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Saccade Analysis App

Background

Saccades are rapid movements of the eye that change the point of fixation, or where a person is looking. They can be voluntary movement, in that you can consciously choose where to look, or involuntary reflexes, but the kinematics of the movement are not consciously controlled, but rather a reflection of neural pathways in controlling motor movements. During saccade generation, burst neurons in the brainstem generate a pulse, or increase in the density of action potential firing, and the height of this pulse is proportional to peak velocity (vigor) of the saccade[3]. The pulse amplitude or length of neural firing is proportional to the amplitude of the saccade[1]. Nasal saccades are eye movements made towards the nose, whereas temporal saccades are eye movements made away from the nose. Thus, saccades provide a unique insight into both brain activity and motor behavior. This app serves as a practical pipeline from raw eye tracker data, visualization of saccade peak velocity-amplitude relationships for data sets, quantitative mathematical models for this relationship and comparisons between data sets. In Parkinson's disease, saccade velocities are slower, and surgical treatments like pallidotomy have previously been shown to cause significant changes in saccade vigor-amplitude profiles[1]. This app can be used to make a more quantitative observation of differences in saccadic motor control for patients with motor disorders or healthy subjects through comparison of individual saccade vigor-amplitude profiles.

How to Use the App

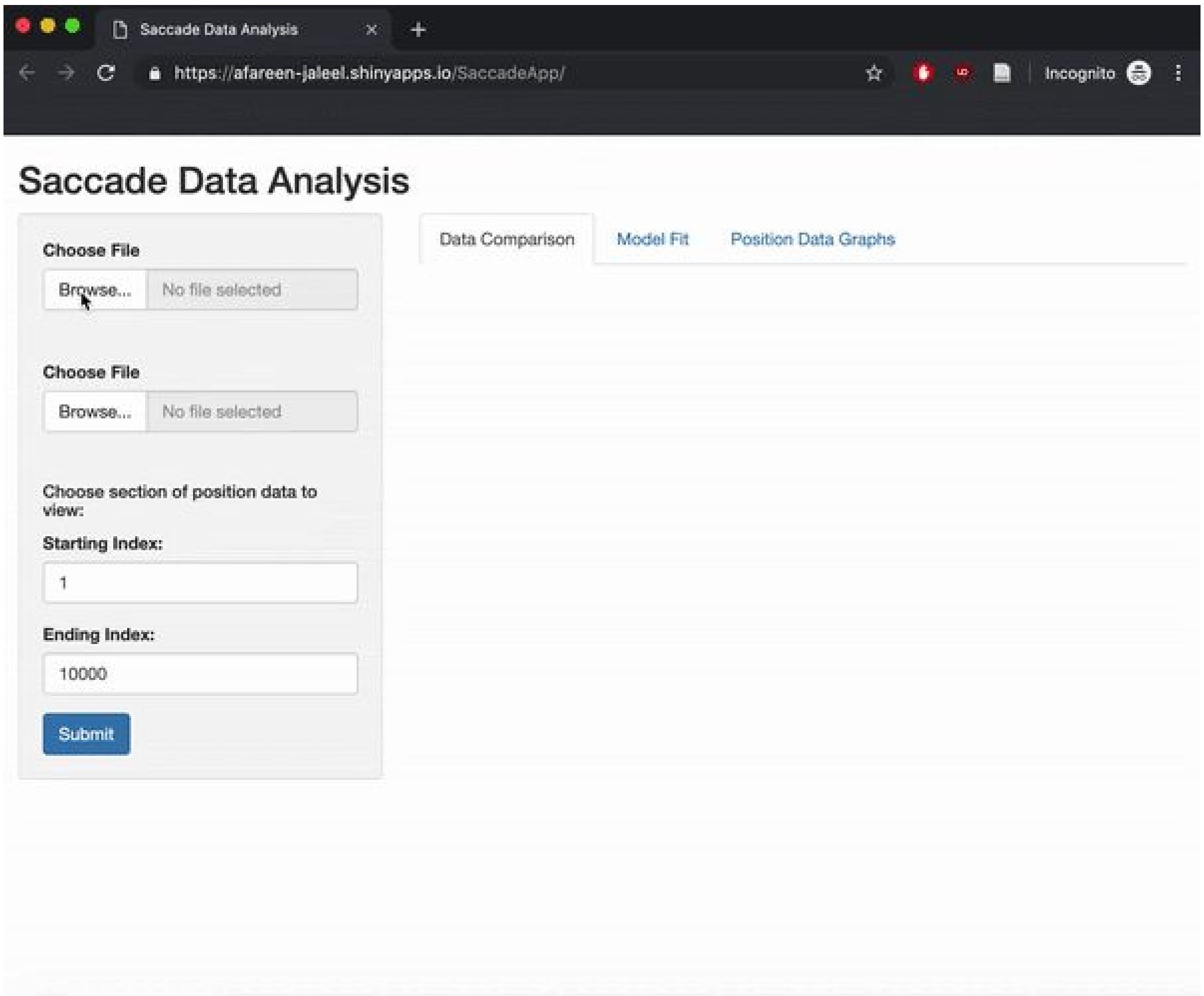
This app was designed to take input from raw Eyelink 1000 eye tracker h5 data that has been converted to MAT files by using the h5_to_mat() function in MATLAB, but the algorithms are generalizable to work for any MAT file that stores a struct with horizontal eye position (right_horizontal_eye), vertical eye position (right_vertical_eye), sampling time points (eyelink_time), starting positions (PC_start_x) and ending positions (PC_end_x) of saccade stimuli, and time points for the starts of each saccade (PC_trial_start).

Users can upload two MAT files into the app under the "Choose File" sections in the sidebar. Sample data files are included in the SampleData folder. The app will filter the position data and then analyze the data to parse saccades, their individual peak velocities (vigor) and amplitudes. In the "Data Comparison" tab, the app displays the best model for the peak velocity-amplitude profile for each data set, with the nasal and temporal saccade data labeled. Using nonlinear regression and least-squares curve fitting, the data is fitted to a hyperbolic function:

$V = \alpha\left(1 - \frac{1}{1+\beta x}\right)$ where V is the peak velocity of a particular saccade and x is the amplitude of the saccade. The optimized values for $a = \alpha$ and $b = \beta$ for the model of each data set is displayed below the graph. A t test is conducted to compare the two modeled data sets, and the resulting p value is displayed, and based on a significance level of 0.05 the app displays whether there was a significant difference between the two data sets. The "Model Fit" tab shows a scatterplot of the original data for the saccade peak velocity-amplitude relationship in each data set as well as the corresponding hyperbolic function model for each data set. In the "Position Data Graphs" tab, a plot of the position data by the index of the sampling point for each data set can be viewed, and the range of position data to be viewed can be adjusted by changing the values in the "Choose section of position data to view" section of the sidebar. This graph basically gives a display of the changes over time in eye position for each data set, so that patterns in motor behavior, like making saccades in steps or large errors in saccade accuracy which are common to patients with Parkinson's disease, can be qualitatively observed.

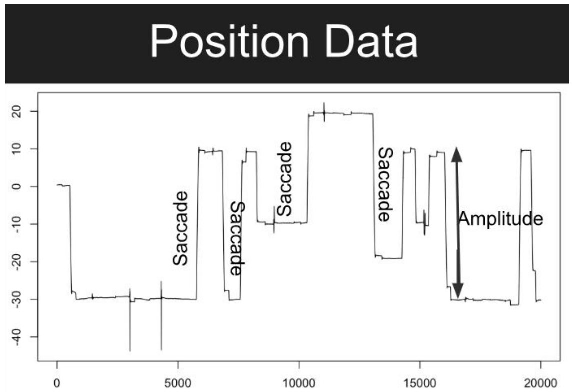
To run the app locally by downloading the code from the SaccadeApp folder, the system requires installing the shiny, rmatio, signal, pracma, and ggplot2 libraries in R.

A demo of how the app functions can be seen in the SaccadeDemo.gif file.

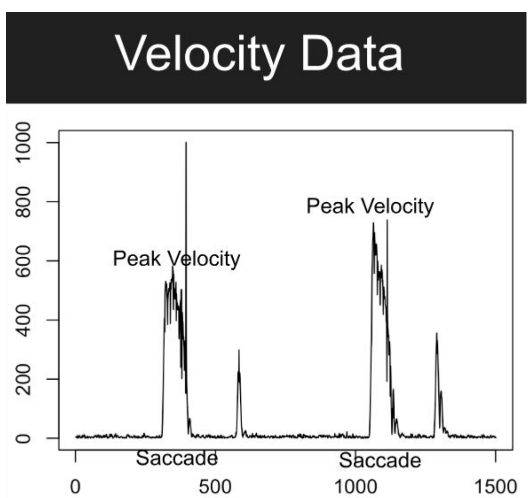


How the App Works

The app takes in raw eye tracker data in the form of a MAT file, and filters position data using the Savitzky-Golay filter. This filtered position data can be viewed in the “Position Data Graphs” tab. An example of this filtered position data is depicted below, with text labels for examples of where saccades occurred in the data, and the measurement for the amplitude (or change in eye position) in a particular saccade.



In the max velocity function in the server of the app, a data frame of peak velocities and amplitudes for each saccade in the data set is extracted. The function calculates a vector of eye speeds over the course of the whole data set by taking the square root of the sum of the squared differences in the horizontal and vertical eye positions for each time point divided by the time elapsed between points of data collection. In equation form, the speed for each time point is $V = \sqrt{(\frac{(x_2-x_1)}{(t_2-t_1)})^2 + (\frac{(y_2-y_1)}{(t_2-t_1)})^2}$, where V is the speed, x_2 and x_1 are the horizontal positions recorded at the two adjacent time points, t_2 and t_1 are the time each of the two points were recorded, and y_2 and y_1 are the vertical positions recorded at the two adjacent time points. A plot of the velocity profiles over time is shown below, with examples of where saccades would be found and the peak velocity of each saccade would be identified. The saccades were identified through iterating through the vector of velocities and identifying regions of the data set where velocities were consistently greater than 120 but less than 1000, and identifying the maximum velocity within each region. An example plot of the speeds over time is depicted below, with labels for where saccades and peak velocities would be identified in the data.



Each of the identified saccade regions was cross-checked with the time points, start and end positions of the saccade stimuli (the dots that appeared on the screen that the person looked at), to check that the identified saccades were valid for the data set. From each saccade region, the peak velocity and amplitude of the saccade was calculated and stored in a data frame. From this data frame, scatterplot of the saccade peak velocity-amplitude profile for a particular data set can be obtained (as depicted in the figure below). Hyperbolic trendlines for nasal saccades (negative amplitude) and temporal saccades (positive amplitude) can be fitted to the data using least squares curve fitting (nonlinear regression)[2]. A t test is then performed to compare the data predicted by the hyperbolic models for each of the two data sets to evaluate if there is a significant difference between the data sets.

Sources:

[1] Blekher, Tanya, et al. "Eye Movements in Parkinson's Disease: Before and After Pallidotomy." *Investigative Ophthalmology & Visual Science*, vol. 41, no. 8, July 2000, pp. 2177–83.

[2] Reppert, Thomas R., et al. "Modulation of Saccade Vigor during Value-Based Decision Making." *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, vol. 35, no. 46, Nov. 2015, pp. 15369–78. *PubMed*, doi:10.1523/JNEUROSCI.2621-15.2015.

[3] Termsarasab, Pichet, et al. "The Diagnostic Value of Saccades in Movement Disorder Patients: A Practical Guide and Review." *Journal of Clinical Movement Disorders*, vol. 2, no. 1, Oct. 2015, p. 14. *BioMed Central*, doi:10.1186/s40734-015-0025-4.