Abstract
Visual acuity in congenital nystagmus is primarily related to the duration of the foveation periods, during which the image of the target is placed on the fovea area and the eye velocity is low. This is true only if the subject is still able to place the target image on the centralmost fovea during the foveation period. In presence of a high variability of the foveation position the target image could not be placed on the centralmost fovea during many foveation periods. An associate vertical nystagmus or a slower horizontal eye movement combined to the horizontal nystagmus could cause such high variability. In several eye-movement recordings of patients affected by congenital nystagmus a very slow oculographic baseline fluctuations have been detected. In these patients the ability to foveate the target seems to depend mainly by the amplitude of the baseline fluctuation. The aim of this paper is to describe and quantitatively characterise these slow movements and try to associate them with the patient visual acuity. Furthermore a method to automatically separate the slow baseline oscillation from the nystagmus is proposed. Our findings suggest that for these patients the maximum effort could be concentrated on the reduction of the eye-position variability during foveation.

Keywords: Congenital Nystagmus, Foveation, Visual acuity

1. INTRODUCTION
Congenital nystagmus is an oculomotor disorder that develops in the first few months of the life. It is described as an inability to fixate a stationary target and mainly consist of involuntary, conjugated and rhythmic horizontal and retro movements of the eyes. In person affected by congenital nystagmus fixation is disrupted by these rhythmic oscillations, producing rapid movements of the target image on the retina. In normal subjects, as the retinal image motion become faster then few degrees per second, visual acuity and contrast sensitivity decrease. Then, it is logical to suppose that congenital nystagmus may cause a decrease of visual activity, but is not exactly the case. Actually, the visual acuity has been found (Bedell and Loshin) [1] (Abadi and Dickinson) [2] sometime close to the normal values for patients affected exclusively by congenital nystagmus. Furthermore, no significant relationship between visual acuity and nystagmus intensity, measured as amplitude by frequency, were found (Bedell) [1]. This unexpected visual acuity in congenital nystagmus could be achieved during the foveation periods (Dell’Osso) [3], in which the eye velocity slows while the target image crosses the foveal region. Hence, visual acuity depends by the foveation period duration and by the correspondent eye velocities. A lot of authors studied the correlation between the nystagmus period spent in foveation and the visual acuity. Some of them found a moderate correlation (Mezawa) [4] others no significant relation at all (Bedell and Loshin) [1]. They suggest that other variables could be taken in account, like the position variability of the foveation period.

Actually the duration of the foveation period is well correlate with visual acuity only if the subject is still able to place the target image on the centralmost fovea during the foveation period. Evans (1989) [5] reported that approximately the 50% of the studied subjects fail to coordinate target foveation with that part of the nystagmus waveform during which eye movement is least. A measure of such ability is the position variability of the foveation period. In presence of a high variability, the target image could not be place on the centralmost fovea during some of the foveation periods. This suggests that an associate vertical nystagmus or a slower horizontal eye movement should be superimposed to the horizontal nystagmus in subjects with low vision acuity. Gottlob [6] found a superposition of two different horizontal eye movement in subjects with nystagmus secondary to low vision, which he called fast (2-14Hz) and slow (0.2-1Hz) nystagmus. Other authors found horizontal and/or small vertical movements superimposed to the nystagmus.

Currie and Bedell [7] measured the acuity for optotypes in healthy subjects, by means of image motion that simulate the effects of congenital nystagmus. They found a relationship almost linear between the intensity of the nystagmus and the logarithms of the minimum angle of resolution and an exponential relationship between the visual acuity and the duration of the foveation period. However, adding variability to the position of the foveation period, the acuity worsened significantly.

Recently Dell’Osso [3] [8] proposed new parameters which better correlate with the visual acuity. He proposed a global approach that consider a foveation function computed on the position-velocity plane.
This approach takes partially into account the position variability but it does not underline the two different dynamic components.

In our hospital laboratory (Dept. of Medicine and Surgery of the University of Naples “Federico II”), equipped with electro-oculography (EOG) and infrared-oculography (IROG) digital recording devices, routinely clinical examinations are carried out. In several data records relate to patients affected by nystagmus, the position variability was high and a very slow oculographic baseline fluctuations (Base Line Oscillation, BLO) was detected (Cesarelli) [9]. When these slow eye movements are superimposed to the nystagmus waveform the above mentioned classical methods of analysis result not satisfactory. If the amplitude of this slow movement is comparable with the amplitude of the nystagmus, the ability to foveate the target seems to depend mainly by the amplitude of the baseline fluctuation. The aim of this paper is to describe and quantitatively characterise these slow movements and try to associate them with the patient visual acuity. Furthermore a method to automatically extract the two components is proposed.

2. MATERIALS AND METHODS

A population consisting in 16 patients was analysed. All had horizontal congenital nystagmus. Only one presents also an associate vertical nystagmus. Two minutes of binocular eye-movements, at 1-meter fixation, were recorded for each patient. A light stimulus was presented to the patient using a horizontal led-bar (Basistrave, Italy) controlled by a computer. The stimulation protocol consists of: primary position, 5°, 10°, 20°, 30° stimuli sequence. The patient seat in front of the led-bar. To minimise patient head movement, a head support and a chin rest was utilised. The patient eye movements were recorded using alternatively an electro-oculography device and an infrared apparatus. The infrared apparatus were preferably used when possible. The EOG and IROG signals were digitally recorded using a PC acquisition board. A sampling frequency of 200 Hz was used. A dedicate software process the recorded signals, automatically extracting various nystagmus information. Frequency, amplitude, intensity (amplitude by frequencies), shape of the waveform for each beat (nystagmus cycle) and the foveation function, as described by Dell’Osso [3] [8], were computed. Standard measure of visual acuity was also performed for each patient.

To extract the baseline oscillation an adaptive algorithm (LMS) (Sawada) [10] was developed. Amplitude, frequency and phase of the sinusoidal low-frequency eye movement were estimated. The last square fitting use a linear combination of sine and cosine function, as:

\[ x(t) = a_0 + \sum_{n=1}^{N_p} \left( a_n \sin(2\pi f_n t) + b_n \cos(2\pi f_n t) \right) \]

In our case a linear combination with \( N_p = 1 \) (single component) is applied to the original signal. A linearization of the equation is achieved by estimate the period \( T \) of low frequency oscillation on the power spectrum of the signal. The frequency of the first peak in the spectrum in the range 0.1 - 1.5 Hz (if present) was considered as the frequency of the base-line oscillation. The choice of the high frequency limit (1.5 Hz) has been determined by the lowest frequency associated with the nystagmus (Reccia) [11] (Abadi) [12] (Bedell) [13]. The lowest limit is chosen considering the lengths of the analysed signal tract corresponding to a given gaze position (approximate duration 10 s).

To extract information on the shape of nystagmus an algorithm to detect the beginning and the end of each beat has been developed. It is based on a recursive digital filter that is a modified version of the algorithm proposed by Juhola [14] for the rotational nystagmus. The input of the filter is the nystagmus eye movement and the output is an almost constant signal during the two phases (slow and fast) of each beat. This signal switches very fast between the two different values when the nystagmus changes phase. The Juhola algorithm has been modified to work properly with congenital nystagmus which phases present higher variability in shape (Cesarelli) [15].

To highlight relationship among nystagmus amplitude, oculogram baseline oscillations (BLO) and visual acuity a covariance indexes were computed.

3. RESULTS

In a database of 16 patients affected by congenital nystagmus a group of 12 patients (75% of the total), who show this slow eyes sinusoidal movement, was found. This phenomenon appears for a single or for both eyes and was observed generally in all gaze position where a nystagmus waveform was recorded. This sinusoidal-like baseline fluctuation (BLO) shows frequency ranging from 0.15 Hz to 0.60 Hz. Its amplitude range from 0.7 to 4.8 degrees. In Fig. 1 and Fig. 2 two different records that show nystagmus superimposed to the base-line oscillation have been reported. On the left the power spectrum of each signal is shown. Two peaks are clearly visible, one in the low frequency range (0.1-1.5), the other one in the band 2-8 Hz typical of the nystagmus.
In Fig. 3 two raw nystagmus signals and the estimated oscillations are shown. The shape of the fluctuation was assumed to be purely sinusoidal. The experimental results suggest that the best fit would be a combination of few harmonics.

The nystagmus shows a frequency range between 2.8 and 4.8 and amplitude ranging from 0.7 to 6.5 degrees. The values reported in Tab. 1 are the mean values for each patient. We tested the correlation
among the variables: only the amplitude of the nystagmus and the amplitude of the BLO show high correlation. The greater is the nystagmus amplitude the greater is the baseline oscillation amplitude. The graphic of their liner regression is drawn in Fig. 4.

### Table 1

The visual acuity do not correlate linearly with any other characteristics of the nystagmus neither with the characteristics of the base-line oscillation (BLO). However, patients showing a base-line oscillation have low value of visual acuity (lower than 5/10), whereas the other patients have higher visual acuity close to 10/10. The characteristics of the nystagmus type have been computed. Pendular nystagmus as well as jerk nystagmus are present in our database. A variety of the jerk nystagmus slow phases were recorded: constant, increasing and decreasing velocity.

![Figure 4: Linear regression between the amplitude of the nystagmus and the amplitude of the Base Line Oscillation](image)

The foveation function as suggested by Dell’Osso was compute for each patients in each gaze position. Often its value was not computed because the signal did not lay in the foveation windows in the phase plane [3].

As examples, a signal showing a base line oscillation has been reported in Fig 5a. The associated phase plane representation is show in Fig 5b. The same signal, corrected by subtracting the estimated base-line oscillation has been reported in Fig 6a. The associated phase plane representation is show in Fig 6b.

It is easy to note that using the corrected signal (Fig. 5b) it is possible to evaluate new values for the foveation function.
4. DISCUSSION AND CONCLUSION
With the exception of 4 subjects, all the patients examined in this study present a base-line oscillation. Two different waveforms (slow and fast) Superimposed to the nystagmus were also found by other authors (Gottlob) [6]. All the patients showing the base-line oscillation present low visual acuity. This result is in agreement with the results of Bedell [13]. He reported that position variability of foveations have significant correlation with optotype acuity. He also reported that the visual acuity is essentially independent of intensity unless the duration of simulated foveation period is less than 40 milliseconds. We can consider that the intensity affect visual acuity only minimally in patients with congenital nystagmus. The ability to foveate the target seems to depend mainly by the baseline fluctuation. To improve the visual acuity of these kind of patients a therapy able to reduce the base-line oscillations could be utilised.

The high correlation between the amplitude of the nystagmus and the amplitude of the base-line oscillation suggests that the source of the two waveforms should be the same or else that the two different sources should be joked.

Acknowledgement
We are grateful to Amhara D'Esposito for assistance in recording the signals in the Institute of Ophthalomology direct by Prof. M. D’Esposito. We wish to thank Prof. M. D’Esposito for helpful discussions.
This research was partially supported by Italian MURST 60% funds and by Italian MURST 40% funds.
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