

Using the NAFX for Eye-Movement Fixation Data Analysis and Display

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The instructions in this tutorial are meant to supplement those in “nafx.txt” and those in the “tutorials” folder, both of which are contained in the OMtools folder. They are illustrated with examples to help the user in understanding how to use some of the more important m-files in the OMtools software downloadable from this site. Investigators are also advised to read, “Recording and Calibrating the Eye Movements of Nystagmus Subjects” (OMLAB 011105). Note: the m-files (or p-files) listed below as ‘filename’ actually refer to ‘filename.m’ (or ‘filename.p’) and the text files “filename” are in the folder “OMtools/documentation/misc docs.”

Theory:

The NAFX and its predecessor, the NAF, originated from the NFF that attempted to relate the time-intervals of fp's and their position and velocity SD's to a measure of the 'quality' of a CN waveform (i.e., how likely it was to allow good acuity). When calculated by hand, each cycle was assumed to have 1 fp and the # of cycles in the interval of interest was included in the calculation. Later, when the NAFX was automated, only 'true' fp's (i.e., those that satisfied the foveation-window (FWIN) criteria) were used in the calculation. For waveforms that exhibited well-developed foveation, this changed nothing. However, for poor foveation due to excessive jitter or high velocities, many cycles were deemed to have no fp's and the resulting NAFX reflected only those few fp's detected. This yielded NAFX values that were not likely to be well correlated with acuity. To overcome this shortcoming, a measure of the total number of potential fp's (or cycles) needed to be reintroduced. That was most easily accomplished by applying the NAFX as described below. In addition, the NAFX vs. acuity line has been made age-specific to reflect the variation of visual acuity with age (a canine line is also included). If the nystagmus is multiplanar the NAFX can be used on data that has been converted to a radial vector array (see APPENDIX A).

Because the NAFX is a measure of the foveation quality that is meant to be predictive of the best-corrected visual acuity of a person with nystagmus, *it must be applied to data from the fixating eye*; the “foveation quality” of an occluded or otherwise non-fixating eye has no meaning in this context. Therefore, the data used must have been monocularly calibrated or, in the case of uniocular recordings, been taken with the other eye occluded. For truly binocular individuals, the monocularly calibrated data from the two eyes will overlap when both eyes are viewing (especially the foveation periods and the target) and the data from either eye can be used to calculate the NAFX (this should *never* be presumed, even when recording subjects thought to be “normal”). However, many with nystagmus may also have strabismus and alternate their fixating eye. In these cases, care must be taken to calculate the NAFX only from the fixating eye data; that may necessitate using data from one eye while fixating at one target angle and the other eye when at another target angle. Identifying the fixating eye from the data of both eyes is an easy task when the data have been monocularly calibrated (see OMLAB Report #011105). Using our paradigm, we allow 5 seconds at each target angle and repeat each twice (once while stepping out in 5°-steps from primary position to 30° and once while stepping back to primary position). For most individuals with nystagmus, that is sufficient to allow target acquisition (0.5 – 2 sec) and leaves approximately 3 seconds of steady fixation from which the NAFX may be calculated. This mimics the time sequence of fixating a new target under normal conditions.

There are rare individuals however, for whom: a) 5 seconds is not enough time; b) there is constant, rapid reversal of the fixating eye; or c) both a and b apply. The first case merely requires presenting each target for longer than 5 sec. Cases of rapid reversal of the fixating eye require careful identification of the small intervals for each fixating eye within the interval of steady fixation being analyzed and using a concatenation of those intervals to calculate a “fixating eye” NAFX (see Appendix B). For the remainder of this report we will presume the fixating eye is constant for the 5-second interval.

Method and Criteria:

Much of the repetitive work in the previous methodology has been automated by 'nafxprep' used in conjunction with the graphical interface for NAFX

1. Filter data using, 'r/lh=lpf(r/lh,4,20,samp_freq)'

NOTE: Since, when using its graphical interface, the nafx function needs rh or lh, rhf or lhf can no longer be used for filtered data. Here, we are filtering at 20 Hz; for noisy data 15 or 10 Hz can be used.

NOTE2: The latest “rd” function offers the option to pre-filter and differentiate the data; if this option is used, no additional filtering or differentiation is required and you may begin at step 2.

2. Run 'nafx' and the GUI for v2.1 in Figure 1 will appear.

Figure 1. The GUI for the NAFX v2.1 program. The first command ‘button’ is “nafxprep.” It is used in conjunction with zoomtool to automatically set the Position and Velocity sub-arrays for the fixation interval you choose. First, use “Subject age:” (drop-down menu) to set in the subject’s age. The “Position Limit:” is automatically set based on the “Delta Y” difference shown in zoomtool for the second set of position cursors (you may also set in a different value from the drop-down menu). The minimum is 0.5° (the foveal radius) and the maximum is 6° in 12 steps.

When you set the “Velocity Limit:” (drop-down menu), start at 4°/sec and increase in 1°/sec steps until a foveation period is detected for each nystagmus cycle or you reach 10°/sec (the maximum value for the velocity of the foveation window. The “Sampling Freq:” is automatically detected and set from the loaded data. “Foveation Criteria:” (drop-down menu) should be set as shown. “Tau:” will be automatically set based on you foveation-window position and velocity choices. The “Calc Fovs.” button will calculate foveation periods and print out several graphs. We usually set “Raw P,V points plot:” (drop-down menu) to “Together”, leave “Show Stats” unchecked, and “Use Tau v2” checked. “Calc NAFX” is the final command button and “Done” closes the program.

3. Choose the age range appropriate for the subject; this will customize the potential visual acuity predicted by the NAFX based on population statistics for visual acuity.
4. Plot the filtered data using an appropriate command (e.g., 'plth' or 'pltv').
5. Use 'zoomtool' on the filtered data to be analyzed and eliminate all data traces except the one being analyzed.
6. Home in on the segment you wish to analyze with the cursors and the X-axis zoom “in” button.
7. Place the cursors at the start and end of the sub-array you wish to use.
 NOTE: To ensure that your interval contains an integral number of cycles (and that no foveation periods are truncated), begin all intervals during a slow phase (away from a foveation period) and end all intervals at an equivalent point in a slow phase.
8. Click on the “C1 get” and “C2 get” buttons (in earlier versions of ‘zoomtool’—as shown in Figure 2—they were “C1 (xy)” and “C2 (xy)”).

9. Place the cursors at the highest and lowest peaks* of the foveation periods. Figure 2 demonstrates what this looks like.

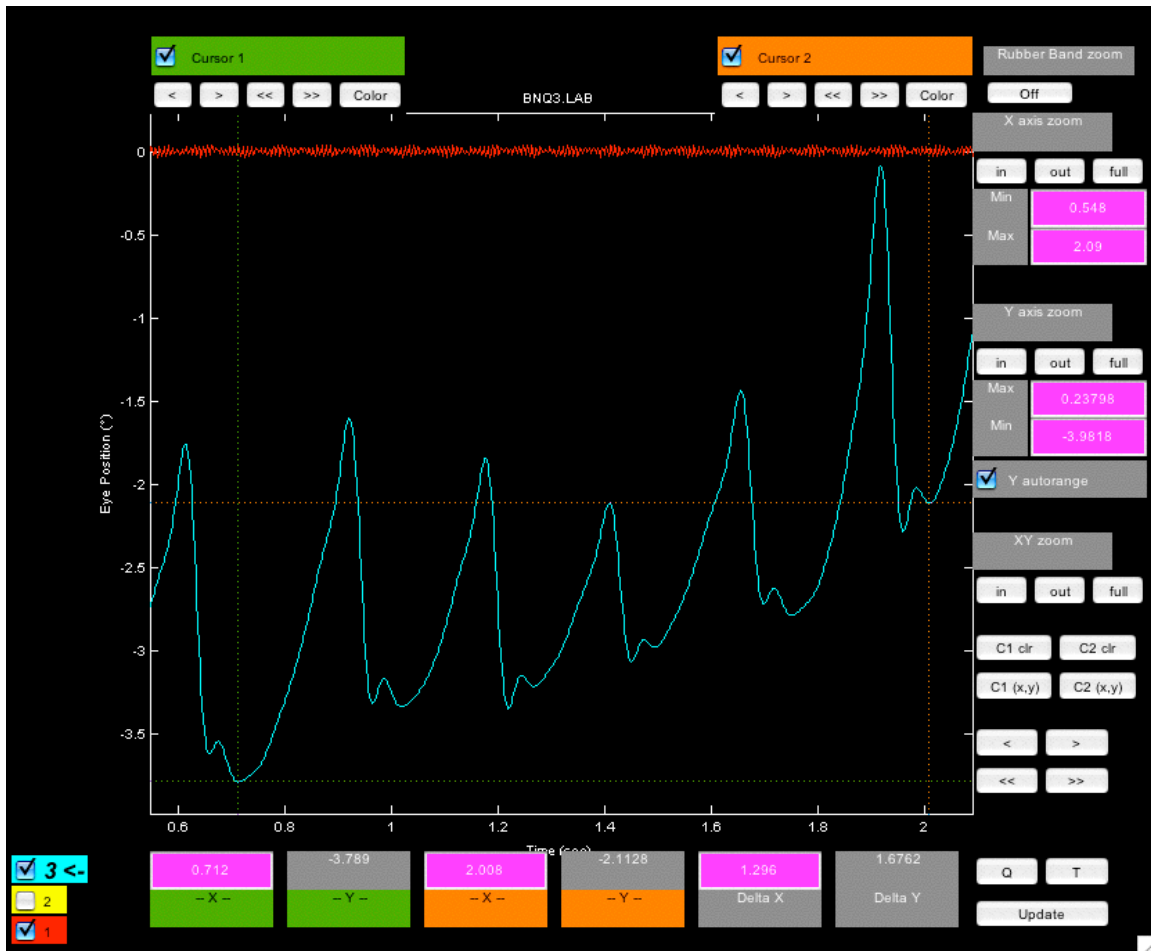


Figure 2. Plot (‘zoomtool’) showing the fixation interval with cursors set at the highest and lowest extents of the six foveation periods in the interval.

10. Click on the “C1 get”/”C1 (xy)” and “C2 get”/”C2 (xy)” buttons.

11. Run “nafxprep” from the GUI (Figure 1).

You will be prompted to enter the data file name (e.g., lh or rh) if more than one data file was plotted.

12. All sub-arrays and bias shifts will be created and entered into the NAFX GUI.

11. The foveation position window will automatically appear as the “Position Limit:” setting. You may also manually enter a different foveation position window from the “Position Limit:” drop-down menu whose \pm value encompasses the cursors' Y interval (as indicated by the “Delta Y” value in the ‘zoomtool’ plot).

NOTE: Available position window sizes are: 0.5, 0.75, 1.0, 1.25, 1.5, 2, 2.5, 3, 3.5, 4, 5, and 6 (for canines use 3 for horizontal data and 1.5 for vertical data). In this example, “Delta Y” is 1.6762 requiring a window size of 1 (i.e., $\pm 1 = |2| > 1.65762$).

13. With the “Velocity Limit:” value set at 4 deg/sec, run the “Calc Fovs.” (‘showpv’) and verify that all foveation periods were counted (i.e., at least 1 foveation period per cycle).

14. If any cycles were missed, increase the velocity window (as indicated by the "Velocity Limit:" value) and rerun "Calc Fovs." until all cycles are counted or you reach 10 deg/sec.

NOTE: Available velocity window sizes are: 4, 5, 6, 7, 8, 9, and 10. Figure 3 shows the first two graphs produced by 'showpv'.

15. Run the "Calc NAFX" using #fovs as defined below.**

16. Copy all relevant commands from the command window to a text file to document your work and to provide an easy way to repeat it (see NOTE below).

17. Run 'xaxshift(nafx_start)' on any Figures you wish to print and then, print them.

* You could use the horizontal cursor lines to straddle the foveation positions if you stay within the start and stop points.

** If "Calc Fovs." ('showpv') detects ≥ 1 fp/cy, use the number of CYCLES as the #fovs i.e., "#fovs" = #cy's (#fps - #extra fps detected)

If "Calc Fovs." ('showpv') misses any cycles (i.e., no fp detected) choose the pos limit of FWIN just large enough to encompass all fp's in the interval to be used (1 fp per cycle)

Then choose the LOWEST vel limit of FWIN (velLim) that allows 'showpv' to detect 1fp/cy or, increase the velocity limit to the LOWEST value that MAXIMIZES the # of fp's detected and use

"#fovs" = #cy's w fp + #cy w/o fp or joined cycles within a fp
(#cy's w fp = #fps - #extra fps detected)

NOTE:

The output of the NAFX to the command window of Matlab includes all the necessary data information and explicit NAFX command lines to reproduce the analysis easily. They should be copied and kept in a text file that can be used for this purpose at a latter date without using zoomtool to define the interval and extent of the foveation positions. All that need be done is to copy the appropriate Matlab command lines (use those with ">>") from the text file to the command window. An example from NAFX (version 1.1)* is shown below for a 49 y/o subject. Use 'help nafx' for information regarding the NAFX command lines.

* Later NAFX versions produce additional output lines that may be copied to the text file.

Text File Data:

```
>> rh=lpf(rh,4,20,500);**
rhv=d2pt(rh,3,500);**
>> rh45_46 = sub(rh, 45.524, 1.362);
rh45_46s = rh45_46 + 3.2905;
rhv45_46 = d2pt(rh45_46, 3);
>> nafx(rh45_46s,rhv45_46,500,[1,6],'showpv',1);
```

** These two lines not used if "rd's" pre-filtering and differentiation are used.

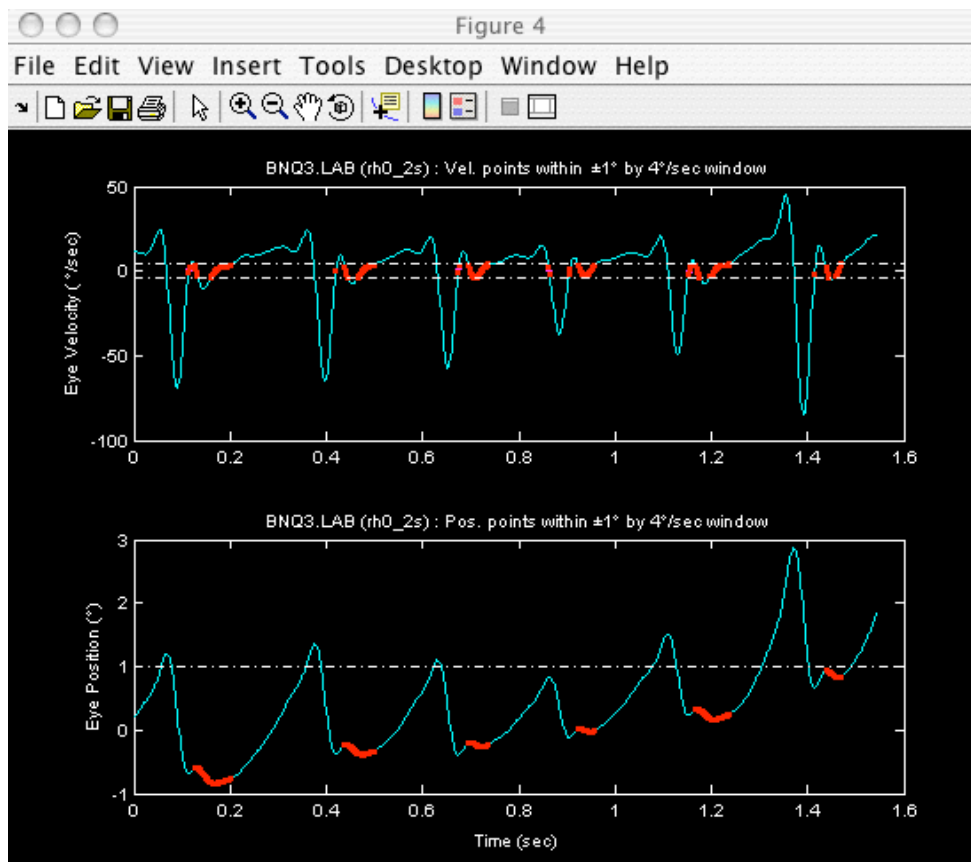
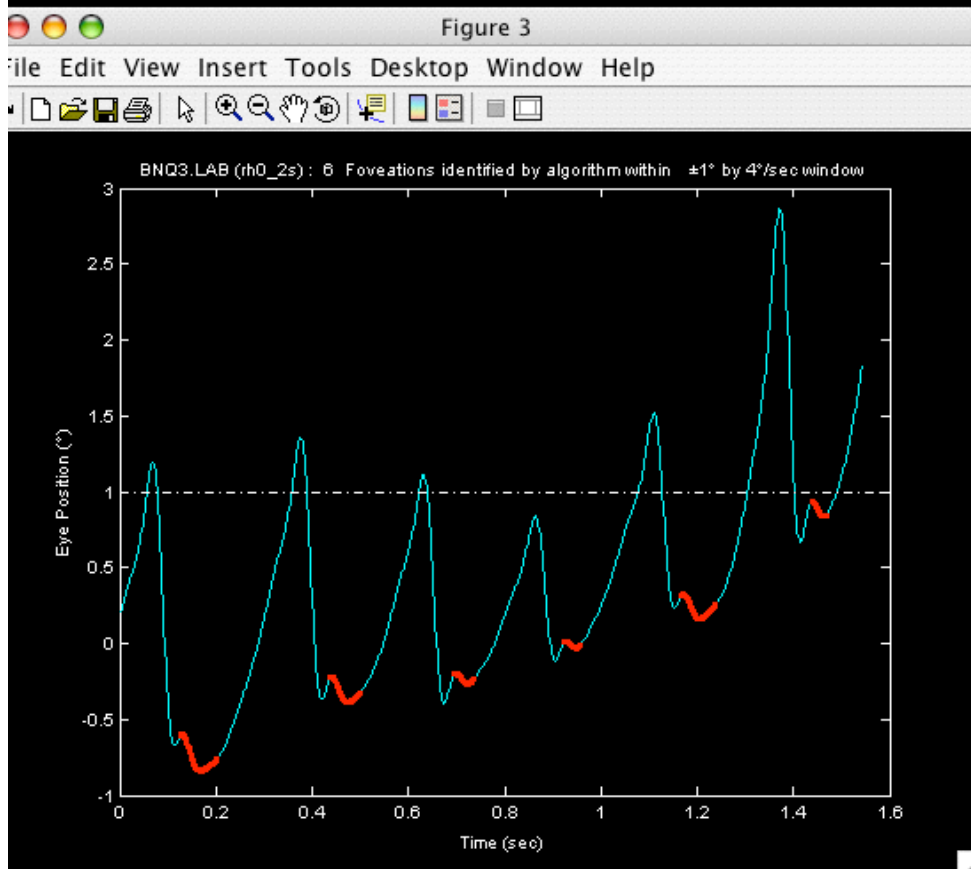


Figure 3.
Outputs of 'showpv'.
(Top)
Velocity and
position
traces with all
points
satisfying the
foveation
window
criteria (dot-
dashed lines)
shown in red.
(Bottom)
Position trace
with
algorithm-
determined
foveation
periods
shown in red.



Enter the subject's age:

- 1) under 6 years old
- 2) from 6 to 12 years old
- 3) from 12+ to 40 years old
- 4) from 40+ to 60 years old
- 5) greater than 60 years old
- 6) A dog of any age

--> 4

% Display foveation statistics (y/n)? n

Total time that meets position criterion = 994 msec. (497 samples)

Total time that meets velocity criterion = 278 msec. (139 samples)

Total time that meets both criteria = 264 msec. (132 samples) [raw]

Total time that meets both criteria = 190 msec. (95 samples)

There were (probably) 9 foveation periods in this interval.

Cycles by manual count: 8 [manually entered by you]

```
>> nafx(rh45_46s,rhv45_46,500,8,'nafx',[0,1,6]);
```

Enter the subject's age:

- 1) under 6 years old
- 2) from 6 to 12 years old
- 3) from 12+ to 40 years old
- 4) from 40+ to 60 years old
- 5) greater than 60 years old
- 6) A dog of any age

--> 4

results: (using NAFX vers. 1.0, DetectFovs vers. 1.0)

NAFX = 0.279 ($\leq 20/59$) -- 40+ to 60 years old

Fov. time per fov. period = 23.8 msec

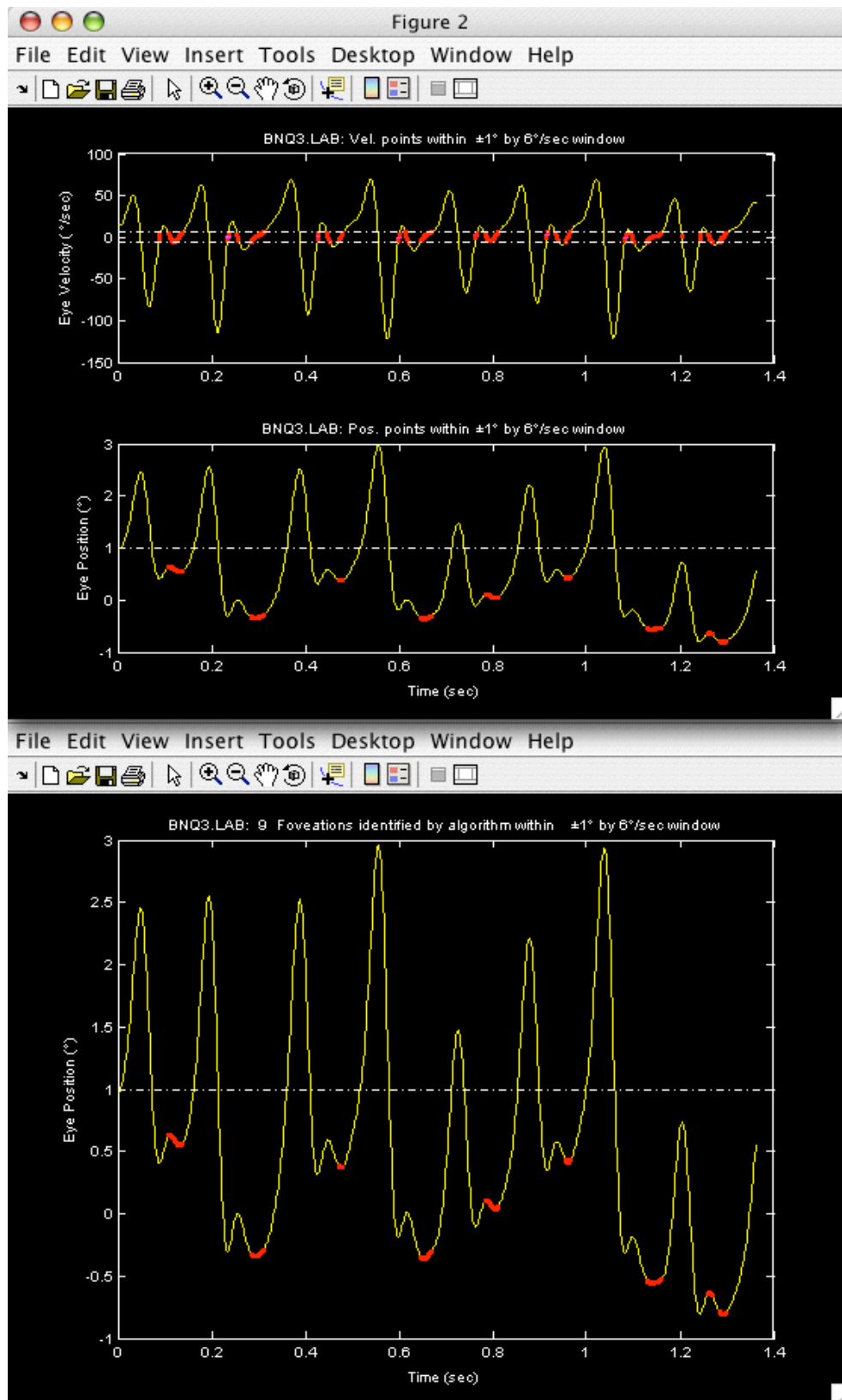
Fov. time per second = 0.14 sec

STD(pos, vel) = (0.464 deg, 3.38 deg/sec)

Fov. window (pos, vel): (1 deg, 6 deg/sec)

tau: 50.4 msec

Figure 4. Outputs of 'showpv'. (See legend of Figure 3 for details.) Note that algorithm detected 9 foveation periods in the 8 cycles; to calculate the NAFX, 8 will be used.



APPENDIX A

For individuals whose nystagmus is biplanar, two approaches are possible. First, for those whose horizontal component far exceeds their vertical component (as is the case in INS), simply calculate the NAFX using only the horizontal data. One can verify this choice by calculating two NAFX’s, one using the horizontal data and the second using the vertical data. The “horizontal” NAFX will be seen to be the acuity-limiting (i.e., lower) value. Of course, if the vertical component is far greater than the horizontal component (rare in INS), use the vertical data to calculate the NAFX. What of individuals whose nystagmus contains two significant components? For those cases, we have developed the two-dimensional NAFX. (1) By the use of the OMtools function, ‘hv2r’ we calculate a vector combination of the horizontal and vertical components that retains direction information and use it to calculate the “radial” NAFX. Figure 5 is a plot of a “radial” vector array. Note the discontinuities that should not be mistaken for saccades.

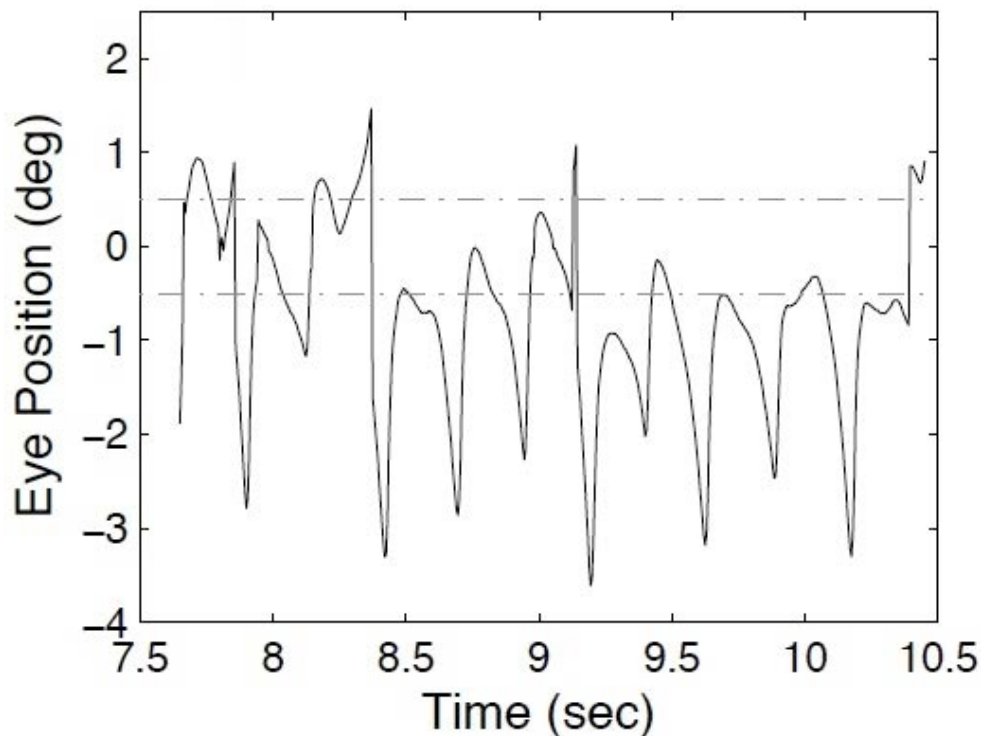


Figure 5. A plot of a “radial” data array for two-dimensional NAFX analysis.

APPENDIX B

For the rare individuals who constantly alternate their fixating eye, there may not be intervals with either eye fixating that are long enough (≥ 1 second) to calculate a meaningful NAFX. For the NAFX to maintain its relationship to visual acuity, it must be calculated using data taken from the fixating eye. How can this be achieved? Using ‘zoomtool’ one can easily determine the beginnings and endings of each interval of fixation for both the right (rh) and left (lh) eyes. These intervals (whose endpoints are chosen to lie in the slow phases away from intrinsic saccades or foveation periods) can be

used to define sub-arrays from the data for each eye (rh or lh) and those sub-arrays can then be concatenated using ‘cat’ to form a new data array that we shall call “fe” (for fixating eye). A new OMtools function, ‘fecat’ can be used to graphically choose each interval and automatically concatenate them (see APPENDIX C). The discontinuities at each of the concatenation points will not affect the NAFX calculation, as they will fall outside of the foveation window. Finally, the NAFX can be calculated using the data in fe. This construct mimics the actual real-world conditions of fixation for that individual, including the times lost during each alternation of the fixating eye, and the resulting NAFX will retain its relationship to visual acuity.

APPENDIX C

Although one could manually use ‘zoomtool’ and create sub-arrays that are then concatenated (using ‘cat’), we have written a graphical program, ‘fecat’ that automatically does this, producing a data file and graph ready for use by ‘nafx’. After loading the data to be analyzed (rh and lh), one has only to type, ‘fecat’. A GUI is opened as well as a ‘zoomtool’ window of the data (move the latter so both are visible—see Figure 6).

- 1) In the ‘fecat’ GUI, choose the first fixating eye
- 2) In the ‘zoomtool’ window, use “Xaxis zoom” to expand the data interval of interest (e.g., fixation at 20°)
- 3) Set the *first* cursor on the fixating eye trace at the beginning of its first interval (pick a point during a slow phase away from either an intrinsic saccade or foveation period) and click on “C1 get”
- 4) In the ‘fecat’ GUI, click on “Use C1 get” and click on “Begin”
- 5) In the ‘zoomtool’ window, set the *second* cursor on the fixating eye trace at the end of this first interval (i.e., when the fixating eye alternates to the other eye—use the same slow-phase criteria for choosing this point as for all NAFX intervals) and click on “C2 get”
- 6) In the ‘fecat’ GUI, click on “Use C2 get” and click on “Set” (a plot of this interval will appear in the ‘fecat’ GUI)
- 7) In the ‘zoomtool’ window move the *second* cursor on the new fixating eye trace to the end of the second interval and click on “C2 get”
- 8) In the ‘fecat’ GUI, click on “Use C2 get” and click on “Set” (a plot of this now expanded interval will appear in the ‘fecat’ GUI)
- 9) Repeat 7&8 as often as necessary to build a fixating-eye data array for analysis
- 10) Click on ‘Finish’ (a plot of the fixating-eye data array will be placed in a Figure, ready for NAFX analysis)

NOTES: 1. The *first* cursor is only used to mark the beginning of the first interval; all other intervals are determined using the *second* cursor. 2. There will be small discontinuities at each transition point from one fixating eye interval to another (see Figure 6, bottom right). They will not interfere with the NAFX calculation and should not be mistaken for saccades. 3. The text box is editable and can be used to change or enter specific start and stop points for either eye (first number indicates eye—1=re, -1=le). Click outside the text box (within the GUI) to read in your changes.

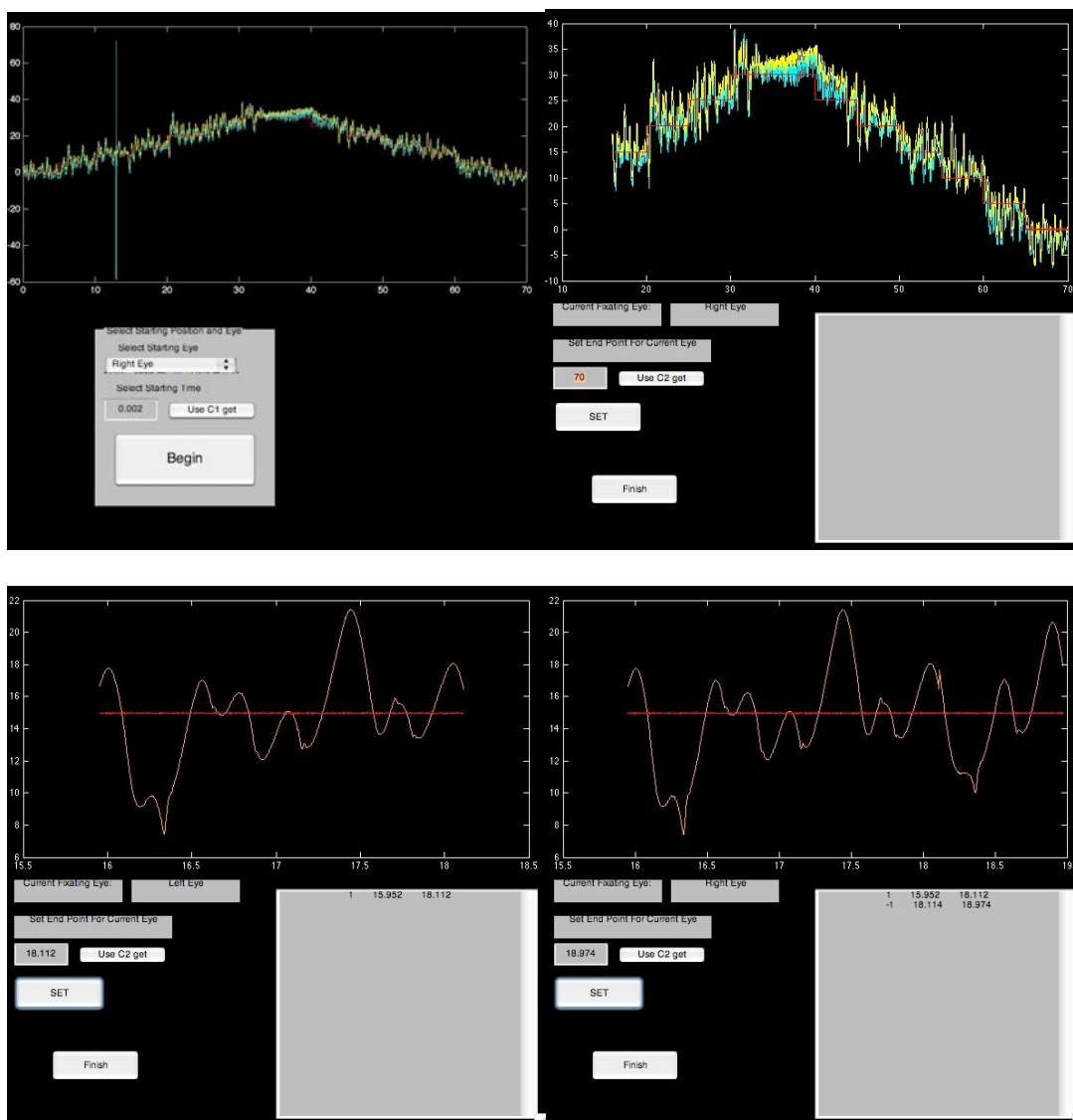


Figure 6. The ‘fecat’ GUI—top left) initial appearance; top right) after using “C1 get”; bottom left) after using “C2 get”; and bottom right) after using “C2 get” again.

REFERENCES

1. Jacobs JB, Dell'Osso LF. Extending the expanded nystagmus acuity function for vertical and multiplanar data. *Vision Res* 2010; 50:271-278.

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