SaccadeMachine: Software for Analyzing Saccade Tests (Anti-saccade and Pro-saccade)

Anonymous Author(s)

ABSTRACT

Various types of saccadic paradigms, in particular, Prosaccade and Antisaccade tests are widely used in Pathophysiology and Psychology. Despite been widely used, there has not been a standard tool for processing and analyzing the eye tracking data obtained from saccade tests. We describe an open-source software for extracting and analyzing the eye movement data of different types of saccade tests that can be used to extract and compare participants' performance and various task-related measures across participants. We further demonstrate the utility of the software by using it to analyze the data from an antisaccade, and a recent distractor experiment.

KEYWORDS

Eye tracking, saccade test, antisaccade, prosaccade, eye movement

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1 INTRODUCTION

Various saccadic eye movement paradigms are extensively used in psychology, oculomotor and cognitive research. These allow examination of different cognitive processes engaged during eye movement control, characterization of psychopathology, and often provide precise assessment of some aspects of top-down cognitive control and inhibitory processes [Crawford et al. 2005; Hutton and Ettinger 2006; Klein et al. 2003; Leigh and Kennard 2004; Luna et al. 2001; Trillenberg et al. 2004].

Despite being commonly used, there has not been an accessible tool for analyzing the eye movements behaviour for saccade tests. The logic behind analyzing eye movements data of many of the saccade tests are quite similar and basically requires evaluating saccadic eye movements in relation to the stimuli in each trial both spatially and temporally. However, until now data analysis typically involves a stage of processing the data using Excel. For example, data collected by SR EyeLink would be extracted using DataViewer. These raw signals would then be loaded into Excel where the data could be processed into meaningful results suitable for statistical analysis e.g. average saccadic latency or correct saccades. Such processing normally involves using formulas and IF/THEN statements in Excel. This can be very complicated and time consuming, especially when there are many trials to process, and when various types of saccades have to be carefully extracted in each trial (e.g., anticipatory saccades and corrected saccades). Also, there is a lot of room for error when the data is manually analysed in this manner and this style of complicated analysis is often a barrier in the way of novice eye trackers processing their own data. In this paper, we introduce a software framework that provides an easy-to-use interface to analyze eye tracking data recorded from various types of saccadic paradigms.

We additionally introduce an algorithm that the SaccadeMachine uses to determine the Target-of-Interest (TOI) of a saccade when one or multiple targets are present in the screen. We define the saccade Target-of-Interest as a target that is most likely that the saccade is directed towards. Most previous eye movement studies have focused on identifying or using fixation AOIs [Blascheck et al. 2016; Hessels et al. 2016; Hooge and Camps 2013], or transition between AOIs [Krejtz et al. 2015]. Fewer studies have focused on saccades TOI (or AOI). However, with SaccadeMachine we aimed to provide a tool which would enable accurate measurement of saccadic events in relation to TOIs which are important when analyzing saccadic tests.

2 PROSACCADE & ANTISACCADE TESTS

In this section, we briefly introduce the most common types of saccade tests (a.k.a. saccade tasks). In general, a prosaccade test is designed to assess the reflexive guided eye movement towards a suddenly appearing visual target in the presence or absence of a set of distractors. An antisaccade test, on the other hand, is designed to assess the inhibitory eye movement towards the opposite direction (mirror position) of a suddenly appearing target. To be consistent, we refer to the target in the antisaccade test as distractor in the rest of this paper.

Prosaccade task (PS) In the prosaccade task, participants visually fixate on a central stimulus (fixation display) that is suddenly replaced by another target that appears at some distance around the initial location (main display), and they have to direct their gaze towards the new target as soon as it appears.

Antisaccade task (AS) The antisaccade test is very similar to prosaccade test except that the participants are told to refrain from looking at the peripheral target and instead direct their gaze to the opposite direction [Hallett 1978]. The antisaccade task is one of the well established eye-movement tests used for measuring volitional control of behavior providing a gross estimation of dysfunction of the frontal lobe.

Inhibition of Recent Distractor task (RD) The Inhibition of Recent Distractor test was first introduced by [Crawford et al. 2005] to assess high level cognitive control and inhibition of a competing distractor. In a RD test, participants are presented with a sequence of two critical displays. In one display a target is presented together with one or multiple distractor. This is followed by a display with a

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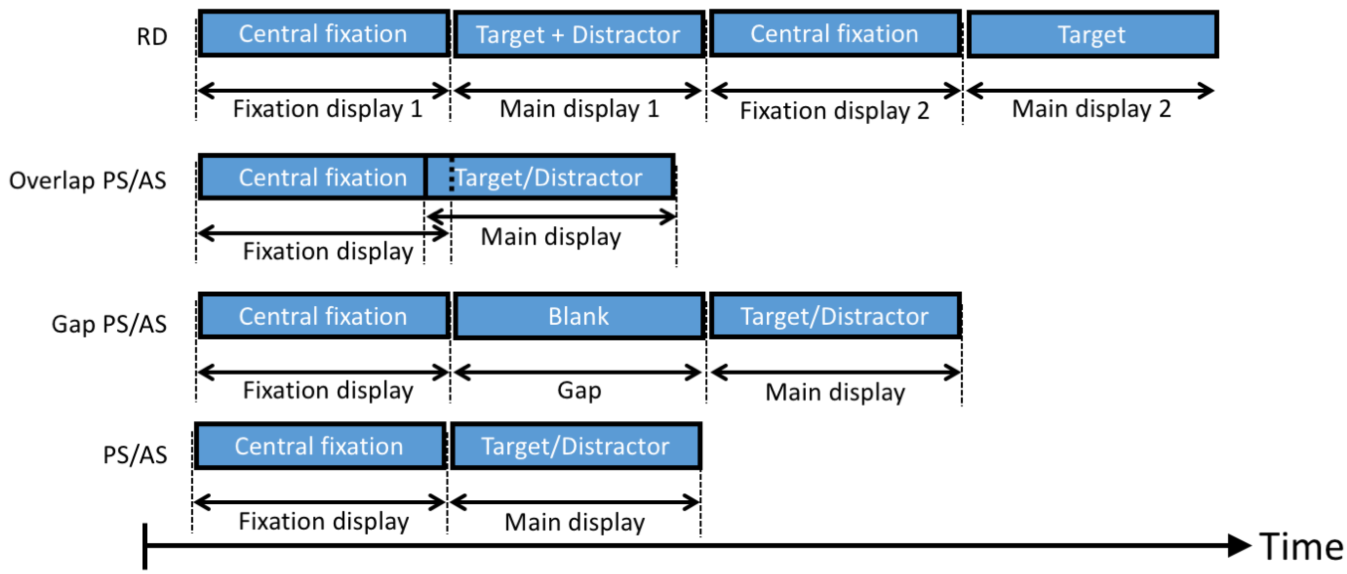

Figure 1: The most common paradigms for saccade tasks and the timing between different sequence of displays involved in each task.

new target presented in isolation either at the location of the recent target, the location of the recent distractor(s), or a new location. Similar to a prosaccade task, participants are instructed to fixate on the target in both displays and to ignore the distractor(s). We classify the RD test as a prosaccade test in the SaccadeMachine because there is no antisaccade involved in the test.

Figure 1 illustrates the timing of various displays in each of these tests. Normally, the main display comes immediately after the fixation display, however, as shown in the figure, there can be a blank display between the fixation display and the main display (gap condition), or the two displays could overlap for a few milliseconds (overlap condition).

3 SACCADEMACHINE

The general idea of the SaccadeMachine is to process eye movements in relation to the positions of the stimuli in the screen. It extracts the main characteristics of the saccadic eye movements (e.g., latency, duration, position and direction) and fixations (e.g., duration, latency, and position) from the eye tracking data of a prosaccade and antisaccade test and annotate each saccade and fixation relative to the visual stimuli (onset and position). This provides an assessment of how each participant has performed in the test e.g., did they look to the opposite side of the target? were there any wrong directed saccades followed by a corrective saccade? what was the latency of the saccade relative to the target onset? The software further conducts a comparison of saccadic status across different groups of participants. The software is written in Python using Jupyter Notebook and has an interactive and user friendly user interface. It analyzes the eye tracking data and generates full reports on the performance of each individual in the test for each of the measures described in Table 1. Additionally, separate results can be generated for different conditions if multiple conditions exist in the test.

3.1 Requirements

The software supports eye tracking data recorded by any eye tracker, however, it requires the saccade and fixation events to have already been detected and included as separate columns in the data. The information about the target positions in each trial should also be included in the data. The eye tracking data must be given as separate CSV files for each individual participant containing the following necessary columns:

- **GAZE_X, GAZE_Y**: gaze coordinates in the screen.
- **IN_SACCADE**: saccade events. 1 during saccade otherwise 0.
- **IN_FIXATION** or **FIXATION_INDEX**: indicating the fixation events.
- **SAMPLE_MESSAGE**: experiment messages indicating the following events:
  FIXATION_TARGET_ONSET: when the fixation target appears
  FIXATION_TARGET_OFFSET: when the fixation target disappears
  TARGET_ONSET: when the main target appears. Use the same msg when distractor appears in anti-saccade test.
  TARGET_OFFSET: when the main target disappears. Use the same msg when distractor disappears in anti-saccade test.
- **TIMESTAMP**: timestamp in ms.
- **TRIAL_INDEX**: trial index.
- **TARGET_X, TARGET_Y**: target location in the screen for pro-saccade experiments.

Table 1: 16 most common measures that are used to asses trial performance in prosaccade and antisaccade tests.

Measure	Description
TRIAL_SUCCESSFUL	Total number of successful trials (with correct or corrected saccades)
TRIAL_CORRECTED_ONLY	Total number of trials with corrected saccade
TRIAL_CORRECT_ONLY	Total number of trials with the first saccade detected as correct
TRIAL_FAILED	Total number of failed trials (wrong saccade, bad data quality, etc)
LATENCY_FIRST_SACCADE	Latency of the first saccade after target onset regardless of its direction
LATENCY_CORRECT_SACCADE	Latency of the first correct saccade after target onset
LATENCY_CORRECTED_SACCADE	Latency of the corrected saccade after wrong saccades
LATENCY_ANY_CORRECT_SACCADE	Latency of the correct or corrected saccades
LATENCY_WRONG_SACCADE	Latency of the first wrong saccade after target onset
AMPLITUDE_CORRECT_SACCADE	Amplitude of the correct saccade
AMPLITUDE_CORRECTED_SACCADE	Amplitude of the corrected saccade
AMPLITUDE_WRONG_SACCADE	Amplitude of the wrong saccade
FIXATION_OFFSET_TO_TARGET	How far the gaze was from the target after correct or corrected saccades
CENTER_FIXATION_MISSED	Total number of trials where center fixation was not accepted (too far from the center)
CENTER_FIXATION_LATENCY	Latency of the center fixations relative to fixation-target onset
CENTER_FIXATION_DISTANCE	Distance to the fixation-target during fixation period

- **DISTRACTOR_X, DISTRACTOR_Y**: location of the distractor in the screen used in anti-saccade or recent-distractor experiments. Multiple distractors can be specified by e.g., **DISTRACTOR_i_X** where i is the index of the distractor.

If the participants are divided into groups, an extra column (named as **SUBJECT_GROUP**) should be added to indicate the group index. The recording could consist of multiple blocks (e.g., a few pilot trials at the beginning), which then the **BLOCK** column should be provided in the recording indicating the block index. The recording could also have multiple conditions, for example, with different background colors. Then an extra column **CONDITION** must be added to the data to show the condition label of each trial.

3.2 Data pre-processing

A pre-processing step will be done on the raw data to filter any existing (0,0) sample from the gaze data. If the information about the blink events are provided in the data (with an optional column **IN_BLINK**), they will be filtered as well.

Each participant will be assigned with a data quality score defined as:

$$S = 1 - Avg(s1, s2, s3) \tag{1}$$

Where $s1$ is the total number of zero-gaze samples divided by the total number of samples, $s2$ is the total number of blink samples divided by the total number of samples, and $s3$ is the average distance between the fixations and the central target in the fixation displays divided by the radius of the AOI set by the user. The quality of the participants' data are then ranked based on this score and a summery of the gaze data quality for all individuals will be given in a plot (e.g., Figure 2) where each subject is represented by a column with a value between 0 (very bad) and 1 (very good). This helps comparing the quality across groups and to identify those recordings that are poor in quality. The plot is interactive and by hovering the mouse on any individual column we can see the name of the corresponding subject.

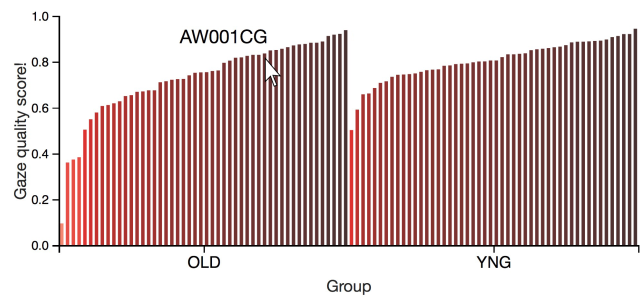

Figure 2: An example of the data quality across groups generated by the software allowing to compare the data quality across different groups of participants. Each column represents a subject and those with lower quality have smaller values.

3.3 Annotating fixations and saccades

The software processes each trial in the recording and extracts the main characteristics of the fixations and the saccades. All the fixations and saccades and their information will be stored in a separate table (*Event_Table*) which summarizes the eye tracking data in each recording. Each row of the table corresponds to either a fixation or a saccade event. The following information are extracted from each fixation: Duration, position, latency from the target onset, and its area of interest (AOI). For each saccade, we measure the latency from the target onset, the angle, and its amplitude, and we determine whether it is toward the target, any of the distractors or their opposite directions in the screen. The AOIs are defined by a circle (of an arbitrary diameter) around each target or distractor and determining a fixation AOI (an area where the fixation is located in) can be simply done by checking whether the fixation is inside the AOI circle. Determining the Target-of-Interest (TOI) or the Area-of-Interest (AOI) of a saccade defined as the target (or the area) where a saccade is directed towards, on the other hand, is not straight forward, because saccades are not always perfect movements from the center of the screen towards a target. The starting point of the saccades could vary due to calibration offset, user performance, and also because other initial saccades could have been made prior to the main saccade (e.g. anticipatory saccades). The direction and the amplitude of the saccades made towards a specific target may also vary especially if the stimulus has disappeared before the saccade. Also, in a typical antisaccade test, the participants are instructed to look away from the distractor without specifying a particular point in the screen for them to look at. SaccadeMachine uses a general algorithm for determining the saccade TOI when there are multiple targets (potential TOIs) available in the screen. To determine whether a saccade (AB in Figure 3) is made towards a specific target, the following criteria have to be satisfied assuming that there are multiple targets (T_i) are available in the screen (Figure 3):

(1) *C1*: The saccade should be facing the target and the target should not be located to far behind the saccade. For this, we ignore any target that is located behind the line perpendicular to the saccade at point M located between points A and B (e.g., T4 is discarded in Figure 3).
(2) *C2*: The angle between the saccade direction and the line that connects the target and point A, should be smaller than a threshold ($\angle TAB < \alpha$). In the example shown in Figure 3, only T1 and T2 meet this criterion and T3 is discarded.
(3) *C4*: When the there are multiple targets meeting the criteria 1 & 2, the one with the minimum distance to the saccade end point B will be picked as the final candidate (e.g., $T1$ in Figure 3).

The $\alpha = 30°$ and point M at 2/3 distance between A and B were set as default values in our software which gave us best result after comparing the results of the algorithm with manually classified saccades on more than 100 trials. Figure 4 illustrates how the algorithm would work for four different saccades made towards a target.

To apply this algorithm in an antisaccade test we consider 3 targets in the screen: The central target, the distractor target, and a hidden target set at the opposite side of the distractor. This allows us to determine whether a saccade is a prosaccade towards the distractor, an antisaccade towards the hidden opposite location, or a saccade towards the center. The position of the hidden opposite target will be set to the screen edge at the opposite side of the distractor. This is because the antisaccades may be very large which is very common as the participants my direct their gaze towards the edges at the opposite side of the screen. The estimated gaze for these large saccades may even fall outside the screen area or it may be that the saccade is registered with no fixation at the end. For example, the Eyelink parser mistakes these saccades as blink saccades which are unreal eye movements detected before each blink. Our algorithm would work in both cases as the saccade TOI determination is not done based on the fixation points.

Depending on the saccade TOI in each trial, a saccade is classified as one of the following types:

- A correct prosaccade made towards the target.
- A correct antisaccade made towards the opposite (in antisaccade tests).
- A wrong prosaccade made towards the distractor.

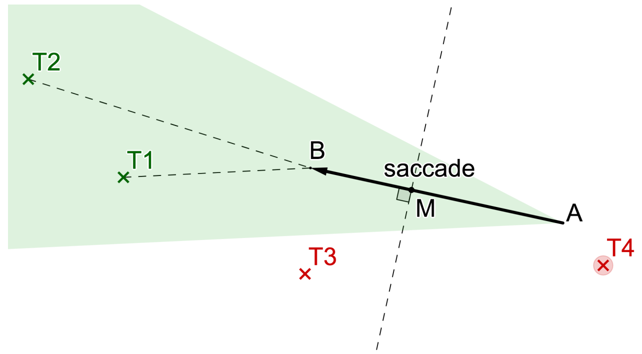

Figure 3: Determining the target-of-interest (TOI) of a saccade AB.

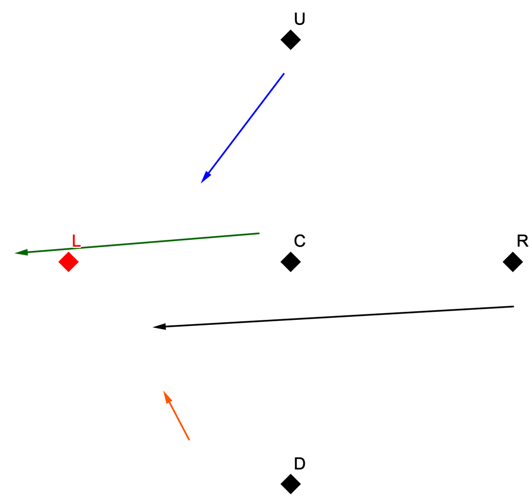

Figure 4: An example showing how the algorithm can correctly identify the right saccade TOI (red target) for four different example saccades made towards target L.

- Corrective saccades made after a wrong saccade.
- Saccades that are made neither towards the distractor nor the target nor the opposite.

The SaccadeMachine also characterizes the saccades and fixations in relation to the position of the target and distractors of the previous trial (e.g., whether a saccade was made towards the distractor location of the previous trial). This is particularly important when processing data from a RD test.

3.4 Processing trials

Each trail of the test will then be processed and labeled as either successful or failed depending on the saccades made within a given time window $[t0, t1]$ relative to the target onset. The window size can be set by the user and defines which part of the trail has to be taken into account; All the saccades outside the given window will be ignored. The time window allows to look at specific parts of the trial (e.g., checking the anticipatory saccades within 50 ms before or after disappearing the central fixation target). It also allows to ignore eye movements made a few millisecond after target onset. All the saccades after $t0$ will be checked in their correct order. The trial will be labeled as successful if there is any correct or corrective saccade in the given time window. A separate table (*Trial_Table*) will be generated that stores the main outputs from each trial in a separate row. The output includes the trial status, condition, details about the correct and wrong saccades, and gaze position relative to the target after the correct saccade.

3.5 Output

The *Trial_Table* will be exported in Excel format as the main output of the software which contains the overall status and results from each trial for all participants. Also a separate result file will be generated for each of the measures described in Table 1.

3.6 Other features

There a few additional features in the software which are described as follows:

3.6.1 Correcting for calibration offset. : The software further checks the fixation status during the central fixation phase of each trial. The trials with wrong fixations (e.g., not fixated at the center or if the fixations were too far from the central target) can be filtered. The software further checks whether there has been any calibration offset (constant offset in the gaze data) by comparing the central fixations across all trials for each subject and can correct the gaze offset if the there is a constant offset from the center in all trials. We later show an example of this in Figure 11.

3.6.2 Target location conditions. : The SaccadeMachine automatically divides the trails in a test into different groups by comparing the target/distractor positions in each trial with the target/distractor position of the previous trial. In the RD test this comparison will be done between two displays within a trial. In addition to the overall result, the user can see the results for each condition and can further compare the results between these conditions. The possible conditions from different target/distractor configurations in prosaccade and antisaccade tests are as follows:

Prosaccade:

- TT: Target was presented at the location that was previously occupied by the recent target.
- TD: Target was presented at the location previously occupied by the recent distractor.
- TN: Target appeared at a new location, not previously occupied by either the target or the distractor.

Antisaccade:

- DD: Distractor was presented at the location that was previously occupied by the recent distractor.
- DN: Distractor appeared at a new location.

3.6.3 Trial Plot. One of the features in the software is the trial plot where the user can select individual trials and see the fixation and saccades in a 2D plot. All the details for each fixation and saccade will also be displayed next to the plot. An example plot is shown in Figure 5 which is for the second display of a RD trial with two distractors in the first display.

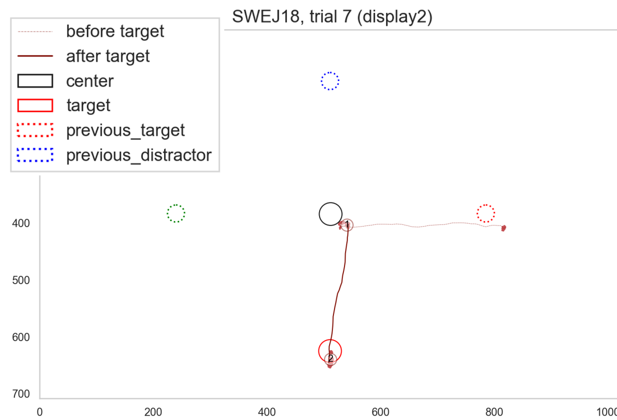

Figure 5: An example plot for the second display of a RD trial with two distractors in the first display. The location of the previous distractors and the current target is shown in the plot as well as the eye movements.

4 CASE STUDIES

To demonstrate the utility of the software, we show how it's used to analyze the eye tracking data collected from two example experiments: An antisaccade test (AS), and an inhibition of recent distractor test (RD). For each of these tests, we used a subset of data from the <Anonymous> dataset that consists of more than 1400 recordings from different groups of participants and various saccade tests.

4.1 Apparatus

Eye movement data were recorded at 500 Hz with the Eyelink 1000 eye tracking system (SR Research Ltd., Ontario, 55 Canada). Participants were sitting 55 cm away from a 24-inch Dell monitor (60 Hz) during the recordings and used a chin rest. All the data were monocular recorded from the participants' dominant eye.

4.2 Antisaccade test

4.2.1 Participants and Procedure. Our antisaccade dataset consisted of 100 participants: 50 young controls (YNG) with ages ranging from 18 to 36 (mean=21.97, SD:3.83), 50 older controls (OLD) with ages ranging from 48 to 82 (mean=67.19, SD:9.3). The AS test consisted of 24 gap trials.

A calibration procedure was performed with 9 points prior to the test. Each trial was preceded by a 1 second instruction screen. Then a white central fixation target was displayed on a black background at the center of the screen and lasted for 1 second. The participants were instructed to fixate at the central point and look at the opposite side of the screen as soon as the distractor appeared. The distractor was then presented after 200 ms gap, in a random order 4 degrees away from the center either on the left or right side for 2 seconds. Both targets were circular and each measured 15x15 pixels (0.9 visual degrees) in diameter.

4.2.2 Analysis. The dataset folder was imported and processed in the SaccadeMachine software. The experiment details such as screen resolution and screen distance have to be set in the main window before processing the dataset. A summary of the dataset details including participants' details and trial conditions were displayed in the software (Figure 6).

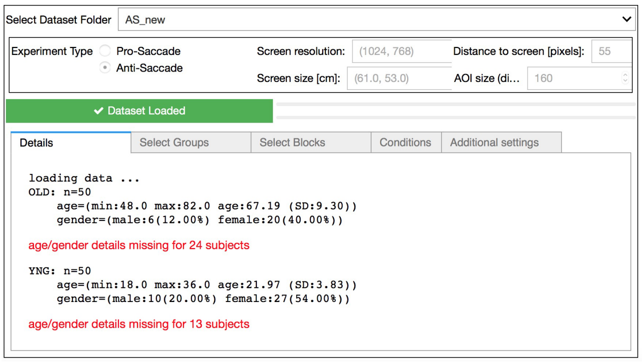

Figure 6: A screenshot of the software after loading the dataset.

After the data were processed, in a separate window we selected the time window of 80 ms to 800 ms (relative to target onset) for which the trials were analyzed. In the following, we show some of the outputs of the analysis:

Number of failed trials: Figure 7 shows the percentage of the trials failed for each participant. A failed trial refers to when no correct or corrected saccade is made in the trial. Note that some trials may be excluded when counting the total number of trials due to problems such as: tracking issues or when no fixation is detected at the center during the fixation display. The details of the individual trial status for each subject can be found in the exported report.

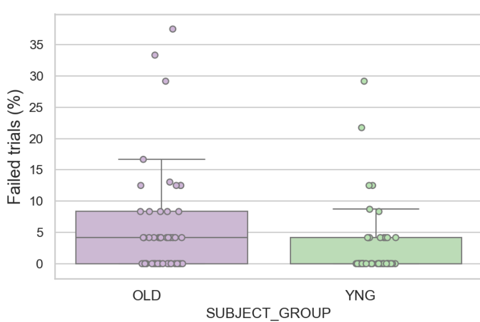

Figure 7: Percentage of failed trials across two groups.

Number of trials with corrected saccade: Figure 8 shows the percentage of those trials where a corrected saccade is detected following one (or multiple) wrong saccade(s). The results showed a significantly higher number of corrected saccades in the OLD group compared to the YNG group ($t(98) = 3.01; p = 0.00$). We further double-checked the individual trials of those subjects with high number of corrected saccades using the Trial Plot feature in the software and verified that in the majority of the trials those subjects first looked at the distractor and then shifted their gaze towards the opposite side of the screen. Figure 9 shows an example trial for one of those subjects.

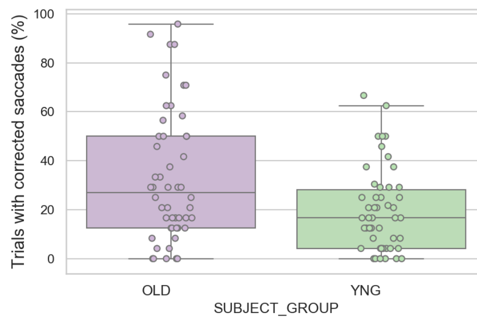

Figure 8: Percentage of trials with corrected saccades in each group.

Reaction time: The average latency of the first saccade (reaction time) across all trials per subject is shown in Figure 10. This latency was more spread out in the OLD group and a t-test that the latency was significantly higher in the OLD group ($t(98) = 2.24; p = 0.03$). This confirms the finding of previous work comparing the saccade latency of children and elderly in reflexive saccades [Hopf et al. 2018].

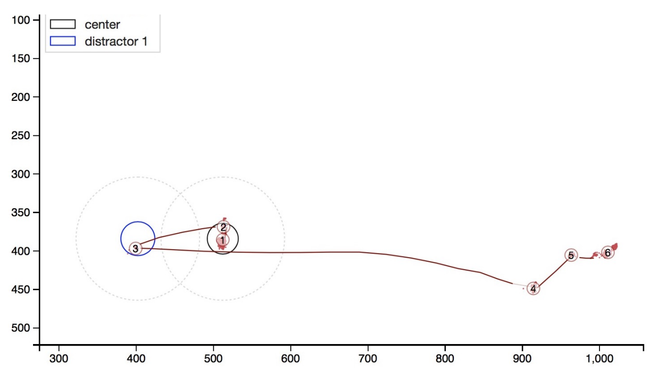

Figure 9: A sample trial from a subject showing a high number of corrected saccades in the results. The subject has made a saccade towards the distractor first (fixation 2 → fixation 3) followed by a corrected saccade towards the other side of the screen (fixation 3 → fixation 4)

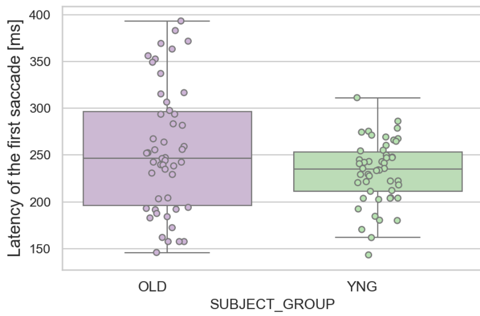

Figure 10: Reaction time in each group.

4.3 Inhibition of Recent Distractor test

4.3.1 Participants and Procedure. We also selected a subset of the data from a RD task consisted of 50 participants with ages ranging from 18 to 26 (mean=21.27, SD:2.78). The RD test consisted of 48 trials with only one distractor in the first display and no temporal blank gap between the fixation and target displays. The duration of the fixation display was randomized between trials and changed between 750âĂŞ1000 ms to prevent anticipatory responses. The duration of the main displays were 1500 ms with their target displayed at 4 degrees away from the fixation point.

4.3.2 Analysis. The CSV files of the RD test had an extra column indicating the index of the first and the second target display in each trial. The data files were imported into SaccadeMachine. The type of the test was set to prosaccade in the main window. After processing the dataset, the practice block that had 4 blocks were excluded from the test and the remaining trials were analyzed for the time widow of 80 ms to 800 ms after target onset in each target display. All the trials with no fixation detected in the fixation display were excluded for each participant. Calibration offset was detected for two of the participants (Figure 11) which was corrected by the software.

Reaction time in different conditions: From various outputs generated for this test, we particularly looked at the reaction time in the second target display to compare our result with previous studies that have shown the inhibition effect of recent distractors as an increase in the reaction time in the second display in the conditions where the new target was presented at the location of the recent distractor (e.g., [Crawford et al. 2005]). Figure 12 shows the reaction time in the second display of the RD task for different conditions. The reaction time is defined as the latency of the first saccade after target onset. Confirming the previous work, a one-way ANOVA followed by a Tukey's post-hoc test indicated a significant increase in saccadic reaction time between the TN and TD condition where the target was presented at the location of the recent distractor ($F(2, 147) = 3.27; p = 0.041$). The SaccadeMachine permits to easily exclude those trials where the first display was failed meaning that no inhibition of the distractor was observed.

5 CONCLUSION

In this paper we introduced software for the automatic processing of eye movement data collected using saccadic tasks. This software

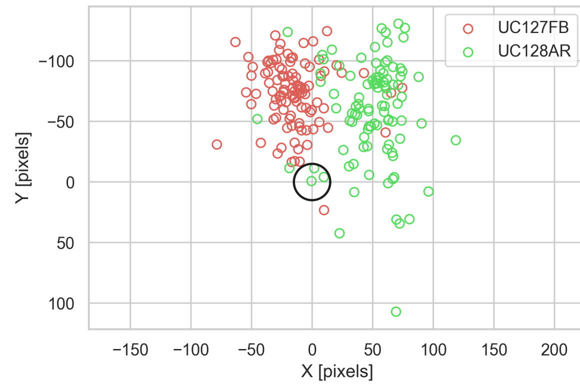

Figure 11: Calibration offsets were corrected for two participants suggested by SaccadeMachine in our RD test. Each dot in the figure shows the median of all fixations during the fixation display of one trial. The black circle indicates the central fixation target.

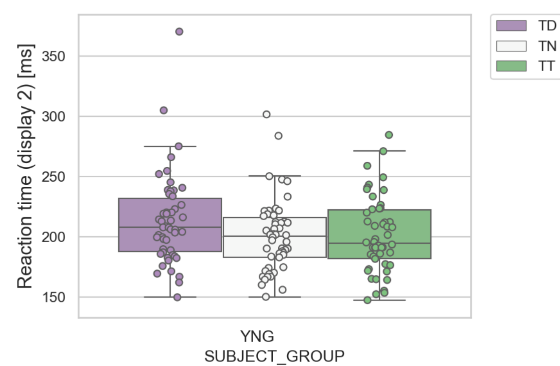

Figure 12: Reaction time in the display of the RD task reported for 3 conditions.

uses an algorithm for labeling the saccade TOIs and classifies the saccades depending on their TOIs (e.g., incorrect saccades, correct, or corrected). This enables the user to bypass a complicated, time consuming, and error-prone stage of eye tracking analysis. By using this software raw eye tracking data can be easily converted into meaningful data which can then be analyzed. Therefore this software would enable novice eye tracker users to process their own data easily and reliably.

The software has been extensively pilot tested in the various tests including the case studies that we described. This involved comparing the data extracted from SaccadeMachine against the results from previous manual extraction techniques. Therefore, we hope that we have demonstrated the overall utility for this software and hope other labs are as enthusiastic as ours at the opportunity for automatic analysis of eye movements of their saccade test using SaccadeMachine.

REFERENCES

Tanja Blascheck, Kuno Kurzhals, Michael Raschke, Stefan Strohmaier, Daniel Weiskopf, and Thomas Ertl. 2016. AOI Hierarchies for Visual Exploration of Fixation Sequences. In *Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research & Applications (ETRA '16)*. ACM, New York, NY, USA, 111–118. https://doi.org/10.1145/2857491.2857524

Trevor J. Crawford, Sarah Hill, and Steve Higham. 2005. The inhibitory effect of a recent distracter. *Vision Research* 45, 27 (2005), 3365 – 3378. https://doi.org/10.1016/j.visres.2005.07.024

PE Hallett. 1978. Primary and secondary saccades to goals defined by instructions. *Vision research* 18, 10 (1978), 1279–1296.

Roy S Hessels, Chantal Kemner, Carlijn van den Boomen, and Ignace TC Hooge. 2016. The area-of-interest problem in eyetracking research: A noise-robust solution for face and sparse stimuli. *Behavior research methods* 48, 4 (2016), 1694–1712.

Ignace Hooge and Guido Camps. 2013. Scan path entropy and arrow plots: capturing scanning behavior of multiple observers. *Frontiers in Psychology* 4 (2013), 996. https://doi.org/10.3389/fpsyg.2013.00996

Susanne Hopf, Matthias Liesenfeld, Irene Schmidtmann, Shahrzad Ashayer, and Susanne Pitz. 2018. Age dependent normative data of vertical and horizontal reflexive saccades. *PloS one* 13, 9 (2018), e0204008.

Samuel B Hutton and Ulrich Ettinger. 2006. The antisaccade task as a research tool in psychopathology: a critical review. *Psychophysiology* 43, 3 (2006), 302–313.

CH Klein, A Raschke, and A Brandenbusch. 2003. Development of pro–and antisaccades in children with attention–deficit hyperactivity disorder (ADHD) and healthy controls. *Psychophysiology* 40, 1 (2003), 17–28.

Krzysztof Krejtz, Andrew Duchowski, Tomasz Szmidt, Izabela Krejtz, Fernando González Perilli, Ana Pires, Anna Vilaro, and Natalia Villalobos. 2015. Gaze transition entropy. *ACM Transactions on Applied Perception (TAP)* 13, 1 (2015), 4.

Richard John Leigh and Christopher Kennard. 2004. Using saccades as a research tool in the clinical neurosciences. *Brain* 127, 3 (2004), 460–477.

Beatriz Luna, Keith R Thulborn, Douglas P Munoz, Elisha P Merriam, Krista E Garver, Nancy J Minshew, Matcheri S Keshavan, Christopher R Genovese, William F Eddy, and John A Sweeney. 2001. Maturation of widely distributed brain function subserves cognitive development. *Neuroimage* 13, 5 (2001), 786–793.

Peter Trillenberg, Rebekka Lencer, and Wolfgang Heide. 2004. Eye movements and psychiatric disease. *Current opinion in neurology* 17, 1 (2004), 43–47.