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Functional Exploration of Vestibulo-Ocular Reflex by a Rotatory Stimulation

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= Abstract =

In this study, we proposed a test to explore the function of Vestibulo-ocular reflex (VOR) which subjected to an angular head acceleration using pseudo random binary stimulus.

Resultant eye movements(horizontal vestibular nystagmus) were digitized, filtered and transformed into the frequency domain. At first we evaluated the transfer function of V.O.R(gain and phase) and the coherence function between stimulus and response by linear frequency methods in view of the quantitative analysis since the vestibulo-ocular reflex can be considered as a linear system. at least, in normals.

Secondly, with the proposed test, we showed a direct possibility that we could interpret the pathological situation quantitatively as an illustration of clinical application.

1. INTRODUCTION

The vestibular ocular reflex(V.O.R) is a biological automatic system whose role is to maintain a stable image of the environment on the retine to the head movement. It is an important element of general equilibrium system of all the living being.

Moreover it has been reported by many authors that important pathological situations induce significant modifications in vestibular reaponses[1~3]. Then it is not surprising that eye movements analysis to vestibular stimulation has been accepted as an important diagnostic and research tool in many medical fields, such as neurology opthalmology and otolaryngology.

Among the classical tests of ocular motility, the vestibular ocular reflex tests gave rise to the major problems. In view of stimulation, many different stimulation profiles have been so far proposed for the vestibular tests.

The post-rotatory test produced by suddenly stopping the chair while rotating at a constant velocity, if repeated several times on the same subject, can induce habituation processes resulting in progressive suppression of the ocular responses[4].

The harmonic oscillations test has been also considered in order to construct the frequency response diagrams of VOR. Obviously harmonic oscillation test requires larger and more tiring experimental sessions than post-rotating test.

Moreover this test also induce habituation

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processes with the repeated harmonic oscillations at frequency upto 0.2Hz[5].

In the clinical practice the caloric stimulation is widely used for the vestibular tests. This test is simple and cheap but it does not allow a rigorous quantitative approach because the stimulus hardly can be quantified and the artifacts due to the use of an unphysio logical stimulation condition cannot be evaluated[1].

Thus in this paper the aim is to propose a rotatory test which derive chair motion with a pseudo-random command signal and to estimate VOR frequency response by means of Fourier analysis of oculomotor responses from the standpoint of quantitative analysis. With the methods above, the quantitative interpretation of Meneiere's disease be given as an illustration of clinical application

2. ROTATORY TEST

Classically the semicircular canal(S.C.C.) is considered to be a sensor of angular head motion. Thus the angular head acceleration represents the specific stimulus for the S.C. C. of vestibular system.

Consequently subject's rotation in the plan of the canal to be tested is more suitable experimental paradigm for functional test.

The rotatory test that we propose is the following :

－The subject is installated on a chair which is made to rotate about a vertical axis in the dark in order to exclude interactions with the visuo－motor system. The head of subject is inclined to 30° forward for S.C.C. to be just in the horizontal plan.

－For the stimulus, we utilize a pseudorandom binary stimulus. This stimulation permits to produce no habituation processes due to the absence of repetitive motion patterns, to minimize exploration time, and to obtain the transfer function in the multifrequency ranges in contrast with a single frequency harmonic oscillation stimulus.

The pseudeo random binary stimulus is generated by a circulating shift register that employs exclusive OR gates in feedback configuration.

The step length of the binary stimulus was selected to correspond to the required high－frequency cut off, and binary sequence length was then selected to correspond to the required frequency band[6].

The binary signal in this test is directly propotional to the angular acceleration of the rotating chair. Thus the input to vestibular system is the acceleration and the output is the resulting vestibular nystagmus.

In general the vestibular system frequency response is between 0.01 and 5.0Hz. So we chose 0.01 as a base frequency and 0.5Hz as a maximum frequency from the limit of the determined transfer function of utilized chair (RACIA).

This stimulus is composed of 10 P.R.B.S of base "6". The period is equal to 100s and is interpolated by cosine function. The first period and last period are modulated linearly in amplitude in order to assure the progressive start and stop of chair. We also chosed 8 as the number of period, which is used to abtain a good ratio of signal to noises.

－ For the recording of the horizontal response we used the classical electronystagmography(E.N.G) method of recording eye movements using skin electrodes for signal pick-up. The data acquisition, the signal treatment and analysis such as detection of a fast phases, the separation of two phases, the removal of fast phase and reconstruction of a cummulated slow phase were realized by a real time processor(Intertechnique 110) with

the help of the of the software which was developed in our laboratory for the nystagmus related dasa[7~8].

This explorating system mainly consists of a rotating chair driven by a servomotor, a light panel for the calebration, a recording chain composed of a preamplification unit, a device for off-set compensation, and the computer(IN110) which permits acquisition and data treatement in real time.

3. CACULATION OF TRANSFER FUNCTION

The vestibular nystagmus is a biphasic movement composed of both slow and fast phases (Fig. 1). Only the slow phase is the origine of vestibular system.

So we must separate two phases, eliminate fast phase and reconstruct the slow eye movements. For this object we set up an algorithm independent of the stimulation.

This treatement is no specific to this test but can be equally applied to other test.

The storaged nystagmus on disc is read in central memory. Signals of velocity(Fig. 2) and of acceleration(Fig. 3) are calculated by

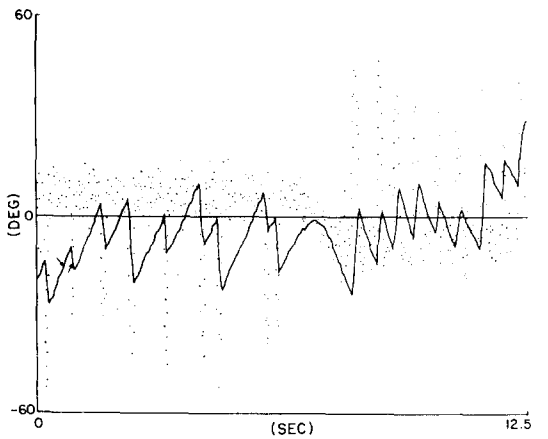

Fig. 1 Vestibular Nustagmus and Eye Velocity. Solid line : vestibular nystagmus. Dotted line : eye velocity. a) Slow phase, b) Fast phase.

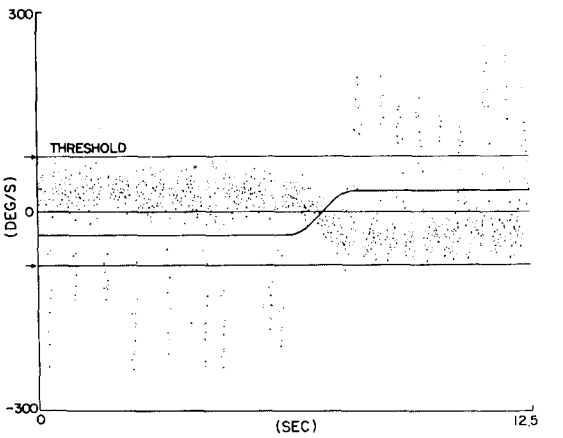

Fig. 2 Chair Velocity and Eye Velocity. Solid line : chair velocity. Dotted line : eye velocity.

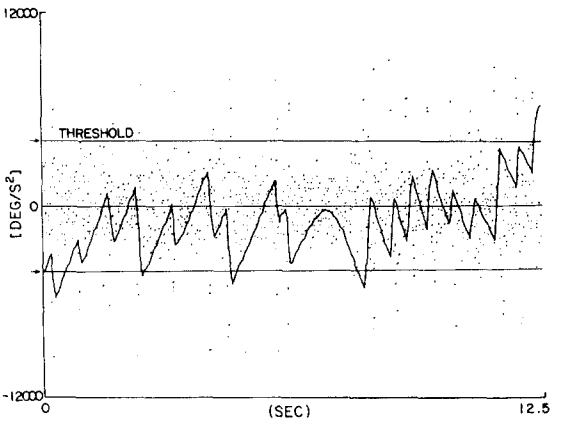

Fig. 3 Vestibular Nystagmus and Eye Acceleration. Solid line : vestibular nystagmus. Dotted line : eye acceleration.

numerical derivation of nystagmus. The fast phase of nystagmus is detectd by a threshehold which separate two phase in velocity signal.

The impotant accelaration signal corresponding to the begining and the end point of fast phase is marked on acceleration signal. The combination of two thresheholds of both velocity and acceleration signal permits to give a corrective estimation of saccade's location.

In addition the existance of an inhibition to the saccade after a saccade make a succesive approach to fast phase impossible. If two saccade we detected succeed to at an intervals of less than 150ms, they are merged in only one saccade.

The thresheholds of velocity(Fig. 2) and of accleration(Fig. 3) are fixed by the operator after the visualization of two signal. The estimator then is determined and appeared as the form of binary signal with a value of "1" localizing the fast phase. The isolated values of the estimator which must be a value of "1" are "0" due to noise on the signal.

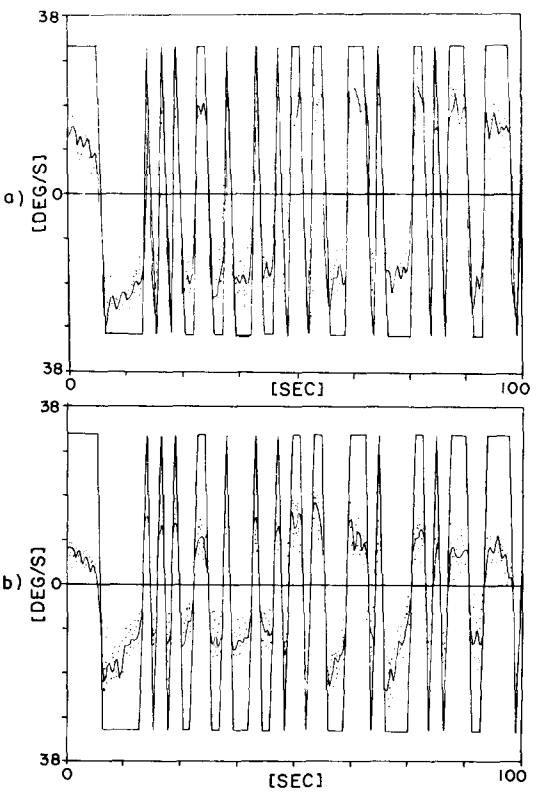

Fig. 4 Chair Velocity and Slow Eye Velocity. a) Case of normal subjects, b) Case of abnormal subjects(Meniere's disease).

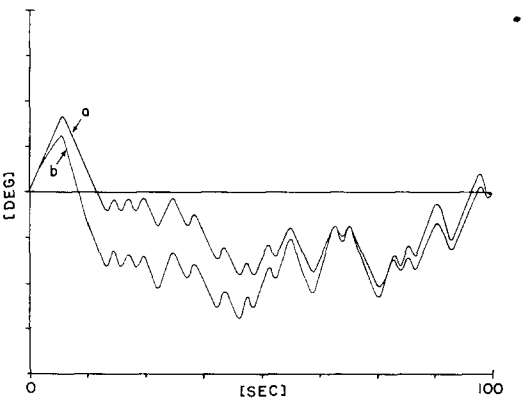

Fig. 5 Cumulograms of Chair and Slow Phase Eye Movements. a) Chair, b) Slow phase eye movements.

This is corrected and the final estimator will have the value of "0" for the fast phase and value of "1' for the slow phase. The velocity signal is multified by this estimator. It results in a signal without fast phases. The velocity signal between defferents slow phases is interpolated linearly. From these results we could calcul the statistic parameters such as standard deviation, mean values, and ratio of signal to noise. For the clinical diagnostic we also evaluate the predominance of slow phase(Fig. 4), cumulogram of slow phase (Fig, 5), frequency response(gain, phase) and coherence function(Fig. 6) by the algorithm [9] shown in(Fig. 7).

4. CLINICAL APPLICATION

The computer aided examination of vestibular function according to the mode which we propose is applied to 10 normal and abnormal subjects were tested, with this test. In the clinical application, the meniere's disease is illustrated as a typical example in this paper.

The inequality between the production and

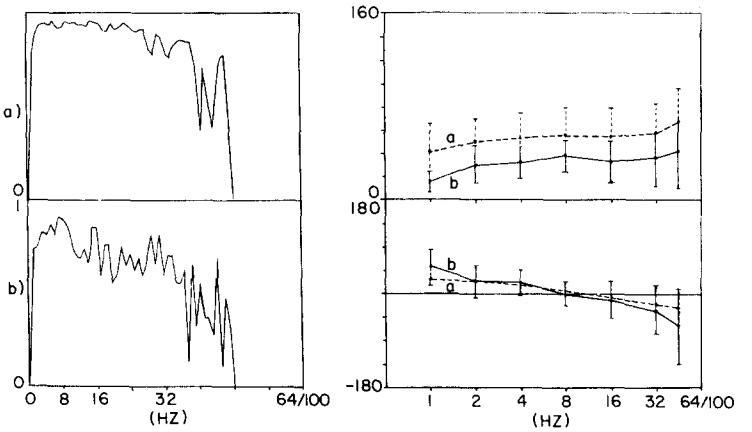

Fig. 6 Frequency Response(gain, phase) and Coherence functions. a) Case of normal subject, b) Case of abnormal subject(Meniere's disease).

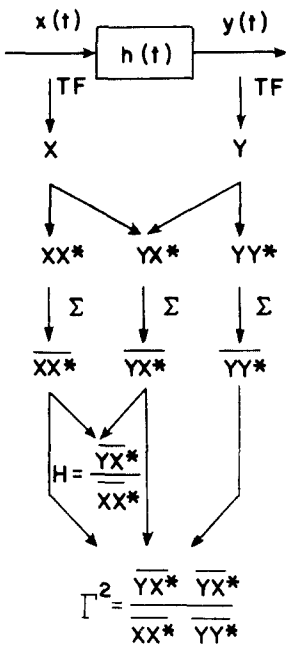

Fig. 7 Algorithm of the Calculation of Transfer Function. X : Fourier Transform of an Input x(t), Y : Fourier Transform of the resulting output y(t), H : Transfer Function, T^2 : Coherence Function, XX* : Input Autopowerspectrum, YX* : Cross Powerspectrum, YY* : Output Autopowerspectrum(*indicates a complex conjugate, indicates an average)

the elimination of endolymph modifys the difference of transmural pression between endolymph and perilymph. This pressional modification creats the mechanical distortion at cavity of inner ear.

The distended cavity is generaly the one with a grand dimension as ampulla of S.C.C, the swollen party of cochlea canal. As a result of this distortion, the subject suffering from this disease has some symptom such as explosive attack of true vertigo, fluctuating hearing loss at low frequency, and tinnitus.

It result in a parameter modifiation of the system formed by S.C.C. Accoding to their system expression[10] the satic gain drops and the time constant of this system drops highly in this disease. As a result of this, it shows the modification of phase and gain in the ranges of low frequency(Fig. 6).

This phenomena is mainly marked in subjects suffering from meniere's disease, signing the augmentation of end-perlympatic pression. Moreover we can see the strong drop of coherence function resulting in the characteristic of nonlinearity, in the machanic neual transformation.

The predominance of slow phase of nystagmus is shown in near the opposite site of the suffering ear. If the predominance is marked over 10% in rotatory test by pseudorandom binary stimulation the subject is diagnosed as a pathological case(Fig. 4).

5. DISCUSSION AND CONCLUSION

In this study, we have described the practical aspects of rotatory test using pseudo random binary stimulus to explore the vestibuloocular (VOR).

At first the gain and the phase diagrams of VOR frequency response was evaluated in view of the quantitative analysis. Secondly the clinical application of this method to Meniere's disease was presented from the stand point of initial attempt to diagnose neuralogical disorder of this system.

With this test we could obtain some satisfactory information about the gain and the dynamic characteristics of V.O.R in the multifrequency ranging between 0.01 and 0.5Hz. We could therefore save the test time in contrast to tests using the stimulus such as a single frequency sinusoid, step, and impulse function.

We could also eliminate the habituation processes resulting in progressive suppression of the system response with absence of repetitive motion patterns. On the other hand, the proposed test require a complex instrumentation for the control of chair movement. The responses obtained in this test cannot also be examined by eye inspection of the records, or by hand.

Thus a computer effort is absolutely necessary for the analysis. Nevertheless, it is widely need in the clinical practice since computerized eye movement analysis has the major advantages of fast reporting of results for use in diagnosis evaluation with the accuracy. The proposed initial approach to interpret pathological situation quantitatively is expected to give a direct possibility to diagnosis the central disorder in relation to the gain of vestibular nucleus, time constant, the gain of paramedian pontine reticular formation, and controls of their parameters by cerebellum, or peripherical disorders in relation to the mechanics of S.C.C, mechano-neural transformation and vestibular nerve.

For these objects it is necessary to propose the definition of an optimal exploration procedures for V.O.R with relation to the suspected pathology, and to realize the computer programs for eye movement processing easy to use but robust enough to stand the test of pathological response analysis.

6. ACKNOWLEDGEMENT

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REFERENCES

1) R.W. Baloh, V. Hourubia : "*Clinical Neurophysiology of the vestibular system*". *Philadelphia, Devis, 1979.*

2) R. Schmid and D. Zambarbiri : "*Eye movement Analysis in Neurological diagnosis*". *Center of bioengineering, University of Pavia, Italy, 1979.*

3) Angelo Buizza : "*Eye Movement Analysis*" *Polish－Italian Symposium on Bioengneering, 1984.*

4) Jeannerod M., Magnin M., Schmid R., Stefanelli M : "*Vestibular habituation to angular velocity steps in the cat*" *Biol. Cybern. 22 : 39－48, 1976.*

5) R.W. Baloh, V. Henn, J. Jaeger : "*Habitua-*

tion of the human vestibulo-ocular Reflex with low frequency harmonic acceleration", Am. J. Otolaryngo., 3 : 235—241, 1982.

6) Panos Z. Marmarelis and Vasilis Z. Marmarelis : "*Analysis of physiological systems*" *Plenum Press, New York, 1978.*

7) N.G. Kim : "*Modeling of Eye movements to the peripheral visual Stimulation : Computer Aided Functional Exploration*" *PH. D Paper, Unviersity of Louis Pasteur, France, 1987.*

8) Karim Kalfane : "*Exploration Foncitionnelle du R.V.O. assistee par ordinateur*", *These de L'universite Louis Pasteur, France, 1987.*

9) J.S. Bendat and A.G. Piersol : "*Random data : Analysis and Mesurement procedures*", *John Wiley & Sons, 1971.*

10) Ebnezer NGEUGNA : "*Mecanique et robotique d'un accelerometre : le canal semi-circulaire.*