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Characterisation of baseline oscillation in congenital nystagmus eye movement recordings

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ABSTRACT

Congenital nystagmus is an ocular–motor disorder that develops in the first few months of life; its pathogenesis is still unknown. Patients affected by congenital nystagmus show continuous, involuntary, rhythmical oscillations of the eyes. Monitoring eye movements, nystagmus main features such as shape, amplitude and frequency, can be extracted and analysed. Previous studies highlighted, in some cases, a much slower and smaller oscillation, which appears added up to the ordinary nystagmus waveform. This sort of baseline oscillation, or slow nystagmus, hinder precise cycle-to-cycle image placement onto the fovea. Such variability of the position may reduce patient visual acuity. This study aims to analyse more extensively eye movements recording including the baseline oscillation and investigate possible relationships between these slow oscillations and nystagmus. Almost 100 eye movement recordings (either infrared-oculographic or electrooculographic), relative to different gaze positions, belonging to 32 congenital nystagmus patients were analysed. The baseline oscillation was assumed sinusoidal; its amplitude and frequency were computed and compared with those of the nystagmus by means of a linear regression analysis. The results showed that baseline oscillations were characterised by an average frequency of 0.36 Hz (SD 0.11 Hz) and an average amplitude of 2.1° (SD 1.6°). It also resulted in a considerable correlation (R^2 scored 0.78) between nystagmus amplitude and baseline oscillation amplitude; the latter, on average, resulted to be about one-half of the correspondent nystagmus amplitude.

1. 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 [1]. Nystagmus oscillations can persist also closing eyes, moreover they tend to damp in absence of visual activity.

In vertebrates, eye movements are controlled by oculomotor system in a complex manner, depending on the stimuli and viewing conditions. In the human eye, the little portion of the retina which allows the maximal acuity of vision is called fovea. An attempt to bring the image of a target onto the fovea can involve up to five oculomotor subsystems: the saccadic, smooth pursuit, vestibular, optokinetic and vergence systems. The vestibular system is driven by non-visual signals from the semicircular canals, while the other systems are mainly driven by visual signals encoding target information. Pathogenesis of the congenital nystagmus is still unknown; dysfunctions of at least one of the ocular stabilization systems have been hypothesized, but no clear evidence was reported.

Nystagmus can be idiopathic or associated to alteration of the central nervous system and/or ocular system such as achromatopsia, aniridia and congenital cataract. Both nystagmus and associated ocular alterations can be genetically transmitted, with different modalities; estimates of the prevalence of infantile nystagmus range from 1 in 1000 to 1 in 6000 [2–5]. CN occurrence associated with total bilateral congenital cataract is of 50–75%, while this percentage decreases in case of partial or monolateral congenital cataract. CN is present in most cases of albinism.

Eye movement recording is an essential tool to study nystagmus. Various techniques are currently in use to record eye movements: electro-oculography (EOG), infrared oculography (IROG), magneto-oculography (MOG) also known as scleral search coil system (SSCS) and video-oculography (VOG). The first technique relies on the fact that the eye has a standing electrical

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potential between the front and the back. Horizontal EOG is measured by placing electrodes on the nasal and temporal boundaries of the eyelids; as the eye turns a proportional change in electrodes potential is measured. The IROG approach relies on measuring the intensity of an infrared light reflected back from the subject's eye. Infrared emitters and detectors are located in fixed positions around the eye. The amount of light reflected back to a fixed detector varies with eye position.

The VOG approach relies on recording eye position using an infrared video camera and applying image processing techniques. The scleral search coil method is based on electromagnetic interaction at radio frequencies between two coils, one (embedded in a contact lens) fixed on the eye sclera and the other external.

According to bibliography, nystagmus can be classified into different categories depending on the characteristics of the oscillations [6]; typically in CN eye movement recording is possible to identify, for each nystagmus cycle, the slow phase, taking the target away from the fovea, the fast (or slow) return phase. According to the nystagmus waveform characterisation by Dell'Osso and Darof [9], in case the return phase is slow then the nystagmus cycle is pendular or pseudo-cycloid; if the return phase is fast then the waveform is defined as jerk (unidirectional or bidirectional). In general, CN waveform has an increasing velocity exponential slow phase [6].

A schematic illustration of a unidirectional jerk nystagmus waveform (pointing to the left) is presented in Fig. 1.

Eye movement recording and estimation of concise parameters, such as amplitude, frequency, direction, foveation periods, etc. are a valid support for an accurate diagnosis, for patient follow-up and for therapy evaluation. Current therapies for CN, still debated, aim to increase the patient's visual acuity by means of refraction defects correction, drug delivery and ocular muscle surgery [7].

Four main surgical strategies have been advocated in management of congenital nystagmus: Kestenbaum surgery for compensatory head posture with null zone; artificial divergence surgery; maximum recession of horizontal rectus muscles and rectus muscle anterior tenotomy [7].

In general, CN patients show a considerable decrease of the visual acuity, since image fixation on the fovea is reduced by nystagmus continuous oscillations. CN patient visual acuity reach a maximum when eyes are in the position of least ocular instability, hence, in many cases, a compensatory head mal-position is commonly achieved, in order to bring the zone of best vision into the straight-ahead position. Such so-called 'null zones' correspond to a particular gaze angle, in which a smaller nystagmus amplitude and a longer foveation time can be obtained, thus reaching a better fixation of the visual target onto the retina. Abnormal head posture could be alleviated by surgery (mainly translating the null zone to straight-ahead position).

In normal subjects, when the velocity of the image projected on the retina increases by a few degrees per second, visual acuity and contrast sensitivity decrease. In CN patients, fixation is disrupted by nystagmus rhythmical oscillations, which result in rapid movements of the target image onto the retina [8]. Ocular stabilisation is achieved during foveation periods [6] in which eye velocity slows down (less than 4°/s) while the visual target crosses the foveal region ($\pm 0.5^{\circ}$); in this short time interval called 'foveation window' is said that the subject 'foveates'.

Visual acuity was found to be mainly dependent on the duration of the foveation periods [6,9,10], but the exact repeatability of eye position from cycle to cycle and the retinal image velocities also contribute to visual acuity [1,11].

Previous works analysed the role of the standard deviation of eye position (SDp) during foveations with respect to visual acuity [12,13]. Fostered also by a remarkable increase in some CN patients' visual acuity, obtained with botulinum toxin treatment, we tried to characterise such foveation variability. A slow sinusoidal-like oscillation of the baseline (baseline oscillation or BLO) was found superimposed to nystagmus waveforms [14–16] and its relation with the SDp was estimated [17].

Presence of similar slow pendular waveforms, superimposed to nystagmus, was also reported by Gottlob et al. [18]. In addition, in eye movement recordings presented by Dell'Osso et al. [12,19] it is possible to recognize slow oscillations superimposed to the nystagmus. Akman et al. [20], using dynamical systems analysis to quantify the dynamics of the nystagmus in the region of foveation, found that the state-space fixed point, or steady state, is not unique. Physiologically this means that the control system does not appear to maintain a unique gaze position at the end of each fast phase. Similarly, Evans [21] reported that some of the analysed patients fail to coordinate target with fovea position (approximately 50% of patients). Kommerell [11] noticed that in CN patients, tracking moving targets, the eye recording presented a slow eye movement superimposed to the stimulus trajectory in addition to nystagmic cycles.

Nystagmus and the slow oscillation could modify visual acuity. Currie et al. [22] evaluated acuity for optotypes in healthy subjects using moving light sources to simulate retinal image motion that occurs in nystagmus. Their results are that acuity depends on both foveation duration and position variability, although the presence of other sensory defects (e.g. astigmatism) must be taken into account. Moreover, they found that an addition of low-frequency (1.22 Hz) waves to the light stimuli, i.e. slow oscillation, caused a worsening of visual acuity.

Those clues addressed our attention to a further insight of this slow oscillation component in order to better characterise this

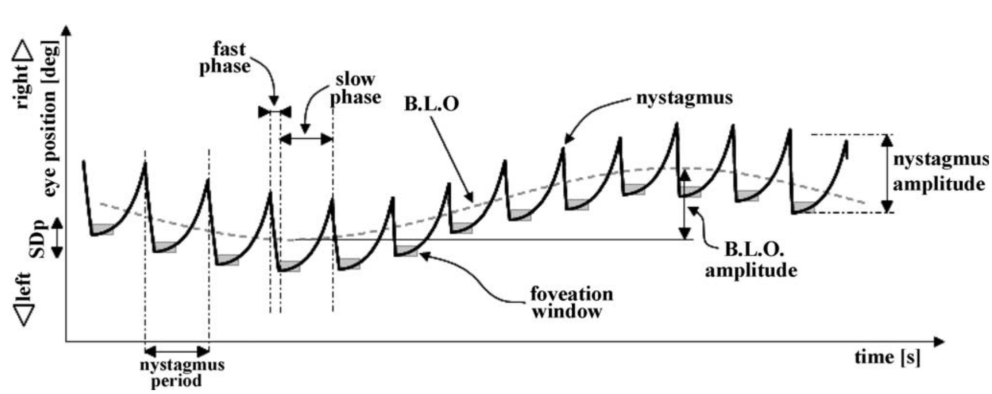

Fig. 1. A schematic illustration of a jerk nystagmus waveform (bold line) with fast phase pointing to the left; on the picture are depicted various nystagmus features, such as: fast and slow phase components, nystagmus period and amplitude; the grey box on each cycle represents the foveation window. The baseline oscillation is shown as a dashed line, and its amplitude is also showed.