

Analysis of Eye Movements Reveals Longer Visual Saccades and Abnormal Preference for Social Images in Autism Spectrum Disorder

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Abstract

OBJECTIVE: The objective of our study was to compare the distribution of attention on two categories of stimuli: 1) social stimuli and 2) objects or geometric shapes, in individuals with autism spectrum disorders (ASD) and a control group. Moreover, we examined the relationship between the parameters of saccadic eye movements and the severity of ASD. Furthermore, we were interested in whether the metrics derived from saccadic eye movements could serve as useful biomarkers for autism spectrum disorder.

DESIGN: There were 79 participants in the research sample, 34 in the ASD group and 45 in the control group. We used two categories of photos: a) social stimuli, which consisted of either facial or full-body photographs; b) objects and geometric shapes, which included photographs of natural still-lives with a distinctive geometric element, photographs of trains, cars and planes. Stimuli were presented in pairs, one photo on the left half of the screen and the other on the right half of the screen. A total of 10 pairs of images were displayed for a duration of 10 seconds each. Eye movements were recorded during presentation of the stimuli. To assess the severity of ASD, the Autism spectrum quotient (AQ) was used.

RESULTS: Visual saccades were significantly longer in the ASD group than in the control group. There was no difference between the groups in the average saccade velocity or in the fixation duration mean. The ASD group had significantly fewer fixations on social stimuli and significantly shorter total fixation time on social stimuli than the control group. The AQ was positively correlated to the average saccade length and negatively to the total fixation time on social stimuli and the number of fixations on social stimuli. When the average saccade length was used as a criterion, we were able to differentiate ASD with a sensitivity of 0.85 and a specificity of 0.60.

CONCLUSION: We attempted to develop an oculomotor registration method for ASD identification. The average saccade length and the total fixation time on social stimuli were the most appropriate biomarkers for identifying individuals with ASD.

INTRODUCTION

There are several objective diagnostic tools available for the psychodiagnostics of autism spectrum disorder (ASD), which identify ASD and the degree of its severity in a specific individual. These tools are primarily based on "behavioral diagnostics", which carries the risk of subjective distortion of the results by the diagnostician. One of the research priorities is therefore the finding of biomarkers that would make the diagnostics of ASD more accurate, and that could be used from an early age with a high degree of objectivity.

Current research shows that the analysis of eye movements during the presentation of various stimuli and the subsequent evaluation of the parameters of visual saccades and fixations could be potentially useful biomarkers of ASD. Individuals with ASD show atypical eye movement trajectories, especially during viewing scenes with social interaction, when viewing faces, and also when viewing various (also non-social) stimuli (Schmitt *et al.* 2014). Chawarska, Macari and Shic (2013) demonstrated that differences between the autistic and healthy population in visual fixations and saccades can be noted already at the age of 6 months, which corresponds to the age when the first biomarkers at the level of brain activity also appear (Wolff *et al.* 2012; Elsabbagh *et al.* 2012), and these differences persist into adulthood.

Saccades of individuals with ASD have less accuracy, less maximum eye movement velocity, and longer duration (Schmitt *et al.* 2014). Their saccadic eye movements take a longer time to reach maximum speed, however, people with ASD do not differ from the control group in the slowing down of eye movements at the end of the saccade. These differences were present in individuals with ASD aged 6-44 years (Schmitt *et al.* 2014). A different result was obtained by Kovarski *et al.* (2019), who found that in children with ASD (2.6-11 years) saccades were faster but less accurate than in the control group.

Many studies have shown that individuals with ASD do not allocate as much attention to social information (they spend less time viewing people and faces in static pictures of social interactions, cartoon images or movies, and clips of naturalistic social scenes) as typically developing individuals (e.g. Riby, Hancock, 2008, 2009; Kirchner *et al.* 2011; Klin *et al.* 2002). Individuals with ASD are looking less at the eye region of the face (Pelphrey *et al.* 2002; Dalton *et al.* 2005; Klin *et al.* 2002). They do not find eye contact unpleasant, but it is not interesting for them (Asberg *et al.* 2014). While watching a film, children with ASD did not differ from controls in time spent looking at the eyes, but they spent less time looking at the mouth, and they spent more time looking at parts of the face other than the eyes and mouth (Asberg *et al.* 2014). Contrary, some studies have found increased fixation on the mouth region (Klin *et al.* 2002; Spezio *et al.* 2007), others have

found no clear difference (Pelphrey, *et al.* 2002; Dalton *et al.* 2005). However, these studies compare looking-time to social and non-social information within a single coherent scene. Therefore, participants in these studies are not required to choose between looking at social information or non-social information as these are both contained within the same stimulus. When a direct comparison of preference for looking at social versus non-social scenes is used, the findings reveal that individuals with ASD do not allocate as much attention to social stimuli as control subjects (Pierce *et al.* 2011).

Sasson *et al.* (2008) analyzed the visual exploration of 12 static images on a computer screen, consisting of social images and objects. They found that people with ASD looked at fewer images overall, while having a longer average fixation time per image and a higher number of fixations per image, indicating a focus on detail, but only on the images they found most interesting. Among different categories of objects, people with ASD have been shown to allocate their visual attention to categories such as trains, cars, airplanes, electronics, computers, and traffic signs (South, *et al.* 2005; Sasson, Touchstone, 2014).

Research on eye movements is focused primarily on finding differences between groups. Only few studies were focused on diagnostic possibilities at the individual level. Pierce *et al.* (2016) created a diagnostic method using eye tracking, which consisted of presenting short videos containing social stimuli in the upper part of the screen, while short videos with changing geometric shapes were presented in the lower part of the screen. It was demonstrated that this method can differentiate ASD with a sensitivity of 0.21 and a specificity of 0.86 in children aged 1-4 years, but it didn't work well for children older than 4 years old.

Based on previous knowledge, we attempted to develop a method for ASD identification by the means of registration of eye movements. Our approach differs from that of Pierce *et al.* (2016) in two fundamental ways: 1) static images were used as stimulus material (which will allow us to conduct more precise analyses of eye movements); 2) the stimuli were placed in a horizontal direction and their position (left or right half of the screen) was balanced for each category of stimuli. In addition to social stimuli and geometric shapes, we also used other types of stimuli that have been demonstrated by research to be visually appealing for individuals with ASD (e.g. Sasson and Touchstone, 2014; South *et al.* 2005) – for instance, images of trains, cars, and planes. The objective of our study was 1) to compare the distribution of attention on two categories of stimuli (social stimuli vs. objects and geometric shapes) in individuals with ASD and a control group; 2) to examine the relationship between the parameters of eye movements and the severity of ASD. Furthermore, we were interested in whether the metrics derived from saccadic eye movements could serve as useful biomarkers for autism spectrum disorder.

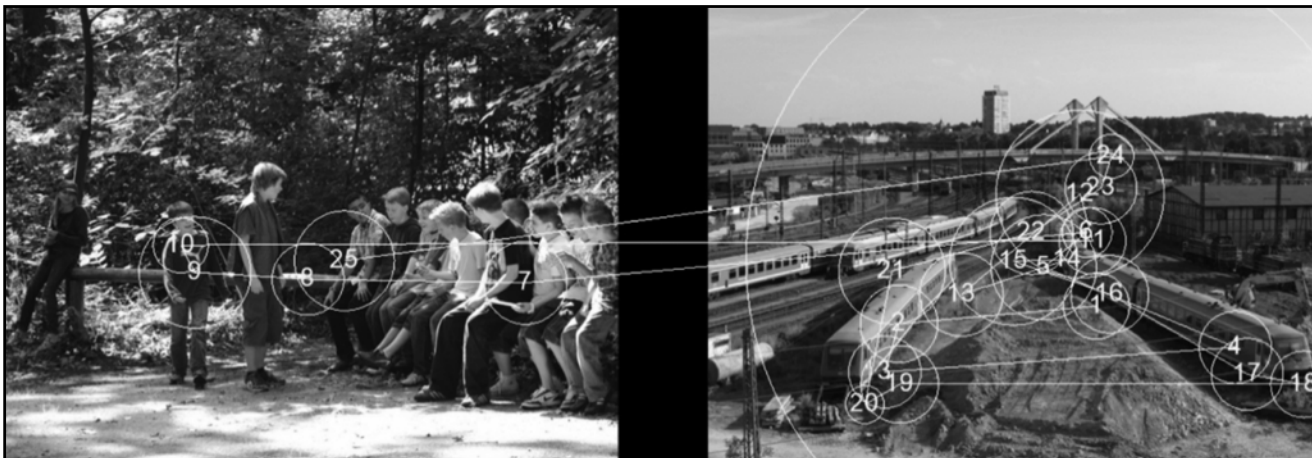


Fig. 1. Example of the visual stimuli arrangement. The trajectory of saccades and visual fixations of a participant with ASD is plotted as an example (numbers indicate the order of fixations, and the size of the circle expresses the duration of fixation at a given location)

METHODS

Participants

The research sample consisted of 79 participants (34 in the ASD group, 45 in the control group). The ASD group consisted of adolescents and adults with ASD: a diagnosis of Asperger's syndrome or high-functioning autism according to MKCH-10 (WHO, 2008) aged 17–35 years (mean age 22.4; SD = 4.53). Participants in the ASD group were already diagnosed and had no comorbid diagnoses. The control group consisted of adults aged 18–29 years (average age 21.5; SD = 2.72). All participants or their legal representatives signed the informed consent.

Visual stimuli

We used two categories of stimuli: a) social stimuli, which consisted of either facial or full-body photographs; b) objects and geometric shapes, which included photographs of natural still-lives with a distinctive geometric element (e.g. a spiral staircase), photographs of trains, cars and planes. These stimulus categories have been shown to be most visually interesting to individuals with ASD in several oculomotor studies (Sasson and Touchstone, 2014; South et al. 2005). Ten photos were used from each category (photographs were either from internet photobanks or taken by the author of the study). Stimuli were presented in pairs (one photo on the left half of the screen, and the other on the right half of the screen – see Fig. 1), while each photo was from a different category. A total of 10 pairs of stimuli were presented; each photo appeared only once in the presentation. The right/left position of the photos was balanced for each stimulus category. Pairs of photos were presented on an 18" computer monitor in random order. The presentation time for one pair was 10 seconds. Before each pair of photos, a fixation point was displayed in the center of the screen for 1 second. Proband's were asked to examine freely the given pair of photographs.

During the presentation, the proband's eye movements were recorded.

Eye movements recording

Eye movements were recorded using a Gazepoint GP3 eye tracker with a recording frequency of 60 Hz, with an accuracy of 0.5 degrees. At the beginning of the measurement, the device was calibrated for each proband using 12 calibration points on the computer screen. Individual fixation points (Fig. 1) and other parameters of eye movements were subsequently calculated from the recording of eye movements - the threshold value of the fixation length was set to 80 ms and the variance to 50 px (e.g. Irvin, 1992; Manor and Gordon, 2003; Holmqvist, 2011).

The autism spectrum quotient

The autism spectrum quotient (AQ) is a standard tool for determining the severity of ASD in adults without mental retardation (Baron-Cohen et al. 2001). It contains 50 items divided into five subscales that assess relevant cognitive and behavioral qualities associated with ASD. In a large-scale meta-analysis including 6900 people, Ruzich et al. (2015) found the mean raw score for the non-clinical population to be 16.94 (95% CI 11.6-20.0) and for those with ASD to be 35.19 (95% CI 27.6-41.1).

RESULTS

We found that visual saccades were significantly longer in the ASD group than in the control group. There was no difference between the groups in the average saccade velocity or in the fixation duration mean (Table 1).

Furthermore, we found that the ASD group had significantly fewer fixations on social stimuli and significantly shorter total fixation time on social stimuli than the control group (Table 1). For stimuli

Tab. 1. Eye movements analysis: differences between the ASD and the control group

	ASD		Control		t-test		
	M	SD	M	SD	t	df	p
Average saccade length [px]	314.40	67.39	268.27	48.24	-3.54	77	.001
Average saccade velocity [px/s]	4.61	1.76	4.86	1.33	.71	77	.478
Fixation duration mean [ms]	299.04	66.67	296.63	59.80	-.17	77	.867
Total fixation time on social stimuli [s]	28.87	13.42	37.55	12.46	2.97	77	.004
Total fixation time on objects/shapes [s]	29.66	11.85	31.66	10.30	.78	77	.440
Number of fixations on social stimuli	99.38	40.11	129.29	39.60	3.31	77	.001
Number of fixations on objects/shapes	105.82	45.62	110.56	30.96	.55	77	.585

containing objects and geometric shapes, there was no difference between the groups in either the number of visual fixations or the total fixation time.

Moreover, correlation analysis revealed that the AQ (mean raw score) was positively correlated to the average saccade length and negatively correlated to the total fixation time on social stimuli and the number of fixations on social stimuli (Table 2).

The analysis of the ROC curves revealed that the average saccade duration was the most appropriate diagnostic criterion for identifying ASD. The sensitivity was 0.85 and the specificity was 0.60 if the average saccade length ≥ 265 pixels was set as a diagnostic criterion. The second most appropriate diagnostic criteria was the total fixation time on social stimuli. If a value ≤ 32.5 seconds was set as a cut-off, a test sensitivity of 0.68 and a test specificity of 0.71 were achieved.

DISCUSSION

Our research revealed an interesting finding, which indicated that saccadic eye movements in subjects with ASD had longer trajectories than subjects from control group. The length of the saccade correlated with the severity of ASD - the more severe the ASD, the longer the visual saccades were. This result applied to social stimuli as well as objects and geometric patterns, so we can assume that it could be a universal biomarker for

autism spectrum disorder. However, further research will be needed to confirm this.

Individuals with ASD had fewer fixations on social stimuli, and the total viewing time for social stimuli was shorter. The severity of ASD has been shown to be negatively correlated with the number of fixations on social stimuli, and the total viewing time for social stimuli - the more severe the degree of ASD, the less fixation on social stimuli, and the shorter the total time spent watching social stimuli.

For stimuli containing objects or geometric shapes, there was no difference between the groups in either the number of visual fixations or the total fixation time. It is important to note that some studies of individuals with ASD showed different results, such as no difference in gaze patterns (van der Geest *et al.* 2002a,b) or abnormal scanning of geometric objects (Pierce *et al.* 2016). The importance of the testing paradigm should be highlighted – such as single-scene or multiple-stimuli viewing at the same time. The arrangement of stimuli on the computer screen is also important factor (e.g. up/down, left/right; in several studies, the position of social/nonsocial stimuli was not randomized). Moreover, it must be distinguished between a free-scanning or a task-directed condition. The specific instructions given to a participant in various studies could modify spontaneous behavior (e.g. individuals with ASD might look at the face in a normal way when required to do

Tab. 2. Relationship between the autism spectrum quotient AQ (mean raw score) and various parameters of saccadic eye movements

	AQ	
	Pearson r	p
Average saccade length [px]	.317	.006
Average saccade velocity [px/s]	-.047	.686
Fixation duration mean [ms]	.035	.763
Total fixation time on social stimuli [s]	-.257	.026
Total fixation time on objects/shapes [s]	.016	.893
Number of fixations on social stimuli	-.295	.010
Number of fixations on objects/shapes	.012	.919

so by a task, yet fail to explore a face visually without a specific reason to do so).

Generally, it has been shown that eye tracking technology can be used to differentiate between people with and without ASD, using measures of social attention. In our research, the average saccade length and the total fixation time on social stimuli were the most appropriate biomarkers for identifying individuals with ASD. When the average saccade length was used as a criterion, we were able to differentiate ASD with a sensitivity of 0.85 and a specificity of 0.60. The specificity value for the total fixation time on social stimuli was slightly higher (0.71), but at the expense of a decrease in the sensitivity value (0.68). Following the trend observed in the study by Pierce *et al.* (2016), our method should yield even greater precision in identifying ASD in younger individuals - therefore, our subsequent research aims to examine the psychometric properties of our method in younger individuals with ASD.

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