·Clinical Research·

A new measure of nystagmus acuity

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Abstract

• **AIM: To construct a new visual acuity measuring function for congenital nystagmus (CN) patients by studying the relationships between acuity, velocities and positions of the eye.**

• **METHODS: After assessing the relationship between acuity, movement velocities and positions of the eye separately, a new function, which we call the automated nystagmus acuity function (ANAF), was constructed to measure the visual acuity of CN patients. Using a high-speed digital video system working at 500 frames per second, each eye was calibrated during monocular fixation. Twenty-six recorded nystagmus data were selected randomly. Using nystagmus waveforms, the best vision position (foveation period) and visual acuity were analyzed in three groups of subjects, and then all outputs were compared with the well-known expanded nystagmus acuity function (NAFX) and ANAF. Standard descriptive statistics were used to summarize the outputs of the two programs.**

• **RESULTS: Foveation periods were brief intervals in the CN waveform when the image was on or near the fovea and eye velocity was relatively slow. Results showed good visual acuity happened during the period when velocity was low and the eye position was near the zero position, which fitted the foveation periods. The data analyzed with NAFX and ANAF had a correlation coefficient of 0.934276, with an average error of -0.00973.**

• **CONCLUSION: The results from ANAF and NAFX analyses showed no significant difference. The NAFX manually identifies foveation eye positions and produces accurate measurements. The ANAF, however, can be calculated simply using the factors eye position and velocity, and it automatically calculates the ANAF without the need to manually identify foveation eye positions.**

• **KEYWORDS:** nystagmus; vision acuity; nystagmus acuity function; eye movement measurements
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INTRODUCTION

Nystagmus is defined as repetitive, to-and-fro involuntary eye movements that are initiated by slow drifts of the eye. It has a prevalence of approximately 24 per 10 000[1-4], so it is commonly encountered in clinical practice [5-9]. The eye movements of persons with nystagmus are accompanied by motion in the retinal image, which is known to degrade visual acuity in persons with normal vision[11-15]. The eye movements in congenital nystagmus (CN) are typically interrupted by brief periods referred to as foveation periods, during which the eye velocity is only a few deg/s or less, and the target of regard is imaged on or near the fovea [10,16-18]. Visual acuity in CN has proven to be primarily related to the duration of foveation periods [7,10,19-22]. A correlation exists also between visual acuity and the position variability of the foveation periods, that is, the standard deviation of the eye position during foveation periods within several seconds of continuous viewing[7,23]. Spatial frequency and temporal frequency are the core factors to describe visual acuity, and spatial frequency and temporal frequency can be calculated by the factors eye position and velocity. Acuity has been proposed to depend on the variability of eye velocity during foveation periods as well [5,16,21]. Similar relationships exist between the duration and variability of the foveation periods and acuity for other spatial tasks [24-26]. In addition acuity will get worse when the retinal image motion[20,27].

We can analyze the main features of nystagmus, such as shape, amplitude and frequency. Depending on the morphology of the oscillations, until now, the expanded nystagmus acuity function (NAFX) and wavelet have been used to determine visual acuity in CN patients [5]. NAFX, mainly a statistical measure, is a widely acceptable tool to evaluate visual acuity in CN patients[5,6].

The movement of nystagmus could be looked as a kind of dynamic process within general eye movement: vision signals are gathered in all slices of time during viewing, and while some are good and some are poor, all of them determine the power of vision. Convolution of the speed factor and position factor could indirectly represent acuity in each viewing slice. The acuity of nystagmus can be looked at as the mean of all the viewing slice acuity power during a given period. In this study, we constructed a vision automated nystagmus acuity function (ANAF) by studying the relationship between acuity, movement velocities and positions of the eye.

SUBJECTS AND METHODS

Subjects We randomly selected 26 data sets of approximately 3 to 5s in length in which the eye was looking at a still fixation target in front center from 12 patients. The data included three typical waveform characteristics: pendulum, jerk and complex [10]. Eye movement recordings were obtained with a high-speed digital video system working at 500 frames per second, and each eye was calibrated during monocular fixation.

Methods There are three factors that play a major role in determining visual acuity: 1) the location of the image cast on the fovea; 2) the quality of the image cast on the fovea; and 3) duration of the image cast on the fovea [7]. We discuss the three factors separately.

Location of the image cast on the fovea In short distance eye movements, visual acuity depends on location. Acuity is best when the image is focused on the center of the fovea and visual acuity is decreased from the fovea to 10° eccentrically. Physiologically, a closely linear relationship has been found between the density of the cones and distance from the fovea[8] (Figure 1).

There is a simple formula for acuity related to position, *i.e.*, acuity function for position (AFP), and we can use AFP to begin to describe the relationship between visual acuity and offset from the center of the fovea. Distance here means the foveation position from zero in degrees.

$AFP=distance^{-0.5}$ (1.1)

Considering the acuity data of patients, an adjustment can be made to arrive at experimental acuity.

$AFP=(distance+1)^{-0.5}$ (1.2)

Quality of the image cast on the fovea As one normally watches something moving slowly or quickly, the retinal-image slip on the fovea is very different. The range of retinal-image slip velocities may produce very different acuities. When a high speed image slip on the fovea occurs, the image should be blurred resulting in loss of details. Higher speed leads to poorer acuity. A linear relationship has been found between velocity and acuity when velocity is between 0°/s and 80°/s.

The ability of the eye to resolve detail is the definition of visual acuity. The normal human eye can distinguish patterns of alternating black and white lines with a feature size as small as one minute of arc [1/60 degrees or π/ (60×180)= 0.000291 radians]. That, incidentally, is the definition of

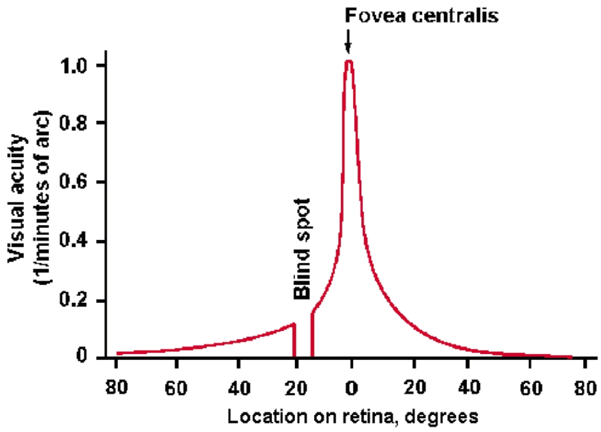

Figure 1 Relationship between the offset in degrees from the center of fovea and visual acuity for normal objects based on the definition of best vision acuity as 20/20[17].

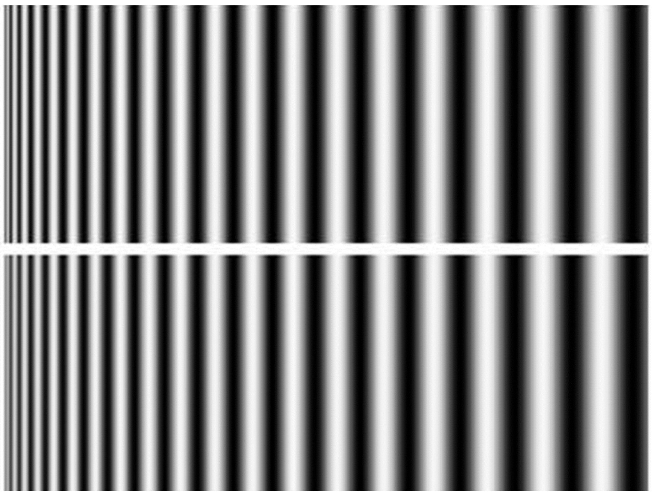

Figure 2 One line moving at different velocities display a blur pattern in different spatial frequencies.

20-20 vision. A few exceptional eyes may be able to distinguish features half this size. However, for most of us, a pattern of higher spatial frequency will appear nearly pure gray. Low contrast patterns at the maximum spatial frequency will also appear gray[9] (Figure 2).

When an image of one dark line (the highest spatial frequency one can perceive) is moving, the image we perceive will change to a blurred bar pattern. The image contrast will be lower and the line will be wider. Image width depends on the velocity of the image movement and spatial frequency, represented as the cycles within a certain distance. As we know, spatial frequency is described as the number of cycles during a certain distance.

For a moving stimulus, distance=speed×time; (2.1)

where Kp=cycle number/time and log (spatial frequency)=log (Kp)-log (speed); (2.3)

Log (spatial frequency), which is on the left part of Equation (2.3), is the log visual acuity. Thus, the spatial frequency changed while the image was moving, and the image acuity is correlated to negative log (speed). Following the relationship (2.3), we analyzed the acuity data from patients in our study. The acuity function for velocity (AFV) was determined as below by data fitting:

AFV=2.5-log (velocity)/2 (2.4) (Figure 3)

Duration of the image cast on the fovea As vision perceptions occur in all slices of time (t) that affect visual acuity, all viewing periods, including the during of foveation period, should be included in the function.

A simple measure of nystagmus acuity

Visual power (VP) here refers to the accumulated visual acuity during a certain period.

VP=∫ T t=0 AFP×AFV dt; (3)

The mean VP during some period could be considered as the visual acuity. We considered the mean acuity power during the viewing time as the acuity of the nystagmus patients.

Acuity=mean (VP) (4)

Equation (4) describe how the AFP and AFV work together to determine the result of acuity. Figure 4 illustrates the relationship between acuity, velocity and distance.

The function is very easy to be translated into program codes, and the program can be used to analyze visual acuity online in real time.

Statistical Analysis The NAFX originated from the nystagmus foveation function (NFF) which was based on foveation periods. The NAFX expands position limits and velocity limits to assess nystagmus acuity, which is mainly a statistical measure. The NAFX is one of the most widely accepted tools to evaluate visual acuity in CN patients. It is a good tool to analyze nystagmus [5]. In nystagmus waveforms, the best vision position (the foveation period) and visual acuity were analyzed in three groups and then all the outputs were compared with the NAFX.

Paired *t*-tests were used to summarize the outputs of the two programs. A value of $P<0.05$ was considered to be statistically significant. Statistical calculations were performed with Origin v7.03. (Origin Lab Corporation)

RESULTS

Location of the Best Acuity Segment Foveation periods are brief intervals in the CN waveform when the image is on or near the fovea and eye velocity is relatively slow[11]. High VP means better visual acuity. In Figure 5, three groups of typical waveform characteristics are represented. The red dots stand for the positions where the patient had good visual acuity and dotted lines describe the dynamic acuity varying with time. We highlighted the position in red to display where high VP occurs. All the highlighted points happen during the period when velocity is low and the position is near the zero position, which fits to the foveation periods (Figure 5).

Visual Acuity We analyzed the data with NAFX and the new program ANAF and found the correlation coefficient of the two sequences was 0.934276, with an average error of -0.00973. Our results showed that, with both NAFX and ANAF, acuity measurements were approximately the same.

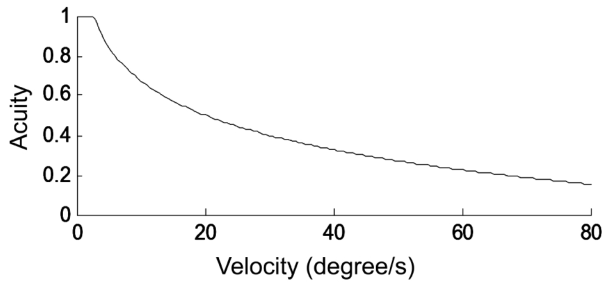

Figure 3 Relationship between velocity and acuity.

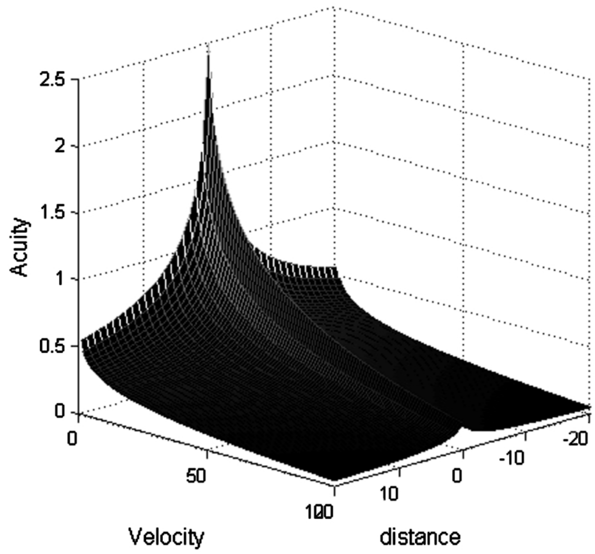

Figure 4 Relationship between acuity, velocity and offset when eye movements are infrequent and the image is focused on the center of the fovea. The best acuity should be found here. With an increase in velocity and offset, acuity should decrease.

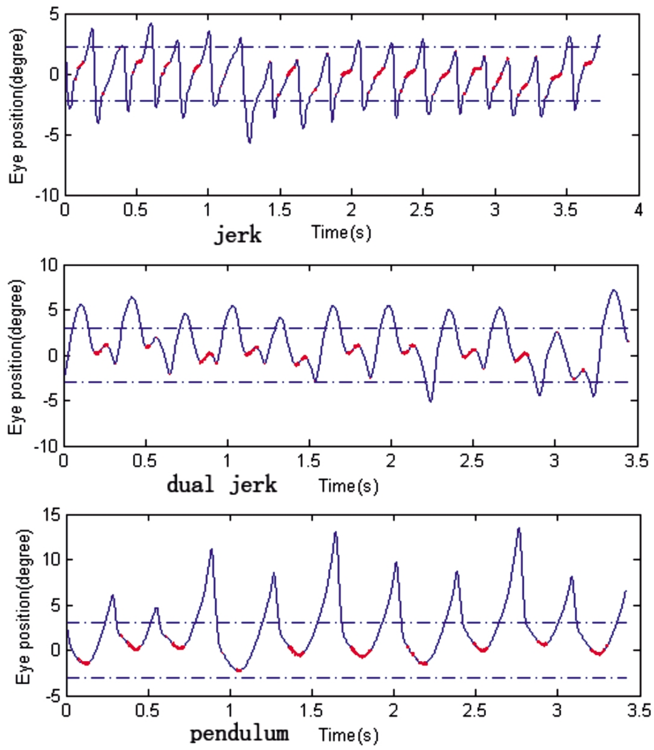

Figure 5 Foveation periods displaying a high VP represent the best visual acuity segments of complex waveforms.

Table 1 Nystagmus acuity functions from the ANAF and NAFX for each individual

ID	NAFX	ANAF	Error	ID	NAFX	ANAF	Error
1	0.209	0.1576	-0.0514	14	0.607	0.59	-0.017
2	0.258	0.1869	-0.0711	15	0.303	0.42	0.117
3	0.129	0.2135	0.0845	16	0.317	0.43	0.113
4	0.3	0.3068	0.0068	17	0.72	0.69	-0.03
5	0.336	0.3	-0.036	18	0.491	0.52	0.029
6	0.396	0.32	-0.076	19	0.28	0.21	-0.07
7	0.218	0.175	-0.043	20	0.314	0.2	-0.114
8	0.741	0.7805	0.0395	21	0.672	0.78	0.108
9	0.72	0.7385	0.0185	22	0.538	0.71	0.172
10	0.652	0.776	0.105	23	0.174	0.1919	0.0179
11	0.301	0.402	0.115	24	0.135	0.1719	0.0369
12	0.264	0.286	0.022	25	0.916	0.8975	-0.0185
13	0.36	0.296	-0.064	26	0.911	0.8799	-0.0311

At the 0.05 (*P*>0.50) level, the population means were not significantly different (Table 1, Figure 6).

DISCUSSION

Using the new ANAF and the well-known NAFX, 26 segments of nystagmus data from 12 patients were used to calculate nystagmus acuity. The results from the ANAF and NAFX showed no significant difference. The NAFX manually identifies foveation eye positions to produce accurate measurements. However, manual operation may produce manmade errors while the ANAF avoids these errors. The ANAF minimized the role of foveation variation in calculating the nystagmus acuity function. This allowed the ANAF to automatically calculate the nystagmus acuity function without the need to manually identify foveation eye positions [29]. The ANAF uses all data points in each nystagmus cycle to calculate the nystagmus acuity function by giving a different score to a data point according to its distance from a best-foveation position in each nystagmus cycle. The ANAF does not place a high degree of importance on variation in the foveation eye position because variation in the foveation position is usually a temporal phenomenon and dependent on the fixation condition. Accurate fixation is the best condition to assess nystagmus acuity. However, the variations have to be properly dealt with because inaccurate foveation occurs frequently. The results show that the ANAF can properly treat foveation variation and assess nystagmus acuity.

With the NAFX method, the zero eye position, *i.e*, where the eye is accurately fixating on a still fixation target, must be determined manually. The acuity function decreased when foveation eye positions varied or the standard deviation of the foveation eye position increased. Variation in foveation positions may be related to the level of attention. Many patients showed little variation in foveation positions when they fixated on a small target, but showed large variation in foveation positions when their fixation was slightly away from the target. If temporally large foveation variation is used to calculate the acuity function, the estimated acuity would be lower than the actual best acuity.

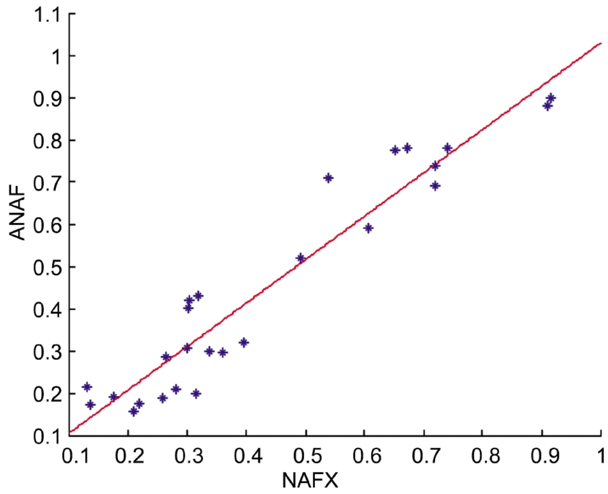

Figure 6 XY scatter plot of NAFX and INAF. The 26 points closely approximate the trend line, which shows the same/ difference between the results of two functions.

Based on the results of our study, it can be concluded that the ANAF method can trim the cycles needed in analyses and locate foveation. The ANAF is easy to use and no extended skills are needed. The nystagmus waveform and bidirectionality were tested can be successfully handled by the new program smoothly and quickly. It yielded a simple and clear explanation for how eye movement can aid or decrease VP.

In foveation theory, foveation is a major contributor to visual acuity [7,10,28]. Many studies on dynamic visual acuity (DVA) showed that drifting-motion and displaced-motion also help vision in addition to fixation [17,22]. Eye fixation and drifting-motion are combined during typical nystagmus eye movements. DVA also can be adapted to evaluate visual acuity on the part of drifting-motion [28]. With the ANAF, the worst visual acuity situation (where eyes move at high speeds or positions far from the fovea) and the better/best vision acuity situation (where eyes move at low speeds or positions close to the fovea) were both considered, instead of omitting the worst visual acuity situation.

As the ANAF can be calculated simply using the factors eye position and velocity, more dynamic vision experiments should be carried out on normal subjects in the future. This will help us determine differences between normal subjects and those with nystagmus.

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