Test-retest reliability of the VOR as measured via Vorteq in healthy subjects

Attendibilità del test-retest del VOR misurato con tecnologia Vorteq in soggetti sani

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Key words

Vertigo • Vestibulo ocular reflex • Head autorotation test • Gain

Parole chiave

Vertigine • Riflesso vestibolo oculare • Test di autorotazione del capo • Gain

Summary

To determine the reliability of the vestibolo-ocular reflex test measured via Vorteq, 16 subjects underwent head-autorotation test at the frequencies 1-5 Hz. All patients underwent the re-test. No linear correlation was observed between the measurements, i.e., no repeatability of the same measurements at the various frequencies. The Head Auto-Rotation Test by Vorteq has demonstrated advantages: patients are not disturbed by the active head movements; the full test protocol, lasts only a few minutes; the method enables the vestibolo-ocular reflex to be evaluated at high head-rotation frequencies. However, the test has disadvantages: poor test-retest inter-individual repeatability, wide standard deviations of results with heterogeneous inter-individual spread with regard to phase and asymmetry values especially at high rotation frequencies. In the light of the above findings, it can be seen that the test-retest of the Vorteq system is not sufficiently reliable and hence cannot be used in clinical practice.

Riassunto

Per verificare l'affidabilità del test per il riflesso vestibolo-oculare (VOR) misurato mediante il sistema Vorteq, 16 soggetti sono stati sottoposti a prova di autorotazione del capo alle frequenze 1-5 Hz. Tutti i pazienti sono stati sottoposti a retest. È emerso che non c'era alcuna correlazione lineare fra le misure, cioè non c'era ripetibilità delle stesse misurazioni alle diverse frequenze. La prova vestibolare d'autorotazione del capo ha dimostrato vantaggi: i pazienti non sono disturbati dai movimenti attivi del capo; un completo protocollo per la prova, dura pochi minuti; la metodica offre il vantaggio di valutare il VOR a frequenze di rotazione della testa elevate. Il test ha però dimostrato i seguenti svantaggi: scarsa ripetibilità inter-individuale della prova test-retest; ampie deviazioni standard dei risultati con eterogenee misure di dispersione interindividuali delle misurazioni per quanto riguarda i valori di fase ed asimmetria soprattutto a frequenze di rotazione elevate. Si può quindi concludere che il test-retest del sistema Vorteq, non è sufficientemente preciso e quindi non può essere utilizzato nella pratica clinica.

Introduction

The vestibulo-ocular reflex (VOR) generates compensatory eye movements during head movements. When the head is moved, in any given direction, the VOR generates reflex movements of the eyes of equal magnitude but opposite in direction to the head movement, thus ensuring visual acuity of objects around us and maintaining visual stability of images when we move. VOR functions at head-movement frequencies ranging from 1 to 4 Hz and beyond; these are the frequencies reached during daily physiological movements such as walking, running, climbing the stairs, etc.

Caloric tests are still the most widespread method used to quantify deficits in the vestibular system; however, this method uses a unilateral, non physiological stimulus and investigates the VOR only in the low frequency range (<0.05 Hz), much lower than the frequencies reached during the natural head movements of activities such as a walking or running (1-6 Hz) [1]. More recently, the rotational chair has been introduced in clinical practice. This enables VOR to be evaluated physiologically since the vestibular receptors on the two sides are simultaneously stimulated; however, the frequencies investigated, albeit higher than those of caloric stimulation, are limited, being little more than 1 Hz. Moreover, patients do not tolerate this test very well [2].

During the last 10 years, a number of systems have been developed which use active head movements to measure VOR during head rotations at high frequencies both in the horizontal and vertical planes. There are two commercially available systems to evaluate VOR via head-autorotation tests: the Vestibular Autorotation Test (VAT; Western System Research, Los Angeles, CA, USA) and the Vorteq (Micromedical Technologies Inc. Chatham, IL, USA). Head Auto-Rotation Tests (HART) involve fitting a headband equipped with a velocity sensor on the patient's head. The patient's head movements in the horizontal or vertical plane, which are carried out at a frequency pre-set by a sound metronome, generate, thanks to VOR, conjugate compensatory ocular movements which are recorded via electronystagmography. A computerised analysis of ocular movements correlated to head movements, permits evaluation of the parameters of the VOR: gain, phase and asymmetry. VAT has been studied in numerous investigations and the anomalies of gain and phase in VOR have been reported in physiological and pathological conditions. The pathological conditions comprised: elderly patients [3], patients suffering from Menière's disease [4], acoustic neuroma [5] and cases of vestibulo-toxicity [6]. VAT has also been used to evaluate the differences in VOR gain between active and passive head movements at high frequency [2 7]. Meanwhile, the reliability of the method was tested and conflicting results reported. O'Leary found a good level of repeatability [8], whereas Guyot reported poor repeatability [9].

In the light of these differences, it was decided to further examine the reliability of the VOR test-retest measured by means of the Vorteq system.

Materials and methods

A group of 16 healthy subjects (8 female, 8 male, age range 20-55 years), with no history of balance disorders, underwent head-autorotation tests. The subjects were recruited after having undergone an objective ENT and otoneurological examination: pure tone audiometry test to evaluate the vestibulo-spinal pathway (march with eyes open and eyes closed, normal and sensitized Romberg's test), detection of spontaneous nystagmus, positional and positioning tests, headshaking tests, cerebellar tests and caloric tests according to Freyss. Test results were within the normal range in all subjects. HART was carried out using the hard- and software of Micromedical Technologies Inc. (Vorteq) connected to a personal computer which recorded and analysed the data. The Vorteq equipment was checked and calibrated by the manufacturer's technical staff before beginning the study. Evaluation of head movements was carried out via a headband, kept firmly in place on the subject's head. The angular velocity sensor, located on the front of the headband, can be turned manually 180° in order to evaluate the head oscillations both in the horizontal and vertical plane. Ocular movements correlated to head movement were evaluated by means of equipment for digital electronystamography manufactured by Micromedical Technologies Inc (Vorteq). The luminous bar of the digital electronystamography equipment was used for fixation purposes. The bar is one metre long and has a luminous (LED) spot, 1 cm in diameter in the centre; it can be rotated 180° and is positioned on a support so that it can be regulated in height in order to be exactly level with the subject's eyes at a distance of 1 metre. Each subject must rotate his/her head in a horizontal plane keeping his/her eyes open and staring at a fixed point (Auto Head Rotation-Eyes Open or AHR-EO). The subject was invited to keep his/her gaze fixed on the target and to rotate voluntarily, without help (active movement) his/her head to the right and left, respectively, by approximately 25° in synchrony with auditory cues generated by a loud speaker connected to the personal computer (PC) which gradually increased in frequency from 1 to 5 Hz. Every test lasted 15 seconds during which the frequency of the auditory cues, to which the patient's head movements should correspond, was gradually increased from 1 to 5 Hz. At the lower frequencies (1-2 Hz), amplitude of the rotational movements of the head varies from 30° to 60°, at higher frequencies (3-5 Hz), this amplitude falls below 30° since the speed and frequency of the head movements do not permit a wider range. All 16 patients underwent the retest at 1-5 Hz frequencies. Statistical analyses of the data were carried out using the S.P.S.S.10.1 programme.

Results

The test-retest from 1-5 Hz was carried out in 16 subjects. Mean values of gain, phase and asymmetry, standard deviations and "r" correlation are shown in Table I. The significant correlations at level 0.05 (2-tailed), and at level 0.01 (2-tailed) are also highlighted.

Discussion

Gain, which expresses the functionality of the vestibular-ocular reflex, is the ratio between the number of efferent impulses, generated by eye movements, and the number of afferent impulses, generated by head movements while following a target; it is expressed as an absolute value and its ideal value in healthy subjects is close to 1. In our study, the measurement of gain during head-autorotation tests yielded results close to 1 at frequency ranges 1-4 Hz (range 0.93-0.96 Hz) with a tendency to decrease at

Table I. Values of gain, phase and asymmetry reported in test-retest for each frequency examined (1÷5 Hz).

	FREQUENCIES														
	1.0 Hz			2.0 Hz			3.0 Hz			4.0 Hz			5.0 Hz		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Gain															
Test	16	**0.94**	0.11	16	**0.96**	0.10	15	**0.96**	0.22	10	**0.93**	0.20	3	**0.88**	0.18
Retest	15	**0.95**	0.14	16	**0.93**	0.12	14	**0.96**	0.19	14	**0.93**	0.27	6	**0.78**	0.10
r		-0.102			-0.167			0.677 *			0.539			-0.736	
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Phase															
Test	16	**1.13**	3.93	16	**-0.94**	6.41	15	**-1.80**	8.99	10	**-2.70**	10.14	3	**-4.00**	11.53
Retest	15	**0.87**	4.06	16	**2.00**	7.32	14	**1.14**	5.80	14	**1.43**	8.04	6	**-1.17**	7.91
r		0.695 **			0.111			0.354			0.818**			0.710	
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
ASYM.															
Test	16	**2.76**	3.06	16	**2.36**	2.77	15	**3.11**	2.64	10	**5.51**	5.86	3	**5.60**	7.03
Retest	15	**3.37**	3.94	16	**1.16**	0.95	14	**1.27**	0.87	14	**4.76**	9.90	6	**5.93**	3.91
								Test - retest							
r		0.461			0.198			0.387			-0.375			-0.439	

N = number of subjects; SD = standard deviation; r = correlation; ASYM. = asymmetry
* Correlation is significant at 0.05 (2-tailed); ** Correlation is significant at 0.01 (2-tailed)

5 Hz (range 0.78-0.88 Hz). This tendency towards a decrease in gain at high frequencies has also been reported by others [10 11] who reported mean gain values of 0.94-0.99 at frequencies of 1-3 Hz falling to 0.78 at 5 Hz. The tendency can be explained by considering that, at high frequencies of head rotation, generally over 4 Hz, the eye movement is unable to compensate the head movement; moreover, it has been found that also normal subjects, when the frequency of rotation is increased, have the perception that the luminous target is blurred and that they can no longer visualize it as a spot of light but rather as a line, and hence it is impossible to follow. Finally, head rotations, at high frequencies, tend to lead to errors in recording ocular and head movements due to slipping of the headband worn by the subject with an ensuing reduction in sensor accuracy [12].

Phase is expressed in degrees or in milliseconds and is calculated as the phase difference between ocular movements and the corresponding head movements. A positive phase difference means that eye movements precede the corresponding head movements, or vice versa if the value is negative. An ideal phase value should be around 0. In our study, measurements of phase yielded positive values at 1 Hz (+ 1.13) and negative values for higher frequencies (-4 at 5 Hz). This tendency, which was not confirmed by retest results, is interesting and might be explained by the fact that, at low frequencies of head oscillation (< 2 Hz), the smooth pursuit system prevails; this seems to be confirmed by a positive phase in that the ocular movements controlled by this system precede head movements. At intermediary frequencies of oscillation, it is possible that the phase tends towards positive in that there is an interaction between vestibular and visual input; at higher frequencies, phase becomes negative in that the "non-visual reflex drive" prevails over fixation and leads to head movements anticipating eye movements [13]. These observations are confirmed by the results of other Authors [5 10 11 14]. Asymmetry refers to the difference, expressed as a percentage, between the gain obtained by turning the head to one side compared to the gain obtained when turning the head to the opposite side. In healthy subjects with full VOR, the value of asymmetry should be 0. In our study, we found that asymmetry values tended to increase with an increase in the frequency of head rotation with values ranging from 2.76 at 1 Hz to 5.93 at 5 Hz. It is reasonable to expect these results, which are confirmed in the literature [10]

[15]. With regard to the repeatability of VOR values with head autorotation tests, conflicting results have been reported in the literature: O'Leary, using VAT technology, found good repeatability of gain and phase values in 4 healthy subjects, tested on more than one occasion [8 16] whereas Guyot, again using VAT technology, found poor repeatability of these values in 12 healthy subjects, especially at higher frequencies of head autorotation (>3.5 Hz). Guyot's explanation for this variation is that it is not easy for subjects to carry out head rotations of a similar amplitude and, hence, of a similar velocity, at every test; furthermore, between one test and another, there might also be factors such as fatigue, stress or even less active participation on the part of the patient [9 16]; thus the test is terminated and cannot be used to evaluate the clinical tendency of a disease. In our study, the test-retest was also carried out at frequencies ranging from 1 to 5 Hz and from an analysis of the results (especially phase and asymmetry), it can be seen that the retest values do not overlap, in tendency, with the test results. To establish the relationship between the measurements of gain, phase and symmetry obtained in the test relating them to the measurements obtained in the retest we used "correlation" as a statistical tool. This statistical method appears to be the most appropriate to quantitatively evaluate the degree to which two mutually dependent variables tend to be associated with one another. In our study, the two dependent variables were the values of gain, phase and asymmetry reported in the test (first variable) and in the retest (second variable). The variables can be influenced by a large number of other variables, related to the subject during performance of the HART test or to the method of recording. With regard to subject-related variables, it should be pointed out that although the subject is correctly instructed as to how the test is carried out, the subject, during recording, might fail to carry out oscillations of the same amplitude and in the same plane; moreover, some subjects might not be able to follow the rhythm of head rotation induced by the auditory cues and, at the same time, concentrate on fixing the target. As far as concerns the methods of recording, it is important to clean the subject's skin and to ensure that the sensor electrodes are positioned correctly before carrying out the test since failure to do so may prejudice the outcome. While HART is being carried out, the headband may slip since it is not possible to fit it securely to the subject's head due not only to the particular anatomical conformations of the head but also on account of intolerance to the headband itself. Pearson's "r" coefficient is the quantitative expression of the connection between two variables. This coefficient varies between -1 and +1. When it approaches the value 1, it indicates that the relation between the two variables can be usefully described by a line sloping upwards. An acceptable correlation is indicated by values r >0.25 or r <-0.25. When r = 0 this means that, for each value of the variable X, there can be all the possible values of Y, i.e., the variables are not correlated. From a statistical analysis of the data, elaborated using the statistical programme "S.P.S.S.10.1.", it emerged that, apart from the gain at 3 Hz and the phases at 1 and 4 Hz of the test-retest, there was no linear correlation between the measurements, i.e., no repeatability of the same measurements at the various frequencies (Table I). Hence the VORTEQ method shows poor test repeatability even in the same subject and is, therefore, not useful in the clinical field. The non-repeatability of the test is also clearly evident in the graphic illustration of the principle variables (Fig. 1) where it can be seen that the variables (gain, phase) do not overlap in the test and in the retest. Moreover, this Figure shows that the gains are grouped in the same quadrants of the test or retest, respectively, which indicates that, from a purely technical point of view, the system functions correctly. Therefore, the non-repeatability of the test is not due to badly functioning equipment but rather lies in the subjects being unable to faithfully repeat the head movements according to the pre-established frequency, speed and amplitude. With regard to the range of the inter-individual measurements obtained (standard deviation), it can be seen that phase and

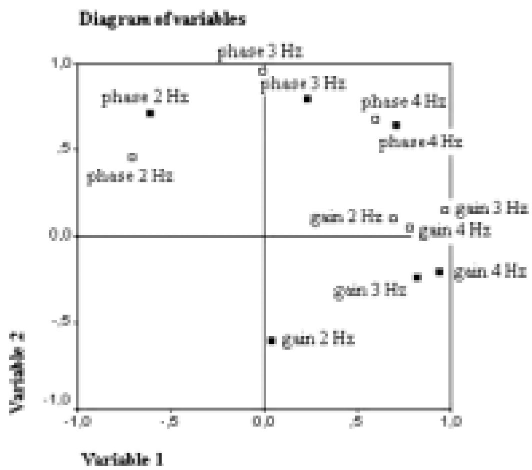

Fig. 1. Test-retest 1-5 Hz. For clarity, amplitudes obtained at 1 Hz have been omitted (frequency not involved in VOR), as well as frequencies at 5 Hz, since few patients reached these frequencies, and values of asymmetry. It can be seen that the variables (gain phase) in the test do not overlap. Gains are grouped in the same quadrant, in the test and the retest, respectively.

Test results: empty squares; retest results: full square.

asymmetry, in particular, tend to increase substantially with an increase in frequency. This leads us to suggest that, of the three parameters used to evaluate VOR, the only parameter currently viable is gain.

Conclusions

The development of a test which enables us to evaluate VOR in response to high-speed head movements is interesting. The vestibular test of head auto-rotation has several practical advantages over other methods currently used to evaluate VOR. Patients are not disturbed by the active head movements which can easily be performed following brief instructions. The full test protocol, including positioning the electrodes, informing the patient and carrying out the tests, lasts only a few minutes. The method has the advantage that it enables VOR to be evaluated at high head rotation frequencies which closely approach the frequencies used in normal daily activities, even in the vertical plane. However, the test has the following disadvantages: poor test-retest inter-individual repeatability, wide standard deviations of results with heterogeneous inter-individual spread with regard to phase and asymmetry values, especially at high rotation frequencies. In the light of these findings, it can be seen that the test-retest of the Vorteq system is not sufficiently reliable and hence cannot be used in routine clinical practice.

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