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Effect of aging on post-saccadic oscillations

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ABSTRACT

Recent research have shown that the eye movement data measured by an eye tracker does not necessarily reflect the exact rotations of the eyeball. For example, post-saccadic eye movements may be more reflecting the relative movements between the pupil and the iris rather than the eyeball oscillations. Since, accurate measurement of eye movements is important in many studies, it is crucial to identify different factors that influence the dynamics of the eye movements measured by an eye tracker. Previous studies have shown that deformation of the internal structure of the iris and size of the pupil directly affect the amplitude of the post-saccadic oscillations that are measured by video-based eye trackers that are pupil-based. In this paper, we look at the effect of aging on post-saccadic oscillations. We recorded eye movements from a group of 43 young and 22 older participants during an abstract and a more natural viewing task. The recording was conducted with a video-based eye tracker using the pupil center and corneal reflection. We anticipated that changes in the muscle strength as an effect of aging might affect, directly or indirectly, the post-saccadic oscillations. Results showed that the size of the post-saccadic oscillations were significantly larger for our older group. The results suggests that aging has to be considered as an important factor when studying the post-saccadic eye movements.

1. Introduction

When looking at eye movements recorded by an eye tracker, we can see some instability and oscillations that often happen at the end of saccades along the saccade direction before they reach a steady-state value (following fixation). The general term for these instabilities is post-saccadic oscillations(PSO) (Eizenman, Frecker, & Hallett, 1984; Nyström, Hooge, & Holmqvist, 2013). Post-saccadic oscillations which may appear both in a form of overdamped or underdamped oscillation were hypothesized to have a neural origin (Bahill, Clark, & Stark, 1975), while later studies have shown that the recording technique (dual Purkinje (DPI), scleral search coils, and video-based eye tracking) significantly influences the dynamics of the measured PSOs (Kimmel, Mammo, & Newsome, 2012; Nyström, Hansen, Andersson, & Hooge, 2016) suggesting that PSOs may have other causes that depend on mechanics of the structures inside the eyeball and the tracking apparatus itself. Slipping of the coil relative to the cornea in coil-based techniques (Träisk, Bolzani, & Ygge, 2005), relative movement between the lens and the cornea in the DPI trackers (Kimmel et al., 2012), and deformation of the internal structure of the iris during and directly after saccades in video-based eye trackers that are pupil-based (Nyström et al., 2013), directly affect the amplitude of the measured post-saccadic oscillations. Therefore PSO signals recorded with video-based eye trackers reflect a combination of dynamic overshoot of the eyeball and deformation of the iris (seen as pupil oscillations caused by lens wobble):

$$PSO = OSC_{eyeball} + OSC_{pupil}.$$

Nyström, Hooge, and Andersson (2016) studied the effect of pupil size on pupil center and gaze signals and they showed that the saccade peak velocity and PSO amplitude differ for different pupil sizes. They found it reasonable to think of iris muscles as two springs that are radially attached to each other. Applying an impulse to the system when the mass element has already been displaced from its equilibrium (e.g. constricted or dilated pupil) generates a lower amplitude oscillation compared to when the mass element is at its natural position. As the other main factor that influences the oscillations of a spring system is the properties of the spring itself, it is tempting to study how much PSO

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signals get affected by changes in elastic properties of the iris. In this paper, we study how post saccadic oscillations change with age. Age is one of the factors that indirectly affects the body tissues and muscles including the muscles of the iris (Loewenfeld, 1979). Studies have shown that the iris gets less reactive (Salvi, Akhtar, & Currie, 2006) and the muscle strength decreases (Booth, Weeden, & Tseng, 1994; Tamm, Tamm, & Rohen, 1992) with age.

2. Methods

2.1. Participants and apparatus

The first experiment included 65 participants: 22 older adults (OLD group) with ages ranging from 50 to 80 (mean = 69, SD:6.9), and 43 young (YNG group) with ages ranging from 18 to 26 (mean = 20, SD:2.6). 16 people from the OLD group and 32 from the YNG group were Male. For the second experiment, we recruited 12 more participants changing the total number of participants as follows: 30 subjects (with ages ranging from 50 to 80 (mean = 68.07 SD:7.96), 22 male) in the OLD group and 47 subjects (with ages ranging from 18 to 30 (mean = 20.9 SD:2.9), 35 male) in the YNG group. Potential participants were made aware prior to the study that the study involves eye movement measurement. Participants were asked to report 'any related medical history'. One of the participants in the OLD group (involved in both experiments) had cataract surgery and the PSO was almost absent in his data. One participant used glaucoma eye drop and 2 were using dry eyes and hay fever eye drops.

Participants' heads were fixed during the experiments using a chinrest with a forehead support. The camera was moved horizontally in order to ensure the camera was directly facing the participants' tracked eye. The eye appeared in the center of the eye image for each participant. Eye movement data were recorded from the participants' dominant eye (determined using the Miles test (Roth, Lora, & Heilman, 2002)) at 500 Hz with the Eyelink 1000 eye tracking system (SR Research Ltd., Ontario, Canada). Participants were sitting 55 cm away from a 24-inch Dell monitor (60 Hz) during the data collection (see Fig. 1). The resolution of the monitor was set to 1024 pixels by 768 pixels. Experimenter Builder software Version 1.10.1630 (SR Research Ltd.) was used to control the stimulus events during the eye-tracking task. A single user calibration with 9 points was performed prior to the experiment. The result of the calibration was assessed by doing a validation test using 9 points right after the calibration. The calibration was repeated when the result of the validation reported by the eye tracker was poor.

Older adults were recruited from a local church and younger adults were recruited from a local university. The experiments were conducted at the same lab. Written informed consent was obtained and the study was approved by the National Research Ethics Service (Health Research Authority (HRA), 11/NW/0723).

2.2. Procedure and data collection

The eye movements were recorded for two different tasks. The first experiment was a pro-saccade task where horizontal eye movements were recorded whilst participants were looking at targets that appear at the left and the right side of the initial fixation point at the center of the screen. In a separate task, participants watched short videos whilst their eye movements were recorded. The second experiment was designed to measure post-saccadic oscillations of more natural eye movements when participants were given different visual search tasks.

3. Experiment 1

Participants completed 16 trials of a prosaccade task. During the task a central fixation target (a white circle with 1° diameter) appeared for 1 s on a black background screen. Following this the saccade target appeared at 4° away from the center for 2 s either to the left or right of where the central fixation had been. The saccade target was a red circle with a diameter of 1°. Participants were instructed to look at the central fixation point. Once the saccade target appeared, they were requested to fixate on the target as quickly and as accurately as possible. There was a 200 ms blank interval between the fixation target disappearing and the saccade target appearing.

3.1. Data analysis

Fixation and saccade detection was done by the EyeLink software (DataViewer) using the default 'cognitive configuration' parameters. Therefore saccade velocity threshold was 30 °/sec, saccade acceleration threshold was 8000 $°/\text{sec}^2$. The peak velocity of the saccades used in the paper was determined as the maximum of the reported velocity during the saccade.

Since in the first experiment targets were shown at fixed positions either at the left or at the right side of the resting fixation (defined at the middle of the screen), only horizontal components of the eye movement data were considered. We then extracted all the saccades that had a starting point within 2 degrees of the middle of the screen with a latency between 100 and 1000 ms and an amplitude within 75–125% of the target amplitude (distance of the target from the resting fixation in the screen). All the gaze data that belonged to the saccades that were towards the right target were rotated by 180 degrees (in the screen coordinate system) such that we can study all the left and right saccades together. Hooge, Nystrm, Cornelissen, and Holmqvist (2015) have observed that the shape of the PSO signals may be very different for abduction and adduction saccades and for left and right eyes. However, in our first experiment the initial fixation is always at the center of the screen and during the experiment only one of the eyes are tracked. Furthermore, the saccade amplitude was similar (about 4°) for all the saccades. Therefore, all the recorded saccades (either towards the left or towards the right) were abduction saccades and the overall shape of the PSO signals for the leftward and rightward saccades were quite similar for each participant. From now, for the sake of brevity we refer to the horizontal components of the selected saccades as PSO signals that change over time.

3.1.1. Signal alignment

We skipped the first 20% of the total samples recorded for each saccade and also included 20 frames (40 ms) of eye data after the end of each saccade to ensure that the most oscillating part of the signals are included. All the PSO signals were 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 was shifted along the spatial axis such that all the signals converge at zero (see Fig. 2). We then found the minimum peak of each oscillation by searching for the first critical point of the signal curve that happens after the maximum velocity. Finally, the signals were 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 in time. Fig. 2 shows an example of PSO signals aligned for one of the OLD subjects (chosen randomly).

3.1.2. PSO median and amplitude and variation

We calculated the median of all PSO signals for each individual participant which summarizes all the PSO signals into one signal. Fig. 2 also shows the median PSO (red curve) for a randomly chosen participant. We used median instead of mean to reduce the effect of any outlier such as: signals that are not aligned properly, noisy signals, missing samples and also signals with different shapes.

The amplitude of each individual PSO signal (and the median PSO) was defined as the distance between the first occurrence of the minimum and the first occurrence of the maximum value of the signal