Vision Research 123 (2016) 20–25

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Classification of infantile nystagmus waveforms

Maria Theodorou [a,b,*], Richard Clement [a,c]

[a] Institute of Child Health, University College London, 30 Guilford Street, London WC1N 1EH, United Kingdom
[b] Paediatric Ophthalmology and Strabismus, Moorfields Eye Hospital, 162 City Road, London EC1V 2PD, United Kingdom
[c] College of Engineering, Mathematics & Physical Sciences, University of Exeter, Exeter EX4 4QF, United Kingdom

ARTICLE INFO

Article history:
Received 21 March 2015
Received in revised form 26 October 2015
Accepted 27 October 2015
Available online 12 May 2016

Keywords:
Eye motility
Nystagmus
Waveforms

ABSTRACT

Classification of infantile nystagmus waveforms is an important problem because the characteristic waveforms can be used to distinguish between infantile and acquired nystagmus. A clear description of the nystagmus is also a necessary first stage in understanding its origin. Currently infantile nystagmus waveforms are classified into at least 12 different types. In this study we analyse a database of nystagmus recordings in order to investigate if this classification can be simplified. Application of principal components analysis revealed that 96.9% of the variance of the waveforms is described by a linear sum of two component waveforms. The components consist of sawtooth and pseudocycloid waveforms that account for 78.7% and 18.2% of the variance respectively for the most common single cycle waveforms. This simplified description of infantile nystagmus highlights the importance of identifying the origin of the jerk component and its synchronisation with the pseudocycloid component for the characterisation and treatment of the nystagmus.

1. Introduction

Infantile nystagmus consists of an involuntary, predominantly horizontal, oscillation of the eyes that develops at birth or shortly afterwards and persists throughout life. An early classification of nystagmus by Cogan (1967) described four types of early-onset nystagmus seen clinically: pendular nystagmus, jerk nystagmus, latent nystagmus and periodic alternating nystagmus. The main problem with this classification was that the attribution of pendular nystagmus to sensory defects and jerk nystagmus to motor defects, which formed an unintended conclusion from this classification (Dell'Osso, Hertle, & Daroff, 2007), was disproven by subsequent investigations. (Abadi & Dickinson, 1986; Dell'Osso, 1982; Yee, Wong, Baloh, & Honrubia, 1976)

Subsequently, Dell'Osso and Daroff (1975) gave an exhaustive classification of nystagmus movements based on eye movement recordings. The waveforms divided into at least 12 different types, with each patient exhibiting at least 2. There has since been a 13th waveform described by Dell'Osso's group Dell'Osso (2006). All subjects with infantile nystagmus have at least one waveform with a pathognomonic increasing velocity exponential slow phase taking the target away from the fovea, a variable fast or slow return phase, and a foveation period of minimum velocity and variable duration (Dell'Osso & Daroff, 1975; Dell'Osso, 1982).

Although this classification is comprehensive it may be unnecessarily complicated because most types of nystagmus waveform can be produced simply by adding a sawtooth and a sinusoidal function as illustrated in Fig. 1. The commonest types of nystagmus waveforms are those of pendular, pendular with foveating saccades, pseudocycloid, jerk with extended foveation and jerk (Abadi & Bjerre, 2002). Pendular movements consist of smooth to and fro movements (sinusoidal). A variant of the pendular form is pendular nystagmus with foveating saccades, in which small corrective rapid movements interrupt the pendular movement after it has passed the target and realign the fovea with the target. Jerk movements consist of slow drifts off the target, followed by a rapid corrective movement. Variants of the jerk waveform include jerk with extended foveation, in which the drift just after the corrective saccade is extremely slow, pseudocycloid, in which the corrective rapid movement is insufficiently large and foveation occurs during the early part of the slow phase. The direction of beating of the nystagmus is defined by the direction of the fast phase of the movement. Other common waveforms in which the beating is bi-directional, such pseudo pendular with foveating saccades, can similarly be synthesized by using a bi-directional sawtooth waveform.

A useful classification will give insight into how different types of nystagmus are related to each other and whether or not one waveform can be changed into another by manipulating variables such as viewing eye, gaze eccentricity or the visual task. The advantage of

---

[*] Corresponding author at: Paediatric Ophthalmology and Strabismus, Moorfields Eye Hospital, 162 City Road, London EC1V 2PD, United Kingdom.

E-mail address: Maria.Theodorou@moorfields.nhs.uk (M. Theodorou).

http://dx.doi.org/10.1016/j.visres.2015.10.017
0042-6989/

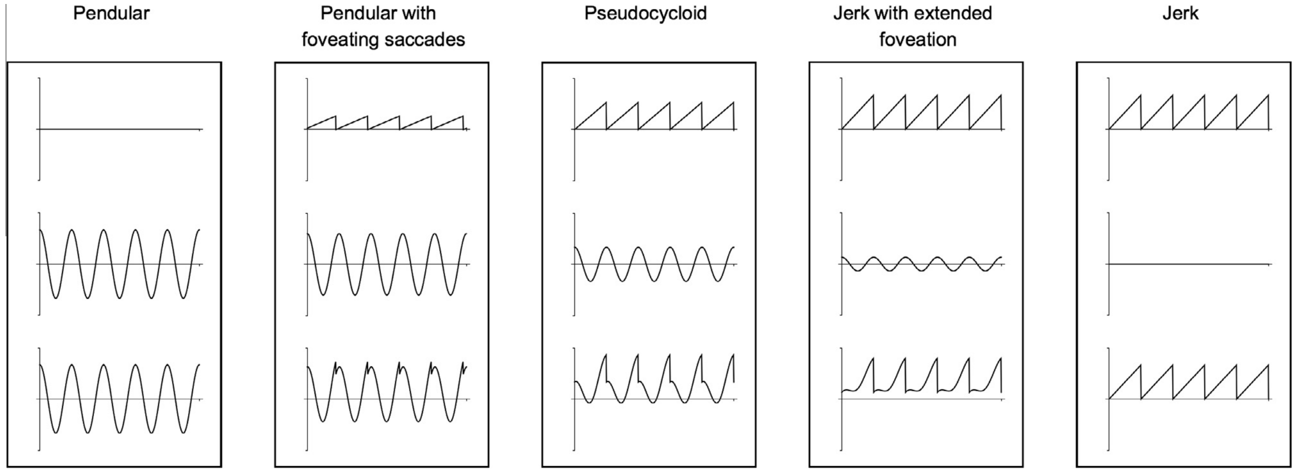

Fig. 1. Plots of eye position (vertical axis) against time (horizontal axis) for simulated nystagmus waveforms created by adding a sawtooth and a sinusoidal function.

considering nystagmus waveforms to be comprised of a jerk and a pendular component is that the different waveforms can be related to each other by altering the balance between the jerk and pendular components. In practice the considerable variability of individual waveforms makes it difficult to discern consistent changes in them (Abadi & Worfolk, 1991). We have tackled this problem using a non-linear time series analysis technique previously introduced to the analysis of nystagmus to identify the underlying oscillations (Clement et al., 2002; Theodorou & Clement, 2007). Subsequently a principal components analysis was used to isolate two components within the oscillations. This approach was used to investigate the relative changes in the components with gaze angle.

2. Methodology

2.1. Collection of data

The eye movement recordings were taken from the baseline data of 38 of the 48 subjects enrolled in a drug trial before any intervention (McLean, Proudlock, Thomas, Degg, & Gottlob, 2007). The use of anonymised data was consistent with the informed consent given by subjects in the original study. Ocular and extra-ocular motility examinations, electroretinogram recordings and visual evoked potentials were used to diagnose 20 of the subjects as idiopathic and 18 of the subjects as having albinism. The mean age in years of the idiopath group was 40.05 ± 8.29 and of the albinism group was 34.11 ± 10.53. The subjects were predominantly male (13 in the idiopath group and 15 in the albinism group). The remaining subjects in the drug trial had additional conditions and so were not used in this study.

Best corrected binocular visual acuity was measured using the preferred head position so each participant could use his or her null position. The mean LogMAR acuity of the idiopath group was 0.33 ± 0.17 and of the albinism group was 0.54 ± 0.14. Binocular eye movements were recorded with the head stabilised in the primary position using a chin rest. Eye movements were recorded in 3 positions of gaze: straight ahead, 15° right and 15° left. Five of the subjects in the idiopath group had a latent component to their nystagmus and 10 in the albinism group.

Full details of the investigations of the subjects are given in report on the drug trial by McLean et al. (2007).

2.2. Data analysis

Underlying periodicities in the waveform were identified using the technique of periodic orbit analysis (Clement et al., 2002; Theodorou & Clement, 2007). Application of this technique involves 4 stages. First, the velocity of the eye movement is thresholded. and the intervals between threshold crossings calculated. Second, the intervals are concentrated onto the periodicity of the waveform by applying a transform based on a linear analysis of the changes in successive interval lengths. Third, the peak in a histogram of the transformed data is used to identify the underlying periodicity of the data. Finally, example cycles matching the periodicity are identified in the eye movement recordings. The width of the histogram bins used was 25 ms. All cycles within ±12.5 ms of the periodic orbit length were selected as example cycles for each subject. The position of the cycle closest to the periodic orbit length was used to represent the underlying periodicity.

To carry out the principal components analyses the collection of cycles was transformed into mean subtracted data by removing the mean offset of each oscillation. The duration of all waveforms was then made the same so that they could be combined linearly. The unit length waveforms were then re-sampled so that each waveform was described by a sequence of 100 data points, and each waveform could be represented by a point in a 100 dimensional Euclidean data space. The goal of the data analysis was to effect a dimensionality reduction so that each waveform could be described by a point in a 2-dimensional Euclidean space where each axis corresponds to a template waveform. Principal components analysis was carried out on eye position and eye velocity data and also on a Fourier series description of the position data because this has previously been used to provide a comprehensive description of the different waveforms (Abadi & Worfolk, 1991).

The position data was taken directly from the re-sampled unit length waveforms. The velocity data was obtained by applying a 5 point digital filter to the position data. For comparison with the results from the position and Fourier series analyses, the velocity templates were integrated to obtain the corresponding position templates. The original Fourier series description used only six harmonics which resulted in some small ripples on the synthesized waveforms (Abadi & Worfolk, 1991) so the number of harmonics was doubled to 12 to eliminate the ripples if possible. All calculations were carried out using the software package Mathematica®.

3. Results

3.1. Visual classification of the waveforms

The individual cycles were classified by the authors into one of the following classes; Jerk (24), Jerk with Extended Foveation (32), PseudoCycloid (11), Pendular with Foveating Saccades (7),