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PSOVIS: An interactive tool for extracting post-saccadic oscillations from eye movement data

Diako Mardanbegi, Thomas Wilcockson, Baiqiang Xia,
Hans Gellersen, Trevor Crawford and Peter Sawyer
Lancaster University ,UK

Post-microsaccadic eye movements recorded by high frame-rate pupil-based eye trackers reflect movements of different ocular structures such as deformation of the iris and pupil-eyeball relative movement as well as the dynamic overshoot of the eye globe at the end of each saccade. These Post-Saccadic Oscillations (PSO) exhibit a high degree of reproducibility across saccades and within participants. Therefore in order to study the characteristics of the post-saccadic eye movements, it is often desirable to extract the post-saccadic parts of the recorded saccades and to look at the ending part of all saccades. In order to ease the studying of PSO eye movements, a simple tool for extracting PSO signals from the eye movement recordings has been developed. The software application implements functions for extracting, aligning, visualising and finally exporting the PSO signals from eye movement recordings, to be used for post-processing. The code which is written in Python can be download from https://github.com/dmardanbeigi/PSOVIS.git

Keywords: template, guidelines, instruction, styles, format

Introduction

Post-saccadic oscillations (PSO) (Nyström, Hooge, & Holmqvist, 2013) (also referred to as dynamic overshoot (Kapoula, Robinson, & Hain, 1986)) are microsaccadic movements that follow primary saccades with no delay. Recent studies have looked at the PSO signals to understand the relative movement between pupil center and corneal reflections (Nyström et al., 2013), and to study the effect of different factors such as saccade amplitude and pupil size on the quality of the recorded gaze data (Nyström, Hooge, & Andersson, 2016; Hooge, Nyström, Cornelissen, & Holmqvist, 2015; Nyström, Hansen, Andersson, & Hooge, 2016). Others have also looked at the possibility of using PSOs as a biometric for person identification. One common preprocessing step that is often required when studying PSO signals is to extract the PSO signals from the eye movement recordings and aligning them so that they can be compared and collated. This may be a challenging task as the fixation onsets after saccades are not often detected accurately due to the instability at the end of each saccade. Also, PSO signals occur in a number of shapes with different amplitudes which can cause difficulty when aligning each signal. Extracting and aligning PSO signals obtained from eye movement data makes it easier to compare PSO across participants and conditions. Eye movement recordings often consist of a large number of saccades and having a tool that can automatically extract PSO signals for saccades that are within a certain range of amplitudes, velocities and directions would be useful for researchers who want to study the post-saccadic eye movements.

PSOVIS

In the following, we introduce different features of the PSOVIS software. The code is written in Python[1] and can be easily extended to add more custom features. The code was originally made (and been tested) to work with data recorded with Eyelink 1000 eye tracking system (SR Research Ltd., Ontario, Canada) and the saccade/fixation detection was done in the Eyelink tracking software which has velocity and acceleration thresholds of 30°/s and 8000°/s^2, respectively. However, it could be modified to support data format recorded by other eye trackers. The code has currently been only tested on the eye tracking data recorded at 500Hz, but it should work on data with higher or lower (as long as the PSO can be seen in the eye data signal) frequencies.

Data extraction & Saccade filtering: As the first step, all

[1]https://www.python.org

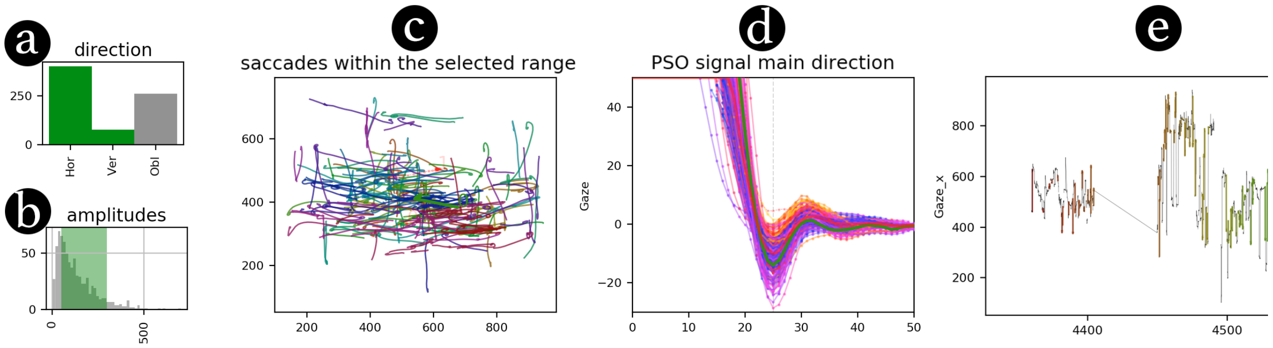

Figure 1. Some of the main tools visible in the main window of the software (running for an example data file) including: histogram of the saccade direction (a), histogram of the saccade amplitude (b), selected saccades plotted in the screen space (c), PSO signals (d), and raw gaze data (e) (figure cropped due to the limited space in the paper).

the saccades are extracted from the data file and will be collected in an array that contains the gaze data, pupil diameter during the saccade as well as the onset and offset, amplitude, direction, and the velocity of the saccade. This information will shown in the main window of the software in a form of intractable histograms that allows the user to select and include certain ranges of amplitudes, velocities and different directions (Figure1). All the selected saccades are plotted in another figure inside the main GUI (e.g. Figure 1.c). The X and the Y channels of the raw gaze data are also plotted in another figure (Figure 1.e). The next step involves extracting the PSO signals for each individual saccade. The first 20% of the total samples recorded for each saccade is discarded (this value was determined empirically on 500Hz data), and 20 frames (40 ms) of eye movement data following each saccade is included to ensure that the most oscillating part of the signals are included. The gaze data of the saccade is transformed by a rotation defined by the angle of the saccade (slope of the vector connecting the fixations at the beginning and the end of the saccade) making all saccades horizontal. This normalizes the direction of all saccades to horizontal making it possible to later plot the PSOs for saccades at different angles in one plot. The PSO signal of each saccade is then defined by the horizontal component of the gaze data over time.

PSO alignment: All the PSO signals are spatially aligned based on the fixation location at the end of each saccade (defined by the median of the eye data within the range of 20-30 ms after each saccade). Each signal is shifted along the spatial axis such that all the signals converge at zero (see Figure 1.d). The minimum peak of each oscillation is then found by searching for the first critical point of the signal curve that happens after the maximum velocity. Finally, the signals are aligned temporally by aligning their minimum peak on a new common timeline. Because different saccades may have different amplitude, we define the reference point (zero) along the time axis at the point at which all minimum peaks are aligned. Figure 1.d shows an example of 540 PSO signals aligned for one person. The mean signal averaged over all recorded signals is also shown with a thicker curve.

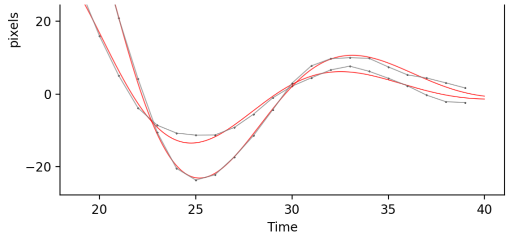

Figure 2. Results of model fitting (red curve) on two sample PSO signals and their row signals (gray color curves.

PSO filtering: The user can select saccades in any of the figures and that saccade will then be highlighted in all the other figures, which makes it easy to locate. The user is able to remove signals that look like outliers or those that are not been aligned properly. All the settings for each subject will be stored in a separate file to be loaded next time.

Output: Data for all the selected PSO signals will be exported in a CSV file which can be later used for analysis. The exported data also includes all the relevant information about the corresponding saccade such as peak-velocity, direction and amplitude. Furthermore, each signal will be modeled as an underdamped harmonic oscillation ($PSO = p_0 + p_1 e^{-p_2 t} cos(p_3 t + p_4)$) and the parameters of the fitted model (p_i) will be included in the output (Figure 2).

Conclusion: PSOVIS is an open-source code for extracting PSO signals from eye movement recordings. The software automatically extracts and aligns the PSO signals, visualizes them and lets the user verify the alignment, and selects and filters signals based on saccade properties. This software could be used as a preliminary step when analyzing PSO signals. We hope that this tool could be useful for researchers who want to study the post-saccadic microsaccades, dynamic overshoot, and pupil oscillations caused by lens wobble and iris deformations.

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