SLOW EYE MOVEMENT OSCILLATION IN CONGENITAL NYSTAGMUS

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Abstract: Congenital nystagmus (CN) is an ocular-motor disorder that appears at birth or during the first few months of life, characterised by involuntary, conjugated, bilateral to and fro ocular oscillations. Its pathogenesis of the CN is still unknown. Eye fixation is then disrupted by these rhythmical oscillations, somehow hindering CN patients' visual acuity. Eye movement recording (by means of EOG, infrared or video oculography) helps in diagnosis, in planning therapy (e.g. tenotomy) and in patient follow-up. Visual acuity is mainly dependent on the duration of the foveation periods (when target image intersect foveal region); also cycle-to-cycle foveation repeatability and eye velocity contribute. By analysing a large eye-movement recordings database, this study focus the attention on cycle-to-cycle repeatability of image placement onto the fovea. In particular, this can be represented by an ideal slow eye movement oscillation superimposed to those characteristic of the nystagmus. Characteristics of such oscillation, concisely approximated by a sinusoid, have been extracted and analysed and then compared with other nystagmus features and with visual acuity. Frequency of this slow oscillation results to be of 0.36 ± 0.11 Hz on average, while the amplitude results correlated with that of the nystagmus waveform.

Introduction

Congenital nystagmus (CN) is an ocular-motor disorder that appears at birth or during the first few months of life, characterised by involuntary, conjugated, bilateral to and fro ocular oscillations. CN is predominantly horizontal, with some torsional and, rarely, vertical motion [20]. When it is not associated to other visual or neurological impairment is termed idiopathic.

The pathogenesis of the CN is still unknown, though some have hypothesised that deficit in one of the ocular motor control subsystems (optokinetic, saccadic, smooth pursuit or vestibular) may contribute to or cause congenital nystagmus, but no clear evidence was ever reported.

In normal subjects fixation is achieved by keeping eyes almost steady in a gaze position, in order to let the target image refract on the fovea (retina's region with the highest photoreceptor's concentration); in CN patients instead, fixation is disrupted by the rhythmical oscillation of the eyeballs, which causes retinal slip. However, visual acuity can be close to the normal values for CN patients [1,2]. Ocular stabilisation is achieved during foveation periods [3] in which eye velocity slows down while the target image crosses the foveal region. Visual acuity was found to be mainly dependent on the duration of the foveation periods [2,4,5]. Cycle-to-cycle foveation repeatability and reduction of retinal image velocities also contribute to an increase in visual acuity [3,6].

Presence of slow pendular waveforms, superimposed to nystagmus, was also reported by Gottlob et al [10]. In eye-movement recordings published by Dell'Osso et al [3,19] a slow oscillation can be recognised superimposed to the nystagmus. Evans [16] reported that approximately 50% of the analysed patients fail to coordinate target foveation with that part of the nystagmus waveform during which eye movement is least. Kommerell [18] noticed that CN patients track moving targets with slow eye movements superimposed on nystagmic cycles. Furthermore, Currie et al. [11], measuring acuity for optotypes in healthy subjects with moving light sources simulating retinal image motion that occurs in nystagmus, recorded a worsening of visual acuity adding low-frequency (1.22 Hz) waves to the light stimuli.

These sort of baseline oscillations hinder precise cycle-to-cycle image placement onto the fovea. Such variability of the position beside the duration of foveation may reduce patient visual acuity.

In particular, the following relationship that combine the foveation time and the standard deviation of eye position during foveation with visual acuity was proposed:

$$\mathrm{NAEF} = \exp(-\mathrm{SDp})[1-\exp(-\mathrm{Tf}/33.3)] \qquad (1)$$

Where NAEF (Nystagmus Acuity Evaluation Function) is a predictor of patient visual acuity, Tf is the average foveation time and SDp is the standard deviation of eye position during foveation (SDp was used to estimate the cycle to cycle foveation repeatability)

This study aims to analyse CN eye-movements recording to outline the baseline oscillation and investigate possible relationships with nystagmus waveform features.

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Materials and Methods

Horizontal projections of eye movements were analysed from 32 CN patients, at different gaze positions.

A standard visual acuity measurement was performed for each patient using a classical Landolt Cs technique. The visual acuity values measured (ranging from 0 to 1 with increments of 0.1) were expressed in tenths.

To record eye-movement signals, a light stimulus was presented to patients using a L.E.D. bar able to provide stimuli in a range of 60 degrees of the field of vision, at fixation distance of 1 meter with head immobilised to reduce head motion.

The stimuli were sequentially presented at different gaze positions (sequence: 0°,5°,10°,20°,30°,0°,-5°,-10°,-20°,-30°,0°) for 10 seconds each. Eye movements were detected using either an infrared apparatus (Oftalmograf, Universal Initram Corporation, El Paso) or an electro-oculography device (Gould ES 2000, Gould Instrument System with bio-signal amplifiers 11-5407-58) and were digitally recorded using a PCI acquisition board (Data Translation DT 2801-A) featuring 200 Hz sampling rate and 12 bits resolution data.

At this stage, eye movement signals were first filtered with a Blackman window calculated on 121 points to reduce high frequency noise and then filtered to reduce power line noise. A specific software was used to recognize nystagmus waveforms and compute nystagmus parameters such as frequency amplitude, intensity and waveform shape (refer also to [14]).

To identify the foveation periods, signal tracts, in which the eye velocity was close to 0°/sec were automatically detected. These corresponded to the sequence of the nystagmus waveform minima and maxima. The physician selected the sequence corresponding to foveations.

The foveation window was computed by considering the time interval for which the eye velocity was lower than 4°/sec [3, 12] and the eye position was contained within 0.5°, with respect to the maximum (or minimum) points selected.

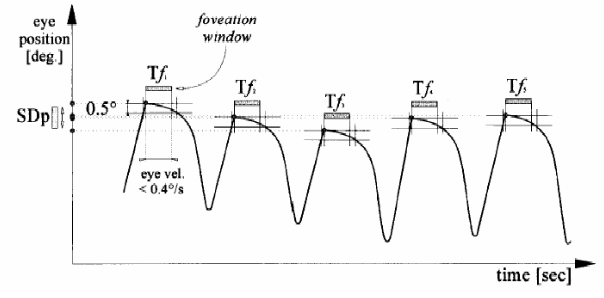

Figure 1: Scheme to represent the computation of the foveation time Tf and the SDp.

The duration (time length) of the foveation window was considered a measurement of the foveation time (Tf). The standard deviation of the eye position during foveations (SDp) was computed as the Standard Deviation of all the samples contained within the foveation windows relating to a specific signal block.

Analysing the data-base of eye movements, recorded in Naples at the Ocular Motility Laboratory (Dept. of Ophthalmologic Science, Faculty of Medicine and Surgery, in cooperation with the Biomedical Engineering Unit, Dept. of Electronic Engineering and Telecommunication - University of Naples "Federico II"), a large variability of eye position during foveations (i.e. greater than 0.5 degrees) was detected in many of the CN patients. This variability was mostly due to a sinusoidal-like baseline oscillation (BLO) superimposed to nystagmus waveforms.

In this study the simplifying hypothesis of considering the baseline oscillation a pure sinusoid has been hold. In order to extract sinusoidal oscillations, a least mean square (LMS) fitting technique was used. A linearisation of the problem can be achieved by using an independent estimation of the baseline oscillation frequency, by means of FFT. In our work, the highest peak of the power spectrum of the eye movement signal in the range of 0.1-1.5 Hz was considered an estimator of the BLO frequency.

The following figure show an example of the results achieved using the described technique: the detected BLO has been plotted as bold line superimposed to the corresponding eye-movement signal (resulting amplitude and period of the BLO are also represented by corresponding segments).

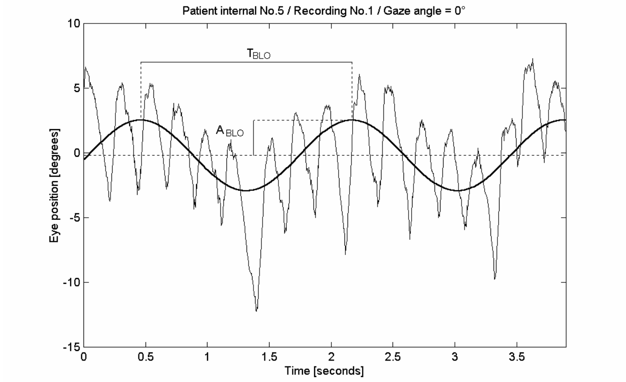

Figure 2: Example of computed BLO from an horizontal eye-movement recording of a nystagmus patient.

BLO frequency, amplitude and phase were computed for each signal block. Amplitude and frequencies mean values, for nystagmus and BLO, on each recording were obtained averaging values of all blocks in the same recording. Finally, nystagmus and BLO amplitudes and frequencies mean values were compared by means of a linear regression analysis.

Results

From the analysis of the CN eye-movement recordings, nystagmus frequencies resulted ranging from 2.4 to 4.4 Hz (average: 3.3 Hz) and amplitudes resulted ranging from 0.5 to 12.8 degrees (average: 4.4 deg.); the BLO frequencies resulted ranging from 0.16 to 0.64 Hz (average: 0.36 Hz), while BLO amplitudes resulted ranging from 0.2 to 7.7 degrees (average: 2.1 deg.). Nystagmus waveforms resulted of different types, mainly belonging to jerk types.

Figure 3 shows histograms of the occurrences of nystagmus amplitude, while Figure 4 show that obtained for BLO amplitude.

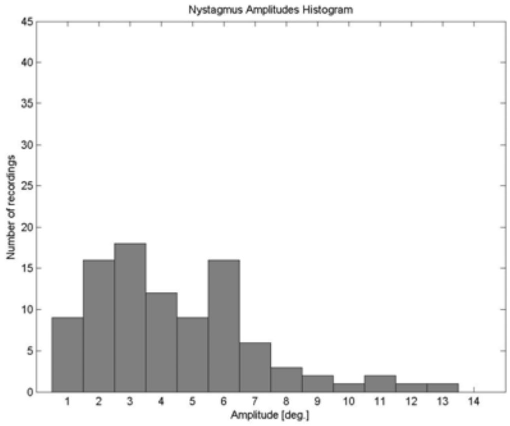

Figure 3: Histogram of the occurrences of the Nystagmus amplitudes.

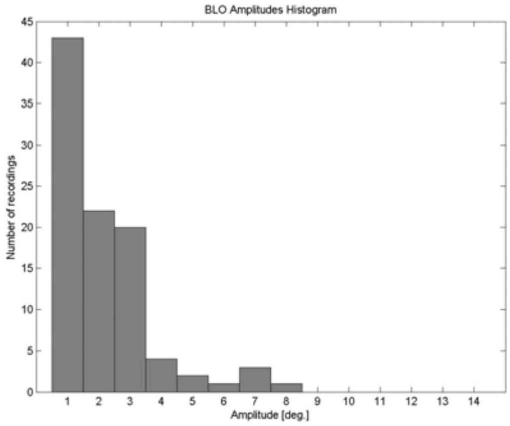

Figure 4: Histogram of the occurrences of the corresponding BLO amplitudes.

In order to highlight the relationship between nystagmus and BLO features, nystagmus amplitudes were plotted against the correspondent BLO amplitudes for each eye-movement recording (see figure 5). On the top of those scatter-plot were plotted the regression lines with the corresponding equations and correlation coefficients obtained.

The high value (R^2 = 0.77) obtained for the correlation coefficient in the linear regression analysis of the amplitude suggest an high level of interdependence between BLO and nystagmus amplitude. Considering the equation of the regression line it result that the baseline oscillation shows, on average, an amplitude of one half of the correspondent nystagmus amplitude.

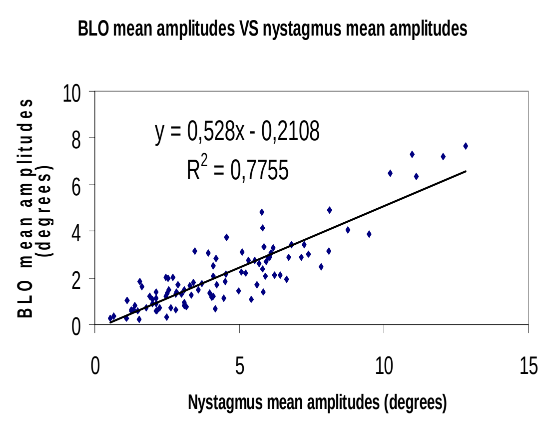

Figure 5: Linear regression analysis: on x-axis are reported the Nystagmus amplitudes, on y-axis are reported the corresponding BLO amplitudes.

A very low value was obtained for the correlation coefficient in the linear regression analysis of the frequencies suggests an independence between the BLO and nystagmus frequency.

Discussion

In a previous work it was reported that the slow eye movement, described as base line oscillation, explains most of the eye position variability during foveations (SDp) [7], which in turn was found exponentially well related to visual acuity [6]. According to the procedure described in methods section, base line parameters can be estimated for any recordings. Results of present analysis shows that almost 75% of the recordings have a BLO amplitude greater than 1° in amplitude. For the rest (about 25% of the recordings) the small amplitude of the BLO should not affect significantly visual acuity.

However, it is worth mentioning that not in all cases a sinusoidal signal completely describes the baseline oscillation. Therefore, a more exhaustive analysis about its shape will be valuable. Moreover, the base line oscillation, which is easy to be automatically estimated, do not exactly represents the ideal line that connect all the foveation positions, which are one of the information directly related to the patient's vision.

An additional further analysis should be the investigation of the BLO and nystagmus relationship in each gaze positions, instead of using average values computed on the entire recording.

The origin of such base line oscillation is unknown. Some authors assert that slow movement can be recorded only in subjects with severely reduced visual experience from birth (like CN patients) [10].

The high value of the correlation coefficient between BLO and nystagmus amplitude found in this study suggests that the two phenomena are somewhat linked together. Therefore the origin of the BLO could be searched analysing within the same ocular motor subsystems considered for nystagmus.

Conclusions

This study presents an analysis of the baseline oscillation, considered a sinusoidal signal, in eye movement recordings of CN patients during fixation and proposes its relationship with the amplitude of the corresponding nystagmus waveform.

Previous work [6] highlighted and expressed as an exponential term the dependence of visual acuity on the SDp; a following study [7] showed a noticeable linear dependence of SDp on BLO amplitude: in other words, most of the eye position variability during foveation (SDp) can be explained by the presence of the baseline oscillation. In this study the linear regression analysis showed a noticeable linear dependence of the nystagmus and BLO amplitudes.

It is worth to mention that our studies were also promoted by some successful botulinum toxin treatments at our Institute of Ophthalmology of CN children, who recovered a remarkable higher visual acuity. Such therapy, by temporary suppressing eye muscles activity, significantly decrease nystagmus amplitudes: reasonably also the BLO will result decreased, consequently, also the SDp will be reduced turning in a increasing of the patient’s visual acuity.

However, at moment, there is no clear evidence of general effectiveness of botulinum toxin therapy.

Furthermore, the role of slow eye movements underneath nystagmus waveform have to be further investigated. In particular, not in all cases a sinusoidal signal completely describes the baseline oscillation and a more exhaustive analysis about its shape, possible association with nystagmus and its origin will be very valuable.

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