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Extension of the eXpanded Nystagmus Acuity Function to Vertical and Multiplanar Data

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ABSTRACT

Our objective was to update and extend the functionality of the eXpanded Nystagmus Acuity Function (NAFX), allowing for its application to biplanar nystagmus and improving its predictive value in clinical evaluations. The original NAFX was based on foveation times taken from a "tau surface," an array with values calculated for each combination of position and velocity limits of a "foveation window." For the updated NAFX, we replaced the empirical surface with a mathematically defined surface that matched the original, but without the idiosynchratic irregularities caused by the waveforms of the subjects used for its calculation. For biplanar data, we have investigated combining horizontal and vertical eye movement data into a single radial vector. Age-related relationships were incorporated for more accurate individual visual acuities. Using the same uniplanar patient data, we verified that the updated NAFX yielded results equivalent to those of the original NAFX for the foveation window limits we tested. For biplanar data, the NAFX values were also comparable to those from uniplanar data of the same magnitude. The new version of the NAFX allows greater accuracy in predicting visual acuity for subjects of all ages, for both uniplanar and, eventually, biplanar nystagmus. This will allow researchers and clinicians to select the best therapies for a wider range of nystagmus patients.

The original eXpanded Nystagmus Acuity Function (NAFX),[1] which was based on the Nystagmus Acuity Function (NAF),[2] is a mathematically derived relationship that relates visual acuity to the attempts at foveation that occur within nystagmus waveforms, based on the duration and cycle-to-cycle stability of these foveation periods. In the original function, the foveation window was defined as the times at which the target was within ±0.5° of the fovea and not moving faster than ±4.0 deg/s with respect to it. However, there are many patients who could not meet these criteria, so their nystagmus could not be analyzed by the NAF, prompting the development of the NAFX, which allows for larger foveation windows (up to ±6° by ±10 deg/s) by varying τ, the foveation duration constant. The collection of τ for all combinations of position and velocity limits is called the "tau surface," and is shown in Figure 18.1A. While the shape does, in general, appear to be regular, there are obvious irregularities in the surface, most notably along the lower position values (left side of Fig. 18.1A). This was a consequence of some of the data that were used to generate the original surface: the "pseudopendular with foveating saccades" (PPfs) waveform has two saccades per cycle,[3] and as the position limit was increased, the slow phase following the braking saccade was included in the calculation, inadvertently increasing the measured foveation time.

As originally developed, the NAFX was applied only to nystagmus that occurred within one plane, as most infantile nystagmus is predominantly horizontal. However, there is no reason why the algorithm cannot be used to evaluate data in the vertical plane as well.

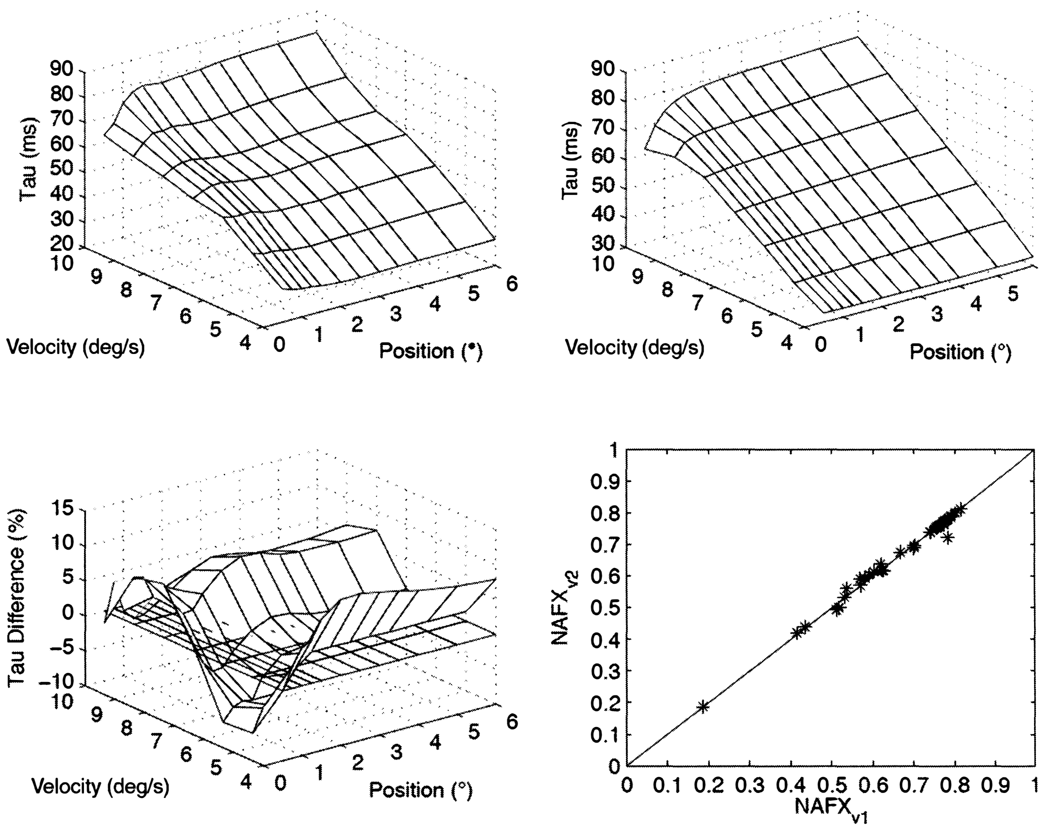


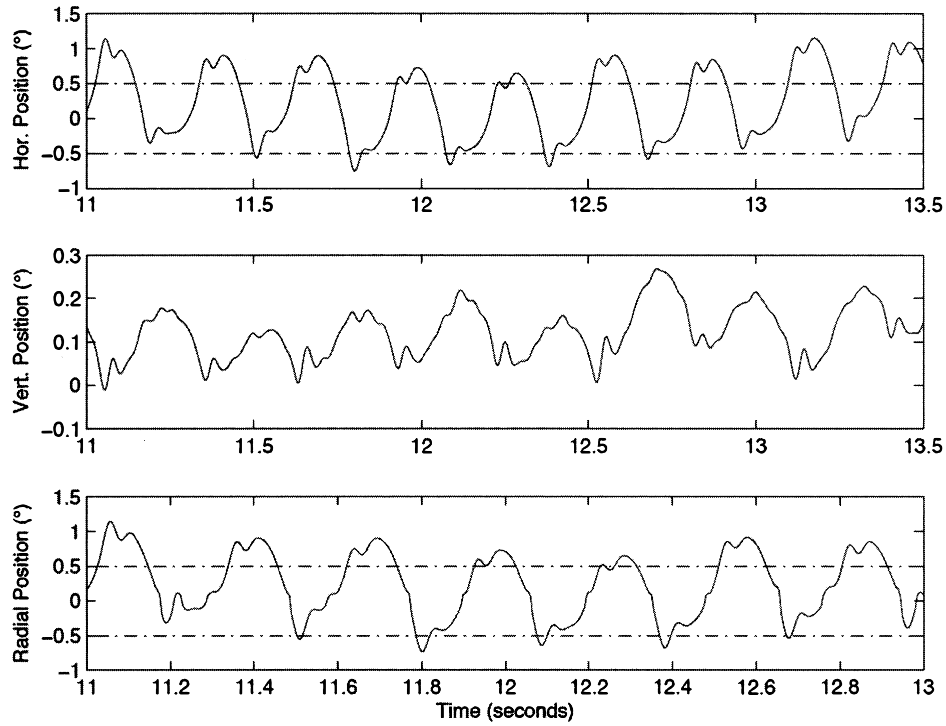
Figure 18.1 The original tau surface (A) generated from multiple data sets from an individual with infantile nystagmus syndrome and used in the software for the first version of the eXpanded Nystagmus Acuity Function (NAFX). Note the unevenness of the surface caused by both fitting the data and the small size of the nystagmus signal from this subject. (B) The revised tau surface. (C) The difference between the revised and original tau surfaces, plotted as a percentage difference. The flat surface is a zero plane, shown for reference. (D) The results of 40 analyses comparing the NAFX using the original tau surface versus the revised tau surface. The 45° line represents perfect equality.

Furthermore, we propose that the NAFX should be suitable for analysis of multiplanar nystagmus waveforms as one operation, by first combining the separate horizontal and vertical components into a *radial* vector.

Finally, as the NAFX is intended for use by clinicians as well as researchers, it must have a user-friendly interface while retaining the ability to allow deeper investigation of the data being analyzed.

METHODS

Rather than discarding the existing flawed tau surface and calculating a replacement using new data, we elected to reconstruct it by modifying its outlying values. To do this, we took each curve of fixed velocity at each position limit and performed a double exponential fit (using the MATLAB curve-fitting toolbox [MathWorks, Natick, MA]) of the form a × exp (b × x) + c × exp (d × x) to the non-outlier points, with the resulting curves having r^2 values of no less than 0.95. We defined the "velocity= 4 deg/s" border to be a constant, $\tau = 33.3$ milliseconds, the original value from the NAF, and in close agreement with the fit of the tau surface data. We also defined the "position = 6°" line to be linear with the endpoints set by the fit to the endpoint of the "velocity = 10 deg/s" curve and the 33.3 milliseconds from the aforementioned 4 deg/s border and applied small shifts to align the previously fitted curves to this border. Finally, we fit all the original points along the "position = 0.5°" border with a simple polynomial, yielding an r^2 value of 0.98 (Fig.18.1B).



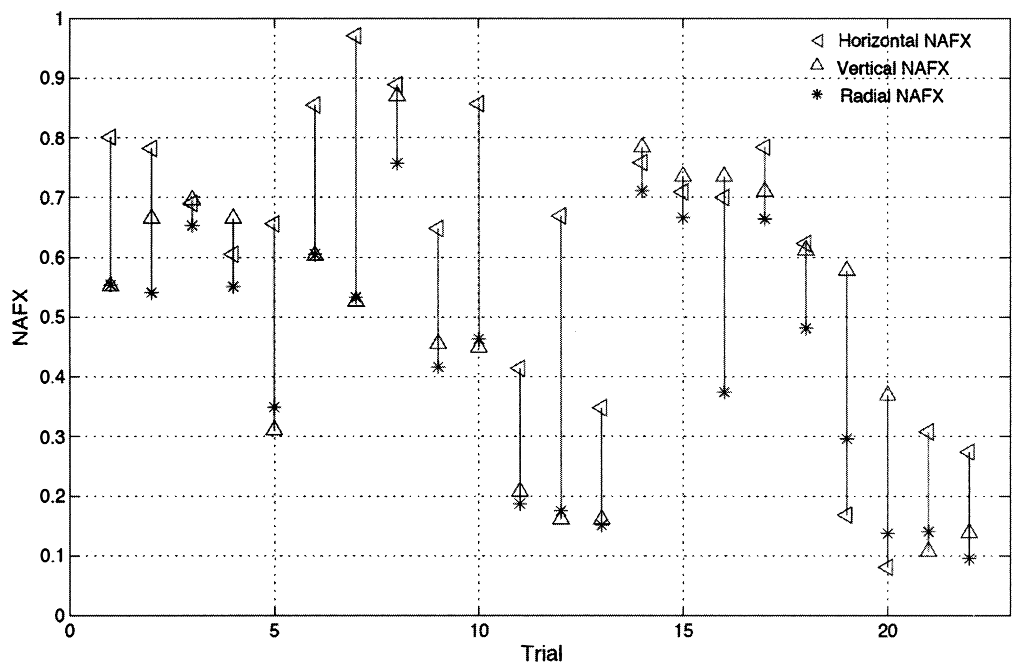


Figure 18.2 (top panel) Combining horizontal (*top*) and vertical (*middle*) eye movement data to create a radial nystagmus waveform (*bottom*). The dashed lines at ±0.5° represent the foveal extent. (bottom panel) The result of 22 biplanar eXpanded Nystagmus Acuity Function (NAFX) analyses compared to analyses of the individual uniplanar components. In most, but not all, cases, the radial NAFX is less than that of both individual components, as expected.

To convert the independent horizontal and vertical eye movement waveforms to a single radial waveform, we performed a simple vector summation of the form $r = \sqrt{(x^2 + y^2)}$, while attempting to preserve the sign of the major component wherever possible.

RESULTS

The overall differences between the original and revised tau surfaces are generally quite small, averaging 2 milliseconds overall, and no more than 5.1 milliseconds in the worst case. The difference expressed as a percentage between the original and the revised tau surfaces is shown in Figure 18.1C. The mean across all points was 2.17%, with a maximum error reaching 10% at only a few locations. We tested the new surface by reevaluating 40 NAFX calculations that had been performed over a variety of foveation-window position and velocity limits. To compare the results, we plotted $NAFX_{v1}$ along the x-axis and $NFAX_{v2}$ along the y-axis, as shown in Figure 18.1D. A first-order fit gives a slope of 0.975 (1.0 is ideal) with an r^2 value of 0.99, showing that the new function is in close agreement with the original. The average absolute error was 1.2%, with a standard deviation of 1.6%, demonstrating that the NAFX equation is relatively insensitive to the τ parameter.

Figure 18.2A shows the creation of a radial waveform from horizontal and vertical components. Here, the horizontal magnitude is approximately five times that of the vertical, and the resulting combined waveform remains recognizable as PPfs with the same magnitude and foveation characteristics as the horizontal component, as shown by the resulting radial NAFX of 0.46, compared to 0.45 for the horizontal and 0.85 for the vertical. The NAFX analyses of 22 (horizontal, vertical, radial) triplets are plotted in Figure 18.2B. Most of the time, as expected, the radial result was nearly the same as, or just slightly worse than, that of the component with the lower NAFX. However, on several occasions the radial analysis unexpectedly yielded a *better* result than the poorer component, for reasons that are discussed next.

DISCUSSION

The original NAFX has demonstrated its utility as a method to predict best potential visual acuity based solely on waveform and foveation characteristics. Our current work has further refined the technique by (a) removing minor irregularities in the tau surface that is used to calculate the NAFX and (b) extending the algorithm to allow its application to multiplanar nystagmus analysis.

The latter part (b) is actually a more difficult problem than it would at first appear. We are attempting to map a three-dimensional waveform (h,v versus t) into two dimensions (r versus t) while being mathematically exact, and this is not always possible. There are cases where the mapping will distort the resulting waveform so that, for example, successive foveation periods will appear closer together than they really are, leading to a decreased standard deviation of foveation position, resulting in an artificially high NAFX. The other challenge is that we would like the resulting waveform to remain recognizable as a nystagmus waveform, so that the investigator can use personal expertise to select appropriate segments of data for analysis and guide (or override) the program's operations as necessary. Unfortunately, these two directives can sometimes be in conflict.

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