Voluntary Eye Movement Patterns while Viewing Müller-Lyer Illusion

A New Screening Method for Scotoma Patients

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Abstract: Diabetic maculopathy and especially advanced glaucoma are the most common eye diseases involving scotomas, blind spots in the visual field. The risk of having scotomas increases significantly with age and over 60 million people worldwide suffer from different forms of glaucoma of whom at least are half are not aware of the eye disease. One of the most common scotoma diagnosis tests is perimetry, a visual field test, which produces a complete map of the visual field, but may not be suitable for large screening of population. We are aiming to develop a new portable screening device for cost effective screening of eye diseases. We studied voluntary eye movement patterns evoked by Myller-Lyer illusion figure. Our study material included six scotoma patients (two with *Maculopahia Diabetica*, and four with *Glaucoma simplex*) and six control subjects. We recorded eye movement patterns with a portable Tobii T120 eye-tracker system on which a Müller-Lyer figure was projected. As a result, the variation of the y-component of the eye movement trajectory indicates that the scotoma subjects had more vertical variation in their eye movement pattern than the control subjects (P< .01). The preliminary experiment suggests that further prospective studies using our method of analyzing eye movement patterns is warranted with larger sampale sizes and different types and stages of defects.

1 INTRODUCTION

Visual field defects are common consequences of different eye diseases. There are different types of defects, e.g. altitudinal field defects, bitemporal and homonymous field defects as well as peripheral and central scotomas. Earlier studies have shown that patients with central scotoma develop different fixation (i.e. during fixation the eye is maintained on a single location) strategies to compensate their impaired visual field (Sunnes et al., 2005); (Schuchard, 2005); (Duret et al., 1999). These fixation strategies involve the use of preferred retinal locus (PRL). By using PRL, a patient can fixate the seeing retina on to the object of interest so that the scotoma is moved away from the object of interest. We hypothesized that special eye movements related to these strategies could be detected from the eye movement data while viewing a visual illusion figure.

In visual illusion the visual sensation differs from reality (Gregory, 1998). One of the most studied visual illusions is a century old Müller-Lyer illusion. Even though it has a long history of study, its mechanism is still obscure (Bodanko et al., 2009).

Müller-Lyer illusion is also known as an arrow illusion. A line with arrow heads pointing *out* (i.e. closed part of the figure) looks shorter than a line with arrow heads pointing *in* (i.e. open part of the figure). We used the so called Brentano version in which the arrow heads are drawn on to a single line (Fig. 1). We use this well-known illusion innovatively to evoke voluntary eye movements while viewing the illusion and, further, to compare the eye movement data between people with and without central scotoma.

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Diabetic maculopathy and especially advanced glaucoma are typical eye diseases causing central scotoma. The damage inflicted by glaucoma is related to optic nerve head, nerve fiber layer and visual field. Too high intraocular pressure destroys retinal fiber pathways leading to defects on the visual field (scotomas) starting typically from the peripheral visual field. It has been estimated that glaucoma is one of the leading causes of blindness together with diabetic eye disease. The risk of having glaucoma increases significantly with age. Some 60 million people worldwide suffer from the disease, half of them unawares. Demographical studies and screenings of population have shown that especially open angle glaucoma patients have not been detected by the opportunistic case finding and there is lack of simple appropriate screening methods (Wong, 2004).

One of the most common glaucoma diagnostic test is perimetry, a visual field test, which produces map of the visual field (Humphrey´s and Octopus static perimetries and Goldmann´s kinetic perimetry). These methods have been approved for clinical studies, but they may not be suitable for large screening of the population.

Our aim was to test the hypothesis and develop a new method of collecting and analyzing eye movement data in order to advance the development of a new portable screening device for patients with central scotoma patients.

2 MATERIALS AND METHODS

2.1 Data Collection

Total of 12 voluntary subjects participated in the experiment: six scotoma patients and six control subjects. Two of the six scotoma patients were diagnosed with *Maculopahia Diabetica* and four patients were diagnosed with *Glaucoma simplex*. The scotoma patients were recruited at routine checkups at the University Hospital of Oulu. The scotoma group included 4 male and 2 female patients aged between 30 and 74 years, with the mean 62.8 years.

The control group consisted of 3 male and 3 female students and faculty members of the University of Oulu who were aged between 23-30 years with the mean 27.2 years.

The eye movements of the subjects were recorded using a Tobii T120 Eye Tracker. Tobii T120 records eye movements using an enhanced version of the commonly used Pupil Centre Corneal Reflection (PCCR) technique. The resolution of the Tobii T120 tft-display, on which the Müller-Lyer figure (M-L) was presented, was 1280x1024 pixels. The line length of the presented M-L figure was 22.5 cm and the line thickness was 0.79 mm, see Fig. 1. The M-L illusion figure consisted of a starting error of 7.5 cm: the closed part of the figure was two times longer than the open part of the figure. The starting error was added in order to clearly show that the line which was to be adjusted, with closed arrowheads, was considerably longer than the line with open arrowheads. The visual angle of the presented M-L figure was 21.2 degrees (i.e. the angle opening from the viewer towards the ends of the line). The angle of the M-L figure arrow head was 45 degrees and its length was 2cm. The sample rate of the Tobii T120 Eye Tracker was 17 ms (60 Hz). The eye tracker was controlled by a laptop computer. The M-L figure was presented on the eye tracker screen by EMMI® software (LudoCraft Ltd, Oulu, Finland).

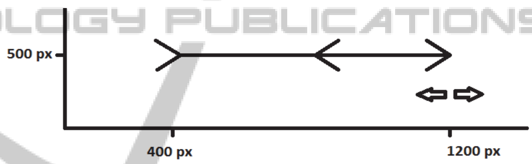

Figure 1: Brentano version of the Müller-Lyer figure as presented on screen. The closed side was adjusted.

The subject was sitting approximately 60 cm from the Tobii T120 tft-monitor. A total of five right pointing M-L figures were presented consecutively on the screen using EMMI® software. The subject was instructed to adjust M-L figure´s lines to be equally long using the left and right arrow buttons of a keyboard. After the adjustment of each M-L figure, the subject had to press the enter-key.

2.2 Data Processing

Each Tobii T120 recording consists of a sequence of triplets (t,x,y) following the eye movement trajectory on the monitor, in which t is the timestamp and x/y are the coordinates of a trajectory point. These data points were further assigned to the same fixation if the velocity remained below a threshold of 30 degrees per second. In addition, the maximum allowed time between fixations was set to 75 milliseconds and the maximum allowed angle between fixations was set to 0.5 degrees; and the minimum allowed fixation duration was set to 60 milliseconds.

EMMI® software recorded the participants' visuo-motor activity and the magnitude of the illusion at a sample rate of 17 ms (60 Hz). The data from the Tobii eye tracker and EMMI® software were integrated and synchronized with an algorithm written in Matlab programming language.

Several indices of eye movement dynamics were computed for both eyes while watching the M-L figures: the illusion magnitude, the number of fixations, the duration of fixation, the standard deviation of the vertical direction on the display, and the standard deviation of the horizontal direction on the display. Differences between the groups were analyzed statistically using the Mann-Whitney U – test.

3 RESULTS

First we compared the magnitude of illusion, the mean number of fixations and fixation durations between the Scotoma Group and the Control Group. Table 1 shows that the illusion magnitude was higher in the Scotoma group (M=38.03%, SD=35.30) than in the Control group (M=35.57%, SD= 14.26) but the differences were not statistically significant. The mean number of fixations in the Scotoma Group was 307.83 (SD= 118.16), and in the Control Group 221.17 (SD= 73.70). There was no statistical difference between the groups. The mean duration of fixations was significantly longer in the Scotoma Group (M=774.50 ms, SD=221.03) than in the Control Group (M=527.33 ms, SD=138.11) with P<.01.

Table 1: Illusion magnitudes, mean number of fixations, and mean duration of fixations (** P< .01).

Groups	Magnitude %	Mean number of fixations	Mean duration of fixation, ms
Scotoma Group	38.03 %	307.83	774.50**
Control Group	35.57 %	221.17	527.33

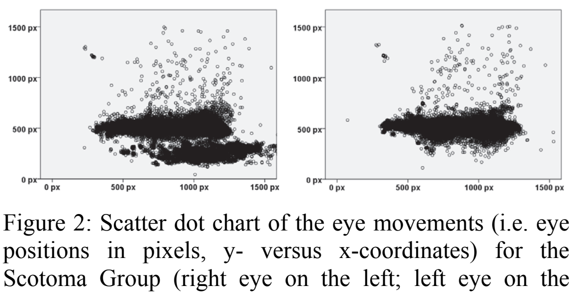

Figure 2: Scatter dot chart of the eye movements (i.e. eye positions in pixels, y- versus x-coordinates) for the Scotoma Group (right eye on the left; left eye on the right).

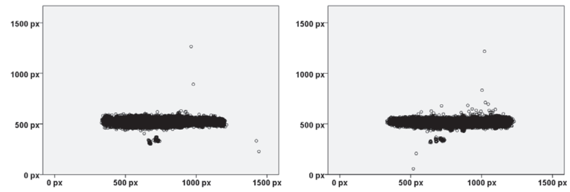

Figure 3: Scatter dot chart of the eye movements (i.e. eye positions in pixels, y- versus x-coordinates) for the Control Group (right eye on the left; left eye on the right).

Then we compared the standard deviations of x- and y-coordinates separately (i.e. eye movements) between the groups. The most significant difference in the eye movement data was the variance in the y-component of the eye movement trajectory over the M-L figure. For visualization purposes scatter dot charts of both eyes were drawn separately for both groups (see Fig. 2 and Fig. 3).

The standard deviation of y-coordinate was significantly greater in the Scotoma Group than in the Control Group in both eyes (P< .01) (see Table 2).

Table 2: Standard deviations of y-coordinates of the eye movement trajectories for the Scotoma Group and the Control Group, subjects presented separately.

Subjects	Scotoma Group	Control Group
Right eye	SD (pixels)	SD (pixels)
1	60.2	24.22
2	73.46	21.95
3	58.6	24.5
4	69.33	17.96
5	35.63	19.03
6	69.3	18.78
Left eye	SD (pixels)	SD (pixels)
1	69.12	25.39
2	38.1	20.92
3	41.34	23.24
4	64.91	20.55
5	36.01	18.37
6	69.96	17.82

The standard deviations of the x-coordinates of the right and left eye did not differ between the groups (see Table 3).

4 CONCLUSIONS

We recorded voluntary eye movements of the Scotoma group and the Control group, consisting of six subjects each, while viewing the Müller-Lyer illusion figure. We analysed the data in regards to illusion magnitude, number and duration of fixations and the x- and y-coordinates of the eye's trajectories across the screen and compared these parameters between the Scotoma and Control groups.

The main novel finding was that the eye movement dynamics differ significantly between the Scotoma and the Control group. This observation was confirmed with two interrelated parameters: the vertical variation of eye trajectories over the M-L figure (P<.01) and the fixation duration (P<.01).

The different trajectories are an indication of compensatory eye movements: Scotoma patients compensate their visual field deficiencies with abnormal eye movement trajectories. The longer fixation duration is also an indication of compensation for scotomas in the Scotoma Group (Duret et al., 1999).

The presented novel method warrants further research with larger sample size as well as different types and stages of eye diseases.

Table 3: Standard deviations of the x-coordinates of the eye movement trajectories for the Scotoma Group and the Control Group, subjects presented separately.

Subjects	Scotoma Group	Control Group
Right eye	SD (pixels)	SD (pixels)
1	184.71	177.17
2	179.59	204.13
3	198.02	220.03
4	263.45	228.36
5	181.59	170.24
6	261.28	189.45
Left eye	SD (pixels)	SD (pixels)
1	186.51	172.34
2	165.09	201.16
3	183.95	223.07
4	284.06	235.73
5	179.03	166.59
6	246.01	186.18

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