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The effects of increased visual task demand on foveation in congenital nystagmus

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Abstract

Commonly, when an individual with congenital nystagmus (CN) performs a visually demanding task their nystagmus intensifies and their visual acuity decreases, probably due to poorer foveation. However, the relationship between fixation attempt and nystagmus waveform has never been quantified. In this study 14 CN subjects viewed a Landolt C of varying orientation and size. They indicated its orientation via a button array whilst eye movements were recorded. Foveation was uncorrelated with optotype size. These results suggest that CN is not exacerbated by visual demand per se rather the need to do something visually demanding of importance to the individual.

Keywords: Congenital nystagmus; Visual demand; Foveation; Anxiety; Motivation

1. Introduction

Congenital nystagmus (CN) is an involuntary ocular oscillation presenting at birth or shortly afterwards (Abadi & Bjerre, 2002; Dell'Osso, 1985). There are many clinical characteristics that differentiate CN from other infantile and acquired nystagmus types. One frequently noted hallmark of CN is the variability of the nystagmus waveform and the assertion that it depends on such factors as fixation effort, stress and tiredness.

It is widely noted in the literature (for example, Abadi & Bjerre, 2002; Abadi & Dickinson, 1986; Dell'Osso, 1982) that fixation attempt results in increased nystagmus intensity and, consequently, decreased acuity. For example, Dell'Osso (1982) states that "increased fixation attempt results in a nystagmus with increased intensity... which makes it difficult for the patient with CN to see clearly details which are near the level of his maximal acuity."; Scheiman and Wick (2002) state that the "effort-to-see can often reduce performance." Surprisingly, however, aside from a single pair of illustrative eye movement recordings (Abadi & Dickinson, 1986) no study to date has used eye movement recordings to formally examine the relationship between fixation attempt and the CN waveform. Anxiety and stress have also been stated to exacerbate CN but such associations have also not been quantified. Even though Abadi and Dickinson (1986) showed changes in eye movement recordings with visual effort in a subject with CN, the fixation target used was an LED, whose viewing imposed no acuity demands. In normal life fixation effort increase not upon command but when an individual with CN tries to resolve an object at the limit of his or her visual acuity. It would therefore seem more appropriate to simulate 'real world' situations by using a range of different size targets, as in a Snellen chart,

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as identification of small optotypes would require greater acuity than would the viewing of an LED. As it is often stated that CN can be greatly affected by psychological factors (Abadi & Dickinson, 1986; Abadi & Pascal, 1991; Dell'Osso, 1982) and as the length of foveation periods has been shown to be a better predictor of visual performance than nystagmus intensity (Abadi & Bjerre, 2002; Chung & Bedell, 1996; Dell'Osso & Daroff, 1975; Dell'Osso & Jacobs, 2002), a study attempting to determine the relationship between visual demand and mental state of CN subjects on their foveation time during reading of varying sized optotype at distance fixation was carried out.

2. Methods

The eye movements of 14 subjects with CN were examined. The diagnosis of CN was initially made by the referring ophthalmologist and was confirmed on the basis of clinical examination and eye movement recording analysis carried out by the authors. Seven subjects were classified as idiopathic (two males, five females), age range: 14–37, mean = 25.4 years, VA range OU (logMAR equivalent): 0.0–0.6, mean = 0.2 (6/9.5) and seven as albino (four males, three females, four ocular, three oculocutaneous); age range: 8–75 years, mean = 42.4, VA range OU (logMAR equivalent): 0.0–0.6, mean = 0.4 (6/15).

All participants were naïve with respect to eye movement measuring techniques and the experimental hypotheses of the study. The study was approved by the La Trobe Faculty of Health Sciences Human Ethics Committee and written informed consent was obtained according to the Declaration of Helsinki. Pertinent characteristics of the subjects are given in Table 1.

Eye movements were recorded using a Microguide binocular infrared oculographic system (Kumar & Krol, 1992). Horizontal eye position data were digitised at 400 Hz with a 12-bit analogue to digital converter for later off-line analysis. Testing was done without refractive correction and no subject wore contact lenses. This could potentially have caused subjects to view the targets with an excessive degree of blur, but as can be seen from Table 1, there was only a one line difference between corrected and uncorrected visual acuity for the seven subjects who wore glasses. Eye movements were calibrated by sequentially presenting light emitting diodes (LEDs) from $-19°$ to $+19°$ mounted on an arc 160 cm in radius and positioned the same distance in front of the subject. Fixation data were scaled using a best-fit regression line. A chin and headrest were used to stabilise head position during recording.

As this study intended to determine the relationship between foveation time and both visual demand and mental state of CN subjects during reading of variably sized optotypes, it was necessary to evaluate each subject's subjective mental state on the day of testing. A visual analogue scale (VAS) was used prior to the eye movement recordings. A VAS is a simple, inexpensive, clinically valid and reliable measure (Benini, Griffifth, Lago, & Gobber, 1996). The VAS comprised a line of 10 cm in length with two opposing words on either end, i.e., anxious/relaxed. Each subject was asked to mark on the line the point they thought was most appropriate in terms of their temperament. The line drawn on each scale was measured in centimetres and this in turn gave a corresponding score out of ten as the quantitative measure of mental state. Each subject had five different scales (anxious vs relaxed; drowsy vs alert; depressed vs happy; bored vs intrigued and angry vs calm) to complete. Separate measures of the VAS were performed during minimal and maximal visual demand. This enabled the authors to determine if there was a change in mental status during times of minimal and maximal visual demand. Ideally, the VAS should have been undertaken by each subject after each level of visual demand with the eye tracker in place whilst reading the different sized optotypes. Undertaking the VAS in this manner would have disturbed head and eye tracker position, necessitating re-calibration of the subject. Therefore, subjects were asked to read a logMAR chart without the eye tracker in place and then were asked to mark the VAS during times of minimal and maximal visual demand. This was performed prior to the eye movement recordings.

Following calibration, subjects were presented with a single Landolt C of varying orientation (up, down, left or right) and angular size (ranging from a logMAR of 1.0 to -0.3, in 0.1 logMAR steps). Each single Landolt C was positioned in the centre of a 17″ flat-screen LCD monitor and contour interaction was produced by surrounding each individual Landolt C by two horizontally tangential bars that were the same width as the gap in the C and of length equal to its diameter. The monitor was positioned 50 cm away from each subject. Subjects performed the Landolt C task with the head stabilised in the primary position on the same chin and forehead restraints that were used during the calibration sequence. Seven subjects performed the task binocularly. Three idiopathic and four albinotic subjects had a manifest strabismus and, therefore, undertook the vision task monocularly. The eye without the strabismus was selected as the viewing eye during recordings.

Each subject was instructed to view the particular Landolt C presented and to indicate the location of the gap in the C via a push button array instead of verbally. The button box was hand-held and comprised four buttons arranged in the shape of a '+' sign that corresponded with the four possible orientations (up, down, left or right) of the C; when pressed, it indicated to the authors the subject's choice. The button box helped min-

Table 1
Clinical details of the subjects

Subject	Age/sex	Clinical diagnosis/ocular alignment	Glasses worn	Best corrected binocular acuity (logMAR)	Best corrected monocular acuity (logMAR)	Uncorrected binocular acuity (logMAR)	Null angle (°)
PH	22 F	Idiopath LexoT	Yes	0.2	R0.2 L0.4	0.2	0
SD	33 F	Idiopath LesoT	No	0.0	R0.1 L0.4		0
LT	19 F	Idiopath Orthophoric	No	0.3	R0.2 L0.4		5
MR	14 M	Idiopath Orthophoric	No	0.0	R0.0 L0.0		−5
NB	32 F	Idiopath Orthophoric	No	0.6	R0.8 L0.7		5
ASJ	21 M	Idiopath Orthophoric	Yes	0.2	R0.3 L0.2	0.3	5
RS	37 F	Idiopath LesoT	No	0.2	R0.2 L0.3		0
AM	8 M	TNOCA Orthophoric	No	0.4	R0.6 L0.5		5
FS	75 F	TPOCA RexoT	Yes	0.6	R0.7 L0.6	0.7	10
TK	41 F	TNOCA LesoT	Yes	0.3	R0.3 L0.6	0.3	−5
AbM	13 M	TNOCA Orthophoric	Yes	0.4	R0.9 L0.4	0.5	10
KS	62 F	TNOCA LesoT	No	0.0	R0.0 L0.0		5
IC	34 M	TPOCA Orthophoric	Yes	0.5	R0.5 L0.6	0.6	−5
KW	64 M	TPOCA ResoT	Yes	0.4	R0.7 L0.4	0.5	5

Ages are in years. TPCOA = tyrosinase-positive oculocutaneous albino; TNCOA = tyrosinase-negative oculocutaneous albino. LesoT, left esotropia; ResoT, right esotropia; RexoT, right exotropia; LexoT, left exotropia.

imise head movement. Viewing time for each optotype was unrestricted, although prompt responses were encouraged. Subjects were urged to look at the stimulus as steadily as possible while minimising blinks. Each C-target was presented in descending order, starting with the largest or second largest size. The order of orientation was randomised. If the subject identified the correct orientation, the authors then presented another C-target of the same size but of different orientation. All four orientations needed to be correctly identified by subjects before the next C-target size was presented. If subjects chose an incorrect orientation then another of the same size Landolt C was presented but of a different orientation. If all four responses given were incorrect, the authors interpreted this to mean that the last C-size where more than one correct response was given as their best possible acuity with effort. If subjects identified two incorrect and two correct orientations of the same sized optotype the researcher then presented the next smaller sized C-target. It was found that if subjects identified only one or two of the four orientations correctly they subsequently would not correctly identify any of the next smaller sized C-targets. However, as the aim of the study was to determine if increased visual demand decreases foveation time the optotype size that was one size smaller than each subjects' best achievable acuity on a logMAR chart was always presented to them. This helped to ensure a concerted visual effort by the subject. Trials were kept to 4 min in length for every subject to guard against boredom because CN intensity is known to decrease with inattention (Abadi & Dickinson, 1986; Dell'Osso & Jacobs, 2002). All subjects undertook practice runs, prior to data collection, in order to become familiar with the procedure.

Eye movement data were analysed for changes in the duration of foveation periods, and whether the CN waveform itself changed during times of increased visual demand. Foveation periods were defined as those periods of the eye movement recording during which eye velocity was ⩽4°/s and eye position ±2° from the point of fixation from cycle to cycle. This position criterion of ±2°, less stringent than the ±0.5° often used in past studies, was used to account for albino subjects who lack a functional fovea (Dell'Osso & Jacobs, 2002; Mezawa, Ishikawa, & Ukai, 1990; Ukwade & Bedell, 1992). Foveation periods were determined by manually positioning the cursor through the beginning of as many slow phases as possible in a given interval of fixation. Points that met the position and velocity criteria for that segment were identified. Blinks and non-fixation points were excluded from analysis. Relationships between foveation and visual effort were examined two ways: via linear regression of foveation duration against logMAR equivalent optotype size and, since we thought it possible that foveation might only change when effort was greatest, via two-way mixed ANOVA, where independent variables were subject group (idiopathic and albino) and visual demand (first and last optotype read). Alpha was set at 0.05. The regression analysis was carried out because one hypothesised relationship between visual effort and foveation was that as the former increased, the latter would decrease. The ANOVA comparing foveation for minimal and maximal demand was used to test the hypothesis that only when demand became maximal would foveation decline.

Although foveation time was our primary outcome measure, much of the literature—especially the more clinically focused—has used nystagmus frequency, amplitude and intensity as outcome measures. We also measured these properties for the first and last optotypes read.

Relationships between foveation time and the affective measures assessed with VAS (anger, alertness, etc.) were examined by evaluating the linear regression of change in foveation time against change in VAS score for minimum and maximum effort optotypes. The VAS scores for minimal and maximal visual demand were also evaluated with two-way mixed ANOVA, where independent variables were again subject group and visual demand. Alpha was again set at 0.05.

3. Results

The major finding was that there were no consistent changes in the duration of the foveation periods with decreasing optotype size. In Fig. 1A and B the relationship between logMAR equivalent visual acuity and the percentage of time that the foveation criteria were met are shown for the two groups of subjects (albino and idiopathic). Linear regressions of foveation time on logMAR equivalent optotype size yielded significant relationships for only 2 of the 14 subjects—AM (slope = –0.49, $r^2 = 0.98$, $p < 0.001$), with albinism, and ASJ (slope = –0.068, $r^2 = 0.79$, $p < 0.02$), with idiopathic CN. The ANOVA found no significant effect of optotype size (df = 1; $F = 0.003$; $p = 0.96$) or diagnostic group (df = 1; $F = 0.041$; $p = 0.84$). Interactions were also non-significant (df = 1, $F = 0.02$, $p = 0.89$). This was supported by the analyses of amplitude, frequency and intensity summarised in Table 3, where, after combining idiopathic and albinotic subjects' data, paired t-tests showed that when assessed for the easiest and most difficult optotypes, none of the three measures differed significantly (amplitude: $t = 1.07$, p = NS; frequency: $t = 0.82$, p = NS; intensity: $t = 0.55$, p = NS).

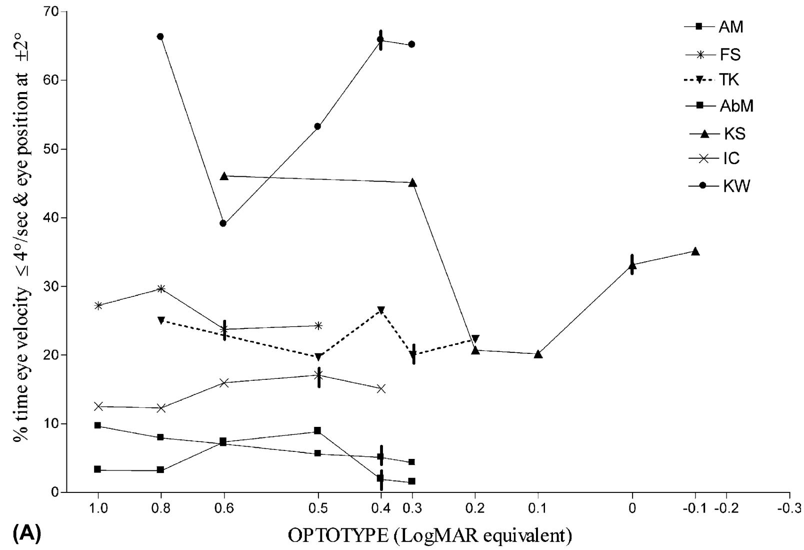
Repetition of the VAS allowed for its analysis with respect to visual demand. All linear regression analyses of VAS change vs foveation change were non-significant (anxious scale, $p = 0.28$; drowsy scale, $p = 0.50$; depressed scale, $p = 0.61$; bored scale, $p = 0.90$; angry scale, $p = 0.35$).

Two-way ANOVAs examining VAS scores during minimal and maximal visual demand for the two groups showed mixed results. Significant effects of optotype size but not group or interaction were found for the anxious vs relaxed ($F = 11.76$, df = 1,12, $p < 0.01$), depressed vs happy ($F = 8.92$, df = 1,12, $p < 0.02$) and angry vs calm ($F = 8.26$, df = 1,12, $p < 0.02$) scales. The remaining two VAS scales (bored vs intrigued and drowsy vs alert) were non-significant for both categories.

The CN waveform itself was also examined during periods of varied visual demand. The results are summarised in Table 2. It can be seen that subjects' waveforms remained relatively unchanged as they read either easy or maximally difficult optotypes. Figs. 2A and B, and 3A and B illustrate the CN waveforms of two examples.

4. Discussion

Although an intensification of CN with increased visual demand is considered one of its hallmarks (Abadi & Bjerre, 2002; Abadi & Dickinson, 1986; Dell'Osso, 1982; Scheiman & Wick, 2002), no previous study has formally examined this relationship with eye movement recordings. Abadi, Dickinson, Pascal, Whittle, and Worfolk (1991) previously noted that some subjects' nystagmus intensity remained unchanged as "effort to see" increased and suggested that the key parameter was attention. This was an observation, however, rather than an experimental result. This study is the first to explicitly examine the relationship between visual demand (and several measures of mental state) of CN subjects and foveation time during their reading of variably sized optotypes. Surprisingly, the results of the present study suggest that that even maximal visual demand generally did not cause a deterioration in foveation, the nystagmus parameter most directly associated with



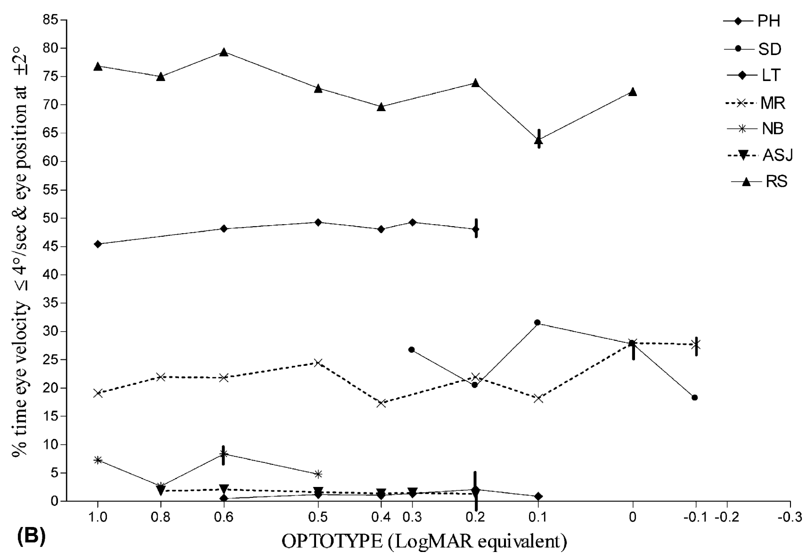


Fig. 1. (A) The relationship between optotype read by the albino subjects on the Landolt C simulation and foveation duration. **|** = best binocular acuity of each subject. (B) The relationship between optotype read by the idiopathic CN subjects on the Landolt C simulation and foveation intervals. **|** = best binocular acuity of each subject.

visual acuity. Neither did it affect the more traditional measures of amplitude, frequency or intensity.

Why has the present study failed to find what is so commonly asserted in the literature? One possibility is that performing a task that is visually demanding does not result in a subsequent adverse change in nystagmus if the subject undertaking the task is unrewarded by it or if there is no motivational drive to perform. Our testing conditions simply required subjects to identify the orientation of smallest possible Landolt C. They derived no personal benefit from performing well on the task. Thus, it is likely that there was no motivation for subjects to be extremely accurate during the task and, for this reason it is possible that they experienced relatively little change in stress levels, despite the increased visual effort expended. That is, even though the increase in anxiety ratings on the VAS as subjects identified the smallest resolvable optotype was statistically significant, it may not have been functionally significant. This assumption is strengthened by the comments that were given by subjects following their Landolt C recordings. For example, 8 of the 14 subjects made comments to the effect that "it did not worry me if I got the letters wrong," 3 of the 14 subjects commented that "nothing was at stake if I got the letters wrong", and 1 of these 3 further commented that "it's not like I do not get my driver's license today if I don't see a particular letter size." These comments emphasise the likelihood that exacerbation of CN is not solely affected by increased visual demand per se.

In deciding to experimentally evaluate the relationship between visual demand and nystagmus, we chose foveation period duration rather than nystagmus

Table 2
Waveforms and foveation durations at times of minimal and maximal visual effort

Subject, diagnostic category	Minimal visual effort		Maximal visual effort	
	Waveform(s)	% Time in foveation window	Waveform(s)	% Time in foveation window
PH (idiopath)	Jef, J	45.4	Jef, J	48.0
SD (idiopath)	Jef	26.6	Jef	18.1
LT (idiopath)	PC	0.5	PC	0.9
MR (idiopath)	Jef	19.1	Jef	27.7
NB (idiopath)	PC	7.3	PC	4.8
ASJ (idiopath)	PPfs	1.8	PPfs	1.3
RS (idiopath)	Jef	76.8	Jef	72.3
AM (TNOCA)	PC	9.7	PC	4.3
FS (TPOCA)	PC	27.2	PC	24.3
TK (TNOCA)	J, Jef	25.0	J, Jef	22.3
AbM (TNOCA)	J, DJ	3.3	J, DJ	1.5
KS (TNOCA)	Jef	46.1	Jef	35.1
IC (TPOCA)	PPfs	15.1	PPfs	17.0
KW (TPOCA)	BDJ	66.2	BDJ	65.1

Nystagmus waveforms were: jerk (J), jerk with extended foveation (Jef), pseudo-cycloid (PC), pseudo-pendular with foveating saccades (PPfs), pendular with foveating saccades (Pfs), and dual jerk (DJ). Other abbreviations as in Fig. 1.

Table 3
Mean amplitude, frequency and intensity for each subject during reading of least and most difficult optotypes

Subject	Amplitude (°)		Frequency (Hz)		Intensity (amplitude $*$ frequency)	
	Minimal visual effort	Maximal visual effort	Minimal visual effort	Maximal visual effort	Minimal visual effort	Maximal visual effort
PH	0.79	0.69	4.71	4.82	3.73	3.31
SD	3.94	3.38	3.41	3.81	13.43	12.88
LT	8.78	10.22	3.44	5.45	30.18	55.71
MR	1.21	1.17	4.49	4.74	5.41	5.54
NB	3.01	3.15	4.90	4.12	14.75	12.97
ASJ	7.06	6.74	3.47	3.08	24.50	20.75
RS	0.46	0.37	2.31	2.14	1.07	0.80
AM	6.39	5.85	2.49	3.57	15.94	20.84
FS	1.08	1.03	2.97	2.71	3.22	2.78
TK	1.08	1.23	3.11	2.86	3.37	3.50
AbM	2.08	1.12	5.17	5.45	10.76	6.13
KS	2.24	1.94	2.64	2.63	5.91	5.10
IC	2.76	1.57	2.85	3.27	7.86	5.13
KW	0.23	0.24	7.82	7.30	1.83	1.75
Mean ± SD	2.94 ± 2.67	2.76 ± 2.92	3.84 ± 1.47	4.00 ± 1.42	10.14 ± 8.79	11.23 ± 14.39

Group means and SD are also shown for each measure under the two conditions. No significant differences were found.

intensity (amplitude × frequency) as our primary dependent variable. We did this on the basis that nearly all studies (Abadi & Bjerre, 2002; Abadi & Dickinson, 1986; Dell'Osso & Daroff, 1975; Dell'Osso & Jacobs, 2002) (but see Bedell & Loshin, 1991) find this to be the best predictor of visual acuity in CN. However, amplitude, frequency and intensity were also uninfluenced by the level of visual effort. The experimental results and subjects' comments obtained in this study suggest that these measures might be influenced by visual demand when the visual task is personally important to the individual with CN. Thus, the idea that increased fixation attempt results in increased nystagmus, which in turn causes decreased acuity (Abadi & Bjerre, 2002; Abadi & Dickinson, 1986; Dell'Osso, 1982; Dell'Osso & Daroff, 1975; Dell'Osso, Flynn, & Daroff, 1974; Scheiman & Wick, 2002) should be more precisely specified. For example, the visual acuity of someone with CN could exceed that required for a driving license during routine clinical evaluation but not at the time of testing at the license bureau, even though the acuity tests were identical. We propose that it is the additional input of psychological stress (e.g. anxiety, fear etc.) brought on by motivation to perform well on the visual task that increases the CN and further reduces acuity. Of course, an individual with CN could be anxious or stressed by circumstances unrelated to vision, or be tired or ill. How such more general emotional factors affect CN has not been the

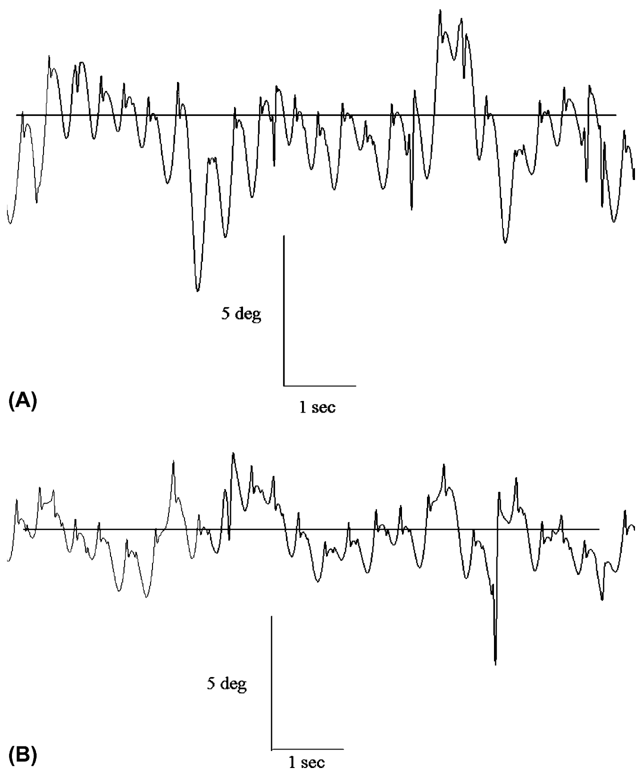


Fig. 2. (A) Recording of IC (albino) whilst attempting the 1.0 logMAR equivalent optotype. This optotype required minimal visual demand. The % eye velocity ⩽ 4°/s and ±2° = 15.1%. (B) Recording of IC (albino) whilst attempting the 0.4 logMAR equivalent optotype. This optotype required maximal visual demand. The % eye velocity ⩽ 4°/s and ±2° = 16.96%.

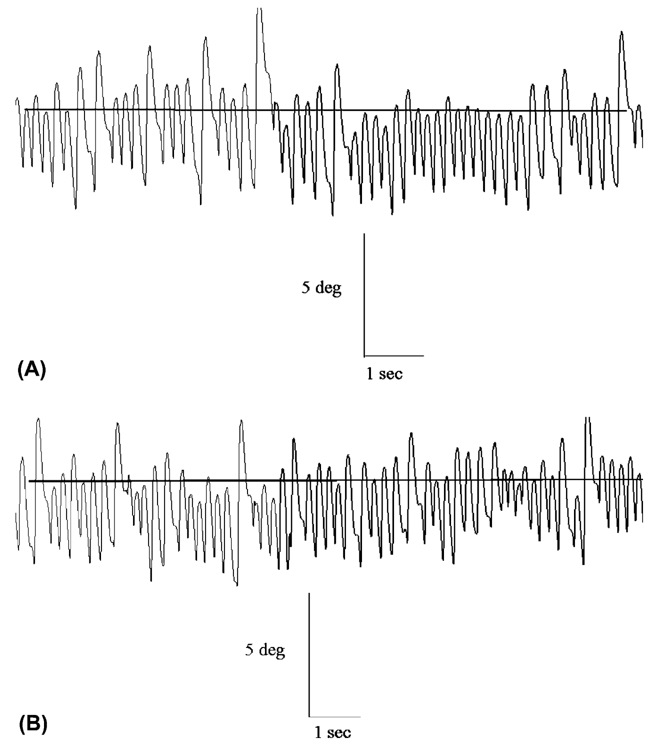


Fig. 3. (A) Recording of NB (idiopathic) whilst attempting the 1.0 logMAR equivalent optotype. This optotype required minimal visual demand. The % eye velocity ⩽ 4°/s and ±2° = 7.3%. (B) Recording of NB (idiopathic) whilst attempting the 0.5 logMAR equivalent optotype. This optotype required maximal visual demand. The % eye velocity ⩽ 4°/s and ±2° = 4.82%.

subject of study, although anecdotally they are often noted by individuals with CN to exacerbate the condition.

The amygdala is the structure most implicated in emotional processing. It projects to structures including the ventral striatum, anterior cingulate cortex (ACC) and orbitofrontal cortex, enabling it to influence complex behaviour (Everitt et al., 1999; Everitt & Robbins, 1992; Royer & Pare, 2002). The motivational effects of emotionally significant stimuli are also mediated in part by the orbitofrontal cortex and the ventral striatum (Schultz, Tremblay, & Hollerman, 2000; Zahm, Jensen, Williams, & Martin, 1999) and the ACC (Gaymard, Rivaud, & Cassarini, 1998; Paus, 2001). Posterior ACC is thought to be strongly connected with all frontal ocular motor areas as well as those in the brainstem (Gaymard et al., 1998; Paus, 2001).

Studies of the effects of reward expectation (Watanabe, Lauwereyns, & Hikosaka, 2003) and anxiety (Yardley, Watson, Britton, Lear, & Bird, 1995) have found that these can influence the programming of eye movements. Assuming that CN arises from instability of the slow eye movement control system (SEM) (Dell'Osso & Daroff, 1975; Dell'Osso et al., 1974; Jacobs & Dell'Osso, 2004), perhaps projections from the amygdala and ACC to the brainstem influence activity in the vestibular nuclei, of potential relevance to the pathogenesis of CN (Tusa, Zee, Hain, & Simonsz, 1992). Another possible point of influence is via the frontal eye fields, known to be part of a network important for smooth eye movement control and which includes the supplementary eye fields, intraparietal sulcus and both anterior and posterior cingulate cortices (Berman et al., 1999; Keller & Heinen, 1991; Krauzlis, 2004; Lynch, 1987; Petit, Clark, Ingeholm, & Haxby, 1997).

The dissociation between visual demand per se and exacerbation of CN suggests that the behaviour of a CN patient's nystagmus in the clinic may differ from what it does in the course of that patient's daily life. Even though a patient's nystagmus remains relatively stable when reading a Snellen chart in an eye clinic, it may still deteriorate markedly when that same patient searches for a house number on a dark night in a strange neighbourhood.

The rather surprising result that foveation in CN may not be affected by the increased visual demand in isolation due to a lack of motivation during the task suggests a need to extend studies examining motivational influences on eye movements (Watanabe et al., 2003; Yardley et al., 1995). Studies such as these suggest that effects of anxiety, arousal, mental stress and motivation can influence the generation of eye movements. Explicit manipulation of these parameters, as well as attention, during recording of CN should aid in broadening our understanding of the behaviour of this disorder under the entire range of conditions under which patients experience it.

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