere's disease. Patients with perforation of the tympanic membrane or those with a cognitive or psychiatric disorder were also excluded because of potential problems in performing the caloric test.

Written information was provided to the patients and an informed consent was obtained for all the individuals after explaining the purpose of the study in accordance with a protocol approved by the Hospital de Poniente Research and Ethical Review Board.

Vestibular examination

A standard caloric test was performed in all individuals with VN by using a Variotherm Plus model water irrigator (Atmos, Berlin, Germany), with a water flow of 250 ml/20 s at 30°C and 44°C. The procedure and reference values for canal paresis in our laboratory have been described previously [9].

Head-thrust test during DVA

A passive, unpredictable manual ht was used as the stimulus for each semicircular canal. Before the start of each ht, the subject's head was placed in the zero reference position for 5 s, enabling eye and head angular position to be calibrated in vivo while the subject fixated an optotype on a screen, which was positioned directly in front of the subject at 3 m along the naso-occipital axis. The room was completely dark except for this monitor. Head thrusts were randomly delivered manually in three planes: first, yaw (horizontal canal plane), second, left anterior-right posterior canal plane (LARP), and finally in the right anterior-left posterior canal plane (RALP). To perform the ht for anterior and posterior canals, the head was turned 45° to bring either RALP or LARP into the sagittal plane first. Then a vertical head impulse was used either forward or backward.

DVA test protocol

A detailed description of the DVA test has been reported previously [1,2]. The optotype consisted of a white letter 'C' of mean luminance 83 cd/m² and 95% contrast against a black background of a 15 inch monitor and subjects were seated 3 m in front of the monitor. Subjects who normally used glasses for distant viewing were instructed to wear them during the DVA testing. If glasses were moved during htDVA, then the test was performed without glasses.

Static visual acuity was measured first by displaying the optotype randomly rotated each trial by 0, 90, 180 or 270° on the monitor. Subjects viewed the optotypes to determine acuity level, with optotype size then being decremented in steps equivalent to a visual acuity change of 0.1 LogMAR ($\log_{10}X$, where X = minimum angle resolved, in arcmin, with 1 arcmin = 1/60°). The better one's visual acuity, the lower one's LogMAR score, with LogMAR = -0.3, 0, 0.3, 0.7, 1.0, and 1.3 corresponding to Snellen visual acuity of 20/10, 20/20, 20/40, 20/100, 20/200, and 20/400, respectively.

Static visual acuity was first determined with the subject's head in neutral position. Static visual acuity was scored when the subject failed to correctly identify

three optotypes. For the dynamic evaluation a single-axis rate sensor (Micromedical Technologies, Inc., Chatham, IL, USA) was positioned on the subject's head by a head band to assure that the device was not moved during the test. The sensor's axis of maximum sensitivity was approximately aligned with that of the semicircular canal of interest [8]. For example, when testing the LA and RP canal pair, the sensor was placed at 45° right (subject's perspective) off the midsagittal line bisecting the skull [6]. Horizontal ht to assess horizontal canal function was performed first, followed by LARP and RALP ht. The direction and timing of the ht was randomized within a given semicircular canal-pair plane. During each ht, the optotype was randomly oriented in one of the four directions on the monitor when the head velocity, sensed by the rate sensor, reached 150°/s for more than 40 ms, as previously defined. The optotype flashed on the monitor for no longer than 85 ms, during which the head would have been rotated.

Controls and patients with VN performed one practice trial for self-generated horizontal head rotations before we collected their htDVA score. Then, an experienced examiner (D.V.) delivered random ht in an individual canal plane as explained above. These data were collected to obtain reference values to compare the DVA score in patients with VN with their age-matched controls. For patients with VN, the examiner was blinded as to which side was affected.

The DVA test was usually started with an acuity level worse (optotype bigger) than the reference obtained with the head fixed (static visual acuity) and three trials were performed per optotype. To avoid a wrong response because of blinking or loss of attention, the subject was allowed to view each optotype a maximum of three times, at which point the subject was required to guess the orientation. Once the subject indicated a response, the next trial started and the acuity level was increased sequentially.

The DVA test for a given plane was finished when the subject did not identify correctly three optotypes or reached the static visual acuity level. Depending on the accuracy of the subject's responses, the htDVA test was performed with a higher or lower new acuity level. The time to complete the htDVA was approximately 20 min. The main outcome measure was the htDVA test score at 150 Hz head velocity, which was calculated by subtracting the static visual acuity LogMAR from the htDVA LogMAR score.

Statistical analysis

A descriptive analysis was performed for htDVA scores obtained for all semicircular canals. Regression

analysis was used to investigate the relationship between htDVA score and age. Test-retest reliability was examined using intra-class correlation coefficients. Level of significance for all analyses was $p < 0.05$. Individual htDVA scores for each canal in patients with VN were compared with the age-matched reference value obtained in healthy subjects. DVA scores higher than the value of percentile 95 for each age group were considered abnormal for each canal. Sensitivity, specificity, and positive and negative predictive values for horizontal canal htDVA were calculated using the horizontal canal ht as reference.

Results

Control subjects

Seventy-three healthy individuals were included to obtain reference values for htDVA (Table I). The values of htDVA scores obtained for each semicircular canal in the control subjects are shown in Table II. Test-retest reliability in normal subjects for htDVA scores was determined for a subset of our controls ($n = 30$; age, 41 ± 14 years) by comparing htDVA score for each canal between the first and the second test. The htDVA test was reliable in normal subjects for all canals (intra-class correlation coefficient (ICC) = 0.44–0.71; $p = 0.001$ – 0.007 ; Table III).

Univariate regression analysis demonstrated that htDVA scores showed an age-dependent increase for all canals (Table IV). Hence, we calculated htDVA in different age groups to obtain reference values for each canal and age group (Table V). The value of the 95th percentile of the htDVA score for each age group was used as the criterion to consider htDVA as abnormal in patients with VN.

Vestibular neuritis group

The mean age of the 50 individuals in the VN group was 57 ± 14 , ranging from 18 to 78 years old; there were 25 women and 25 men. The horizontal canal ht was positive for 37/50 cases (74%; 19 left, 17 right, 2 bilateral).

Table I. Age (years) and sex distribution of the healthy subjects who performed the htDVA test ($n = 73$).

Sex	Age group				
	18–30	31–40	41–50	51–60	60–88
Women	9	5	11	10	4
Men	6	6	6	5	11
Total	15	11	17	15	15

Table II. Static visual acuity (SVA) and total htDVA scores obtained for each semicircular canal in healthy subjects ($n = 73$).

Parameter	SVA	LH	RH	LP	RP	LA	RA
Mean	0.082	0.041	0.040	0.042	0.034	0.040	0.044
Median	0.100	0.000	0.000	0.000	0.000	0.000	0.000
SD	0.093	0.080	0.074	0.071	0.067	0.062	0.067
p95	0.200	0.200	0.200	0.200	0.140	0.100	0.200

Score is shown as the difference between dynamic and static visual acuity (LogMAR). Semicircular canals: LH, left horizontal; RH, right horizontal; LP, left posterior; RP, right posterior; LA, left anterior; RA, right anterior. SD, standard deviation; p95, 95th percentile.

The ht DVA was performed at 5 ± 3 months after the clinical diagnosis (range 1–16). In all, 44%, 30%, and 16% of patients had an increase in htDVA score for one, two or all three canals, respectively, on the affected side, suggesting that DVA can be impaired in one individual canal. Eleven cases were evaluated in the first 2 months and five of them (46%) had abnormal scores for htDVA (two for the three canals, one for horizontal and anterior canals, one for the anterior and posterior canals, and one case selectively for the horizontal canal).

In our series 10 (20%) patients had abnormal scores for htDVA for the horizontal canal (Table VI). The sensitivity and specificity of the htDVA test for the horizontal canal was 22 and 85%, respectively. The positive predictive value of htDVA for the horizontal canal (individuals who tested positive on the htDVA and who had a positive ht for the same semicircular canal) was 80%. The negative predictive value (individuals who tested negative on the htDVA and who had a negative ht) was 28%.

Discussion

This study shows that htDVA is a reliable test in control subjects for vestibular evaluation of all

semicircular canals. The test is simple and easy to perform in the clinical setting and it takes approximately 18–20 min. As expected, htDVA is also dependent on age. Specifically, older subjects had poorer visual acuity during ht than younger subjects. This age-dependent performance of DVA was described for the horizontal [1] and vertical head rotations [2]. However, this effect was not reported in the series of 19 normal subjects when the htDVA was described [8]. Aging affects the aVOR gain at several velocities of head rotation [10]. Using a rotatory stimulation at 0.05 Hz with peak velocities of $120^\circ/s$, the mean aVOR gain was reduced by 30% for the horizontal canal (from 0.60 in young individuals to 0.43 in older subjects) [10]. The increase in DVA scores observed with age is probably related to a decrease in aVOR gain for all canals with an increase in retinal slips during the ht.

The htDVA test also gives information on the aVOR gain in anterior and posterior semicircular canals and it may help in the evaluation of vertical canal function in the clinical setting. Although some studies have tried to evaluate vertical canal function using head-shaking or head tilt during sinusoid rotatory stimulation [11,12], the tests for vertical semicircular canal function have been employed in neurophysiology research laboratories [13], but they have not become widely used as clinical tools,

Table III. Test–retest reliability for htDVA at $150^\circ/s$ in normal subjects ($n = 30$).

Parameter	ICC	p value
SVA	0.852	< 0.001
LH	0.519	0.001
RH	0.619	0.000
LP	0.570	0.000
RP	0.708	0.000
LA	0.437	0.007
RA	0.532	0.001

ICC, intra-class correlation coefficient; SVA, static visual acuity; semicircular canals: LH, left horizontal; RH, right horizontal; LP, left posterior; RP, right posterior; LA, left anterior; RA, right anterior.

Table IV. Relationship between htDVA score and age in healthy subjects at $150^\circ/s$ ($n = 73$).

Parameter	r	p value
SVA	0.852	< 0.001
LH	0.519	0.001
RH	0.619	< 0.001
LP	0.570	< 0.001
RP	0.708	< 0.001
LA	0.437	0.007
RA	0.532	0.001

r , regression coefficient; SVA, static visual acuity; semicircular canals: LH, left horizontal; RH, right horizontal; LP, left posterior; RP, right posterior; LA, left anterior; RA, right anterior.

Table V. Reference values for htDVA scores obtained at 150 Hz head velocity in the different age groups.

Age group (years)	LH	RH	LP	RP	LA	RA
18–30						
Mean	0.007	0.007	0.013	0.000	0.020	0.013
SD	0.026	0.026	0.035	0.000	0.041	0.035
95th percentile	0.030	0.030	0.100	0.000	0.100	0.100
31–40						
Mean	0.036	0.018	0.055	0.045	0.018	0.036
SD	0.048	0.039	0.050	0.050	0.039	0.048
95th percentile	0.100	0.100	0.100	0.100	0.100	0.100
41–50						
Mean	0.024	0.024	0.012	0.006	0.018	0.029
SD	0.044	0.044	0.033	0.024	0.039	0.059
95th percentile	0.100	0.100	0.100	0.020	0.100	0.120
51–60						
Mean	0.047	0.033	0.040	0.040	0.067	0.047
SD	0.064	0.062	0.063	0.063	0.062	0.052
95th percentile	0.130	0.130	0.130	0.130	0.130	0.100
> 60						
Mean	0.093	0.107	0.093	0.087	0.073	0.100
SD	0.139	0.116	0.110	0.106	0.088	0.093
95th percentile	0.330	0.300	0.300	0.300	0.230	0.230

Semicircular canals: LH, left horizontal; RH, right horizontal; LP, left posterior; RP, right posterior; LA, left anterior; RA, right anterior.

probably due to the technical difficulties associated with most of the research tests. The ht delivered in the LARP or RALP planes seems to be the best stimulus to explore vertical canal function, but the use of a scleral search-coil system to provide short-latency and three-dimensional eye responses has limited their use to research laboratories. The examination of visual acuity during ht accelerations in canal planes could be a more accessible method to evaluate vertical canal response to ht, since angular accelerometers have become commonly used during vestibular examination and rehabilitation.

The sensitivity of DVA testing depends on the following features: transient head rotation at a peak acceleration of at least $1600^\circ/s^2$, temporal

unpredictability of head motion, directional unpredictability on head motion, and synchronized optotype presentation of a duration not exceeding 75 ms [14]. These conditions minimized extravestibular compensation during DVA testing and demonstrated its utility in unilaterally deafferented subjects [14].

To explore the application of htDVA in clinical practice, we also evaluated the diagnostic effectiveness in patients with VN. Our results demonstrate that htDVA has a low sensitivity and a high specificity for the horizontal canal. This indicates its utility as a diagnostic tool for DVA impairment, which may be useful to monitor the functional recovery of DVA in patients with VN performing gaze stability exercises.

Previous studies used computerized DVA in horizontal and vertical planes to investigate vestibular hypofunction by self-generated head rotations [1,2]; however, these studies used canal paresis as the gold standard, reporting a higher sensitivity of DVA for diagnosis of unilateral vestibular hypofunction for horizontal canal, but a low sensitivity for the vertical plane. In this study, we used horizontal ht as the reference. The rationale for this is that frequency of stimulation of the canal is the same during ht with or without the DVA test, but in previous studies the self-generated movements at $120^\circ/s$ were compared with a

Table VI. Diagnostic value of htDVA test for the horizontal semicircular canal in patients with VN.

Parameter	Positive ht	Negative ht	Total
Positive htDVA	8	2	10
Negative htDVA	29	11	40
Total	37	13	50

Sensitivity 22%, specificity 85%, positive predictive value 80%, negative predictive value 28%.

very low frequency stimulus delivered by caloric irrigation. In addition, horizontal canal paresis cannot be used as reference to calculate the sensitivity of DVA test in the vertical plane, since we are stimulating different canals.

Gaze stability exercises can improve the visual acuity during head rotation via two mechanisms: an improvement in active aVOR gain and an increase of the centrally programmed eye movements [15]. These eye movements include compensatory saccades and high-velocity slow-phase eye movements (velocities of 80–120°/s) [15]. The partial improvement of aVOR has been demonstrated in afferent neurophysiology studies in animals after unilateral vestibular damage, since central vestibular neurons maintained their rotational sensitivity [16].

The purpose of the current investigation was to determine if htDVA may be useful to identify individual semicircular canal function separately. The htDVA could estimate the aVOR gain and compensatory saccades for each canal.

The gain of the normal VOR during horizontal ht is 0.9 at velocities of 200–400°/s [3,16]. Therefore the eye rotation compensates the magnitude of head rotation for the ht stimulus. However, the gain of aVOR during LARP or RALP planes is only 0.7–0.8, since the aVOR during diagonal ht is the vector sum of the pitch and roll VORs [17]. Based on published data, it is clear that the aVOR gain is reduced to 0.2–0.3 during the ht directed to any one of the three semicircular canals in deafferented ears [7]. So, the htDVA scores should reflect this impairment until the aVOR gain is improved or the frequency of compensatory saccades is increased enough to restore DVA. However, the aVOR gain differs between horizontal, anterior, and posterior canals among different patients with VN, suggesting that VN may affect superior and inferior vestibular branches separately [8]. These findings suggest that there are several degrees of vestibular dysfunction in VN, probably related to the extent of the lesion.

Compensatory saccades is an essential mechanism to assist gaze stability and maintain DVA during ht [18]. A 40% increase in the number of compensatory saccades was found in patients with chronic unilateral vestibular hypofunction after gaze stability exercises. Moreover, the recruitment of compensatory saccades was inversely correlated with the aVOR gain, and in some cases an aVOR recovery was observed [10,15]. The individual recovery of DVA is probably related to the individual ability to improve aVOR and to recruit compensatory saccades.

Our study has several limitations. The ht was performed for the horizontal canal and 13 patients with VN had a negative ht. The ht depends on the expertise

of the examiner and the clinical judgment rather depends on the observation of catch-up saccades than on the gain of the aVOR [5]. Moreover, some patients with VN may have a limited number of nerve fibers affected and those remaining are enough to maintain the aVOR. It has been demonstrated that a canal paresis of 45% is required to elicit a positive ht for the horizontal canal in patients with unilateral vestibular hypofunction [19]. In addition, the ht was not performed in the LARP and RALP planes in most patients during the first visit to the clinic, so we cannot calculate the sensitivity and specificity of htDVA for vertical canals.

Conclusions

The htDVA is reliable in normal subjects. It has a low sensitivity and a high specificity, so it may be useful to monitor vestibular rehabilitation and DVA in patients with VN.

Acknowledgments

This study was funded by a research project 07/0181 from Consejería de Salud, Junta de Andalucía, Spain. We thank Pablo Garrido-Fernandez for revising all the statistical methods.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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