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SacLab: A toolbox for saccade analysis to increase usability of eye tracking systems in clinical ophthalmology practice

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ABSTRACT

Purpose: Many open source software packages have been recently developed to expand the usability of eye tracking systems to study oculomotor behavior, but none of these is specifically designed to encompass all the main functions required for creating eye tracking tests and for providing the automatic analysis of saccadic eye movements. The aim of this study is to introduce SacLab, an intuitive, freely-available MATLAB toolbox based on Graphical User Interfaces (GUIs) that we have developed to increase the usability of the ViewPoint EyeTracker (Arrington Research, Scottsdale, AZ, USA) in clinical ophthalmology practice.

Methods: SacLab consists of four processing modules that enable the user to easily create visual stimuli tests (Test Designer), record saccadic eye movements (Data Recorder), analyze the recorded data to automatically extract saccadic parameters of clinical interest (Data Analyzer) and provide an aggregate analysis from multiple eye movements recordings (Saccade Analyzer), without requiring any programming effort by the user.

Results: A demo application of SacLab to carry out eye tracking tests for the analysis of horizontal saccades was reported. We tested the usability of SacLab toolbox with three ophthalmologists who had no programming experience; the ophthalmologists were briefly trained in the use of SacLab GUIs and were asked to perform the demo application. The toolbox gained an enthusiastic feedback from all the clinicians in terms of intuitiveness, ease of use and flexibility. Test creation and data processing were accomplished in 52 ± 21 s and 46 ± 19 s, respectively, using the SacLab GUIs.

Conclusions: SacLab may represent a useful tool to ease the application of the ViewPoint EyeTracker system in clinical routine in ophthalmology.

1. Introduction

In our everyday lives, we regularly make various types of eye movements because of the activity of three pairs of antagonistic muscles that support each eye. Saccades are rapid conjugate movements of the eyes as they jump from fixation on one point to another, bringing an object of interest into focus on the fovea. Their amplitude can range from the small movements made while reading to the wide movements made while scanning the surrounding environment [1]. Since saccades are the result of the joint action of the visual, oculomotor and central nervous systems, saccadic abnormalities can be seen in a wide variety of disease states [2].

In recent years, the increasing number of reliable Eye Tracking (ET) systems has raised growing interest in studying eye movements and gaze patterns on a quantitative basis [3–5], which is replacing the previous, purely qualitative approach [6,7]. Particularly, video-based ET systems have become more and more popular because of their non-invasive nature, the rapid progress in electronic data processing and their continuous fall in prices [6,8,9]. Moreover, the results obtained with video-based ET systems have been proved to be comparable with those provided by well-established, more invasive systems used for research purposes, such as scleral search coils [10,11]. In the past, a non-invasive solution for tracking the eye movements (CENOG system), based on the use of four small skin electrodes attached around each eye and small voltages measurements by these electrodes, was proposed by Ledley et al. [12]. However, this system had little impact since no further evidence of applications in research or clinical fields can be found.

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Therefore, the video-based ET systems remain the most promising approach for the non-invasive quantification of eye movements.

Despite ET systems can be powerful non-invasive tools, they usually require considerable amount of time for setting the system and creating the ET tests, as well as some programming skills for post-processing analysis of the recorded data [13,14].

Recently, many free software packages have been developed to be used with video-based ET systems [13–17]. However, they have been mainly addressed to neurological and psychophysiological research and none of these is specifically designed to encompass in a single package all the main functions required for carrying out an ET test, from the creation of the visual stimuli test, to the automatic aggregate analysis of the recorded data.

In this paper we introduce SacLab, a new MATLAB toolbox that we have developed for the analysis of saccadic eye movements while using a commercial eye tracker, the ViewPoint EyeTracker by Arrington Research, without requiring that users have programming skills and knowledge. Our aim is to provide a tool that may simplify the use of the ViewPoint ET system, in order to encourage the introduction of this technology in the clinical ophthalmology practice.

2. Methods

SacLab is based on intuitive Graphical User Interfaces (GUIs) and automatic processing functions for the analysis of saccades. These functions work on raw data collected by commercially available ET systems. Raw data are typically a set of *x* and *y* coordinates for each eye (*Gaze Point*), which represent the horizontal and vertical positions of the subject's gaze on a screen on a normalized scale (using the screen size as reference).

The SacLab software is composed of 4 modules: Test Designer (TD), Data Recorder (DR), Data Analyzer (DA) and Saccade Analyzer (SA). These modules allow to perform all the operations required to carry out an ET test for the analysis of saccades, starting from the creation of visual stimuli tests to the analysis of saccadic parameters collected from multiple recordings. SacLab has been developed in MATLAB environment and it is compatible with every operating system that supports MATLAB (Microsoft Windows, Mac OS and Linux). In this first version, SacLab has been developed to be interfaced to the ViewPoint EyeTracker Binocular SceneCamera System (Item BSU07), a commercial ET system manufactured by Arrington Research (Scottsdale, AZ, USA).

The functions of each SacLab module and communication functions with the native ViewPoint ET software are summarized in Fig. 1, and described in detail in the following paragraphs.

A periodically updated version of the SacLab source code will be made available on the Mathworks File Exchange Central.

From SacLab Startup Window (Fig. 2) each SacLab module (TD, DR, DA, SA) can be accessed. By pressing the SacLab Startup icon provided in the GUI of each SacLab module, the SacLab Startup Window can be recalled or it is automatically recalled when a SacLab module is closed by the user.

2.1. Test Designer (TD) module

TD module allows to quickly and easily create the visual stimuli tests to elicit saccadic response in the subject under examination, without requiring the user to have experience with graphic editors. A visual stimuli test is a series of images showing a target, which changes its position on the screen; the subject is asked to look at the moving target to elicit saccades of different amplitudes, while the eye movements are recorded by the ET system.

TD module allows to set all the features of the desired visual stimulus image, including background color, target size, target shape and target position on the screen (*Stimulus Data functions*).

Other functions (*Geometry Data functions*) are provided to set all the features (screen size, screen resolution, aspect ratio, viewing distance) required to calculate the target position, i.e. to convert it in pixels, within the created stimulus images. The order of the stimulus image presentation can be changed by selecting the desired image from a created image list and by applying “add”, “delete” and “modify” functions to the image list (*Image List functions*). Also the duration for each image presentation can be set.

A collection of newly created stimulus images can be saved in a *Test File* or a previously created *Test File* can be loaded (*File Management functions*) to be used for the ET test.

A preliminary library of standardized diagnostic tests for the analysis of saccadic movements, which may underlie pathologies involving disturbances of oculomotor behavior in various gaze directions (tests for horizontal, vertical and oblique saccades) has been prepared, following suggestions from ophthalmologists and taking as reference some previous works in the literature [3].

The output *Test File* provided by the TD module contains information on both stimulus data and geometry data, as well as software command lines to load the created stimulus images and show them on the screen.

The GUI of TD module is reported in Fig. 3.

Screen (monitor) size, screen resolution and viewing distance can be set in the top-right corner of the GUI (functional block **2**). Features of the stimulus images (color, target size, target shape and position) can be set using the controls in the bottom section of the GUI (functional block **1**). The image list and timing for image presentation on the screen can be managed in the box on the right side of the GUI (functional block **3**). The created stimulus image is displayed in real time in the white central box of the GUI (functional block **5**). By pressing the ‘SAVE TEST FILE’ button in the bottom-left corner of the GUI (functional block **4**) the created visual stimuli test can be saved, or by pressing the ‘LOAD TEST FILE’ button a previously created visual stimuli test can be loaded.

2.2. Data Recorder (DR) module

DR module allows to record eye movement data by implementing the communication with the native ViewPoint ET software. DR functions allow to load or unload a visual stimuli test created with TD module (*Test functions*) and to start data recording (*Recording functions*). The DR module implements functions for a two-way communication between SacLab and the native ViewPoint ET software (*ET communication functions).* This two-way communication takes place through dedicated MATLAB libraries provided by the native ViewPoint software (Fig. 1). In details, DR module sends inputs for various functions that are managed by the ViewPoint software (i.e. calibration, setting of the viewing distance, loading/presentation of the stimulus images created with the TD module). Particularly, the stimulus image presentation is managed by ViewPoint software and its timing is stored by ViewPoint and then retrieved by DR module during data recording in order to ensure the highest possible accuracy of timing for stimulus presentation.

The above functions are essentially duplicates of the native ET software functions, but we provided all of them also in the DR module frontend to allow the user to manage them from a single interface. The DR module frontend can be used simultaneously with the ViewPoint frontend or as a stand-alone window. However, we recommend, while using the DR module, to check the ViewPoint frontend in order to see if the native ET software is working as desired.

On the other hand, the ViewPoint software sends the acquired eye movement data to DR module for data recording and further data analysis.

Via the graphical interface of DR module, the user can select the eye movement data (*Eye Data*) that will be recorded, by choosing from a list of recordable *Eye Data* available in the native ViewPoint ET software *(Eye Data selection functions*). See Table 1 for the set of