Visual Behavior Analysis Between Neuro-typical Children and Children with Autism Spectrum Disorder
Md Atiqur Rahman Ahad, Uzma Haque Syeda, Ziaul Zafar, Miftahul Jannat Rasna, and Koichi Kise

Abstract—Autism Spectrum Disorder (ASD) is a complex and diverse neuro-developmental condition. Little research has been done globally which is not commensurate with the multifariousness of ASD and in developing countries like Bangladesh, such fields of research are almost void. This research investigates the visual behavior of 24 neuro-typical children and 24 children with ASD in smooth pursuit and saccadic eye movement. The smooth pursuit experiment contained animations of objects moving horizontally across the screen and the saccadic tests contained animations of predictable and non-predictable saccades. To attain the gaze data, Tobii EyeX Controller was used and the data was processed and analyzed in MATLAB. Significant differences in results were found in the two areas of investigation. Children with ASD were found to have higher saccadic latency, lower accuracy in smooth pursuit and an overall poorer performance in these basic visual tests compared to their control counterparts. Fundamental eye movements are connected to the sensory-motor processing of the brain and such behavior might be the product of flawed cerebellum and motor functions of the brain. To fully understand this, further eye-tracking, neuroimaging, and behavioral studies should be done in integration.

Keywords- Autism Spectrum Disorder, atypical visual behavior, smooth pursuit, saccadic eye movement, eye-tracking, Tobii EyeX Controller.

I. INTRODUCTION

Autism Spectrum Disorder, otherwise known as ASD is a developmental disability that includes a range of atypical behaviors. The main characteristics of these disorders consist of social and communication incompetency, repeated activity, sensory problems and delay in learning. ASD is often attributed to atypical visual behavior [1], [19]. To understand the visual behavior of individuals with ASD, firstly it is necessary to study their fundamental eye movements. There are four fundamental types of eye movements: smooth pursuit, saccadic, vergence, and vestibular-ocular [2]. With the availability of non-invasive eye-tracking devices in the market, visual behavior studies of individuals with ASD have become a research field with immense potential. The importance of research in this field using eye-trackers is that it will give more accurate results than behavioral studies and is more feasible than costly neuroimaging studies.

To keep the line of sight of an object of interest in the visual field, smooth pursuit eye movements are used [3]. This type of eye movement is relatively smooth and matches the target velocity and the gaze velocity to keep the target in the center of the retina which is focused in the fovea and where the retinal cones are concentrated. Smooth pursuit measures can be classified into the open-loop pursuit and closed-loop pursuit [4]. Open-loop pursuit means initializing the pursuit i.e., locating the target by making a saccadic movement of the eye. Closed-loop pursuit, on the other hand, means maintaining to keep track of the target till it ceases to move. Smooth pursuit is greatly linked to the sensory-motor processing in the brain [5]. Research evidences tell that individuals with ASD have significant sensory-motor
problems [6], [7]. Hence, people with ASD are expected to differ in smooth oculomotor tracking than typical people.

Saccadic motions are rapid eye movements that are made to focus the fovea on an object of interest. One of the main parameters of interest here is the saccade latency. Saccade latency is considered to be the combination of the time needed to process the target stimulus, and the process of the brain to determine ‘when’ to begin a saccade and ‘where’ to locate the saccadic target and a final motor implementation. Whether individuals with ASD have abnormal saccadic eye movement is still a debated issue and there are few contradictions in literature, although stronger evidences prove that people with ASD have atypical saccadic eye movement [8], [9]. This abnormality may deliver important information about the impairment in the cerebellum and cortical areas of the brain [9]. However, due to insufficient number of researches about the saccadic motion of the eye in individuals with ASD, no clear conclusion can be drawn till date. There are very few studies regarding this using other methods but there is almost no study of this using commercial eye tracker. As mentioned earlier, ASD is very diverse and hence visual characteristics of those with ASD are only expected to differ widely. To keep balance, a large number of research are required to be carried out in this field.

The purpose of this research is to carry out a visual behavior analysis between neurotypical children and children with Autism Spectrum Disorder (ASD) and to identify distinct parameters that indicate these dissimilarities. This is done by studying visual data provided by these two groups in two types of analysis tests. The tests consist of smooth pursuit and saccadic eye movement analysis. The atypical visual behavior of children with ASD is likely to spring from their inability to effectively process information that they see. This study is a stepping stone to understanding the visual behavior of children with ASD. An understanding of the difficulties these children experience by those around them can make a big difference to their ability to integrate effectively in the society.

The paper is organized as follows: Section I is an introduction of the work. In Section II, related works on such visual research done using eye trackers are covered. Section III presents the method and Section IV delineates the data analysis. The result is discussed in Section V and finally, Section VI concludes the paper.

II. RELATED WORKS

A. Smooth Pursuit

Even though few studies exist, smooth pursuit eye movement in ASD has not yet been well documented in research literature [10], [11]. One significant paper on smooth pursuit was done by Takarae et al. [12], which compared the pursuit eye movement of 60 individuals with ASD and 94 age, IQ, and gender-matched controls. There were three tasks in this research: a foveo-fugal step-ramp task, a smooth ramp task, and an oscillating task. In all the tasks, participants were asked to keep track of the target. In the first task, targets were displayed at the center and then it moved 3 degrees to the right or started to move smoothly at a constant speed. The second task involved keeping track of a target moving smoothly and the third task required the participants to look at an oscillating target that oscillated back and forth and also accelerated and decelerated. For all cases, the group with ASD showed decreased pursuit gain (ratio of the average velocity of the eye to the velocity of target) in both open-loop and closed-loop pursuit. This study of Takarae was in agreement with the neuroimaging findings that maturation disturbances in the frontal lobe, mainly in the frontal eye field were present in individuals with ASD [13].

B. Saccadic Motion of the eyes

The earliest researches that investigated the fundamental oculomotor functions in ASD, involved the technique of electrooculography (E.O.G). Ronsenhall et al. [9] used this method in his study to study visually guided saccade in 11 children with ASD. The participants were
required to fix their gaze on a light emitting diode whenever it glowed at the center of the screen. 8 of the 11 children with ASD showed reduced saccade accuracy than their control counterparts. This result was inferred to indicate flawed cerebellum vermis. The cerebellum vermis plays a vital role in maintaining a consistent accuracy of saccades and correcting systematic errors in saccade amplitudes [14]. In a second E.O.G study, Minshew, Luna and Sweeney [15] recorded the saccade velocity, latency and accuracy of 26 adolescents with ASD using a visually guided saccade. They found no difference in the latency, velocity and accuracy between the group with ASD and their control peers in the visually guided saccade.

Individuals with ASD exhibit increased differences in saccade velocity, longer saccade latency and inconsistent fixations throughout development [16]. In a study by Pensiero et al. [16], the eye movements of 14 male children with autism and 20 control children were analyzed using a visually guided saccade task. The results showed that typically developing children almost successfully kept track of the stimulus but the group with autism showed poor performance in following the stimulus. Children with autism were also found to show lower levels of attentional engagements in saccadic task related researches [18]. These results are in phase with the abnormal ocular behavior studies that link abnormal saccade in ASD to flawed cerebellar functions. Contradiction to these results about longer latency is also found in the literature [13]. It can be said that there is a considerable amount of discrepancies regarding saccade latency and velocity between individuals with ASD and their control counterparts. This gap in the literature needs to be filled with further researches in this field.

### III. Method

#### A. Participants

A total of 27 children with ASD were considered, of which 18 were male and 9 were female. However, 3 children were excluded from the study due to a complete lack of attention to the screen and hence inadequate data. Therefore, finally, the total number of children was 24 (16 male [mean age: 8 years and 6 months] and 8 female [mean age: 8 years and 9 months]). The age range of the children was between 5 to 12 years (average age: 8 years and ~7 months). They were recruited from an Autism habilitation school. All the children were previously diagnosed by doctors and met the DSM-IV criteria for Autism Spectrum Disorder. This was verified by the school authority as they admit only those who met the DSM-IV criteria (DSM-V now).

For the control group, a total of 24 typically developing children were selected from the local community. The participants were gender-matched with the ASD-affected group, i.e., 16 male (mean age: 8 years 6 months) and 8 female (mean age: 8 years and 10 months). The age range for the TD children was taken between 4 to 11 years (average age: 8 years and ~7 months). These children had no previous record of neurological or mental illness. In total, 48 children participated in the research experiment.

The research was conducted with utmost regards to all ethical issues since it involved dealing with clinical subjects who have been diagnosed with ASD. Ethical clearance was received from the Head of Pediatrics Department and the Director of Dhaka Medical College Hospital. Individual parental permission was also received for each participant.

#### B. Stimuli

The visual experiment that the participants took part in consisted of two parts. Each part contained a test that was developed to analyze the visual behavior difference between the group with ASD and the control group. The same laptop was used to all throughout the research to display the stimuli.

a) **Part I: Smooth Pursuit**
This part consisted of a smooth pursuit test. There were two sections in it. The first section contained a simple background with a boat moving approximately smoothly across the screen. The animation was made using Pivot Animator. There were 27 frames in this animation. The resolution of each frame was 851x480 pixels. Each frame had duration of 400 milliseconds. The total animation was 10.8 seconds long. The frames are shown in Figure 1. The second section contained a similar animation. This time the background was completely noiseless and plain. A car moved across the screen for 6.4 seconds. This animation had 16 frames and each frame had a resolution of 1280x738 pixels and duration of 400 milliseconds. The frames are shown in Figure 2.

**Figure 1:** Frames of the first animation (Smooth pursuit)

**Figure 2:** Frames of the second animation (Smooth pursuit)

b) **Part II: Saccadic Motion**

This part consisted of saccadic motion test. There were two sections in it. The first section investigated predictive saccadic behavior. It contained an animation of a ball that is bouncing across the screen. To make the motion even more predictive and obvious, the path of the ball was shown in dotted lines across the screen. The animation contained 14 frames and each
frame had a resolution of 950x503 pixels. The duration of each frame was 600 milliseconds and the total time of the animation was 8.4 seconds. The frames are shown in Figure 3. The second section studied a non-predictive visual behavior of the control group and the group with ASD. This part contained a very simple animation of a smiley face that appeared on the screen 8 times in a non-predictive and random manner. This animation contained 9 frames and each frame had a resolution of 950x503 pixels and duration of 600 milliseconds. The total animation was 5.4 seconds long. The frames are shown in Figure 4.

C. Experimental Setup and Procedure
The experiment was carried out in a dimly lit room which ensured that distractions would be minimum and the concentration of the child will mostly be on the display screen. The room contained a table where the laptop was set with the Tobii EyeX Controller attached to its LCD display. The chair was set an approximately 60 cm away from the table. To avoid calibration errors, an adjustable chair was used and the participants were directly seated in front of the screen with a zero degree angle between their eyes and the screen. The
participants were accompanied by their parents/ guardians/ teachers all the time if they wished to. The experimenter explained the procedure of the experiment to the child and the guardian. Once it was clear that the guardian and the child understood what he/she was required to do, he/she was seated in the chair ~60cm away from the laptop screen. The experimenter was seated far behind the participant in case they get distracted or feel uncomfortable being in the company of a stranger. The guardian of the child was allowed to be in the vicinity of their sights if they wished to. After the child was comfortably seated in the chair, the process of data collection began with the calibration process. The participant’s posture was adjusted so that the eye tracker can correctly identify his/her eyes. It was a 9 point calibration and if 6 points were correctly viewed out of the 9, then the calibration process was deemed successful. Once the calibration process was done, the experiment began. The participants were required to look at whatever was displayed on the screen. In both the parts, they were asked to follow the object on the screen.

IV. DATA ANALYSIS

The Tobii EyeX Controller was used to record the gaze data of the participants. This device has a data rate of ~60 Hz and can operate at a maximum range of 90cm. However, it does not support internal memory and cannot store raw data. Hence, an open source MATLAB toolkit was used to interface and store the data acquired from the Tobii EyeX Controller [17]. A code was devised to run the tests sequentially and to simultaneously acquire and store the data received. After the data was acquired, it was processed and analyzed using MATLAB.

A. Smooth Pursuit Data

Two methods were used to process the data acquired: (i) area of interest (AOI) and (ii) scanning pattern analysis. In AOI method, an area of interest is predefined and the number of data that fall in that particular defined area is calculated. On the other hand, scanning pattern analysis means analyzing the data to find the areas of the stimulus on which the participant fixated and studying his/ her visual pathways. For the scanning pattern analysis, a code was devised to find the fixation points numbered with respect to time. For example, the first fixation point becomes number 1; the second becomes number 2 and so on (shown in Figure 7 and 8). For analyzing smooth eye pursuit data, closed loop pursuit has been used. This means the gaze pathway of the participant was analyzed to study whether he/she could keep track of the target moving across the screen until it stopped. The gaze fixation points during the smooth pursuit were numbered with respect to time according to the gaze patterns of the participant. The first animation was 10.8 seconds long and the second one was 6.4 seconds long. A measure of the amount of time the participant could keep the target in his/her fovea was given as a percentage of the total screen time. This gives a measure of smooth pursuit accuracy of the particular participant. This accuracy measure is then converted to a percentage value giving an idea of the general attention level of the participants.

B. Saccadic Motion of the Eye Data

As mentioned earlier, the tests used in this research consisted of two types of saccades. The first one was predictable saccade and the second one was unpredictable saccade with random positioning of the target object in each frame of the animation. In this part too, the area of interest (AOI) method was used to calculate the saccade latency for each frame of the animations for both the predictable and unpredictable saccade test. The difference from the first acquired data and first successful gaze data that was positioned on the target was used to calculate the latency. For predictable saccadic motion analysis, the number of frames used in the animation was 13 and latencies were measured for each of them using the AOI method. A minimum threshold target duration was used to determine whether the participant
successfully looked at the target object or not. For saccades that were considered to be successful, the latencies were taken and averaged to obtain the average saccade latency for that particular participant. The same procedure was followed to calculate the latency of the second animation that contained nine frames. A measure of the percentage accuracy of each participant was also calculated using the minimum threshold target duration. This gave us an overall measure and idea about the general attention level of the participants. It was expected that latency of predictable saccade was going to be lower than that of unpredictable saccade.

V. EXPERIMENTAL RESULTS AND ANALYSIS

A. Smooth Pursuit

The smooth pursuit eye movement test showed significant differences between the children with ASD and their control counterparts. Beginning with the first animation accuracy results, it can be seen from Figure 5 that children with ASD performed very poorly compared to the TD (typically developing) children. The TD children had an average percentage accuracy of 89.02% (standard deviation of 9.17) and that of the ones with ASD was 48.79% (standard deviation of 26.02) which is almost half of the former. The accuracy values for TD children ranged from 64.92 to 99.85 percent and that of children with ASD ranged from 15.35% to 91.87%. However, this maximum value of 91.87% was for only one participant and most of the rest values were between 20 to 65%, which was again very low compared to the TD children. The percentage accuracies of the second animation are shown in Figure 6. Even for the second animation, the difference between the average accuracies was significant. The accuracy average for the ASD-affected participants was almost half of that of the TD participants (45.50% with standard deviation of 21.58 and 85.43% with standard deviation of 8.02 respectively). For both animations, the results of the TD children are much less dispersed compared to the ones of the children with ASD. One possible reason that the children with ASD performed well in the first animation was because it was more attractive and vibrant. However, in both Figure 5 and 6, it can be noticed that the fluctuations in the number of data for that of children with ASD are much higher than that of the control children. Even though somewhat erratic, the whole set of data still falls way below that of the data of TD children, indicating poorer smooth pursuit performance.

![Percentage accuracy for the first animation](image_url)

Figure 5: Percentage accuracy for the first animation (data given to the nearest integer)
Figure 6: Percentage accuracy for the second animation (data given to the nearest integer)

Figure 7: Gaze pattern of a participant representing the TD group (red and blue patterns are right and left eye gaze respectively; the numbers are the first, second third and so on fixations)
The gaze patterns shown in Figures 7 and 8 also show significant gaze path differences in the two groups. The gaze pattern for TD children has a pattern that shows that they could follow the moving object but one for the ASD-affected children is extremely random and shows no sign of tracking the moving object whatsoever. Another point that should be noted is that the number of gaze points for the children with ASD was a lot higher than the ones for TD children. This indicates that during the smooth pursuit, a huge number of saccadic eye movements were made by the children with ASD. This can also be a measure of inattentiveness or lack of concentration. In the figures, the red patterns represent the right eye gaze and the blue patterns represent the left eye gaze. The numbers indicate the sequence of gaze, i.e., number 1 represents the first gaze, number 2 the second and so on. Overall, from the results obtained, it is found that smooth pursuit eye movement deficiency is most likely to be a visual characteristic of ASD children.

**B. Saccadic Movement of the Eye**

The saccadic eye movement of the group with ASD was found to be atypical. This result coincides with the previous evidences in the literature [23]. For the predictable saccade animation, the average latency of the ASD group was remarkably higher than that of the TD group. This means that the group with ASD took a longer time to locate the target with their eyes than the control group. The average saccade accuracy percentage was also very low for the group with ASD. It was found to be less than half of that found for the TD group. The percentage accuracy for the TD group was fairly high and their average latency was found to be much less than the ASD group. This indicated that they were able to predict where the object will be moving next and hence had less saccade latency. On the other hand, the ASD group was not that adept at predicting the next position of the object and hence had low accuracy and higher latency.
Figure 9: (a) Average saccadic latency for predictable and unpredictable saccade; (b) Average percentage accuracy for predictable and unpredictable saccade.

The saccade latency for the unpredictable saccadic motion was found to be higher than the predictable one for both groups. This was expected because there was no way to know where the target will appear next. Here too, the average latency for the ASD group was much higher than that for the TD group but the difference in latency was less than that for the predictable saccadic motion. The percentage average difference was also found to be lower than that for the predictable saccadic motion. Here too, the difference between the latency of ASD and TD group was large with TD group having the lower value. The average latency and saccade accuracy for both the predictable and unpredictable saccade are given in Figures 9(a) and 9(b) respectively.

VI. CONCLUSIONS

The research carried out a visual behavior analysis between children with ASD and TD children. The study consisted of two areas of oculomotor analysis: smooth pursuit and saccadic motion of the eyes. The results found indicated that children with ASD differ a lot in these two areas compared to their control counterparts. It found that children with ASD perform relatively poorly in smooth pursuit and saccadic eye motion tasks. Previous neuro-imaging studies on eye movements of individuals with ASD show similar results and it has been inferred that this might be a result of flawed cerebellum and motor functions of the brain that are vital to maintaining these oculomotor functions [5], [6], [7], [8], [9]. The visual behavior analyses between children with ASD and TD children exhibited results that are open to interpretations and are in parallel with previous findings.

There are many scopes for future work in this field of study. Firstly, the same research can be further revised with different stimuli to see how much of the result varies or stays same based on the usage of different stimuli. Such atypical behavior of children with ASD is suspected to be a product of flawed cerebellum and motor functions. To investigate the truth in this, it is important that future researches be carried out by integrating brain imaging, behavioral and eye-tracking technology. This might give a fuller and clearer picture of data and aid in the deeper understanding of the atypical visual behavior of the individuals with
ASD. Autism Spectrum Disorder is a condition that has multifarious problems under its umbrella and to effectively understand this complex situation, an equal proportion of researches must be carried out.

Acknowledgements
The authors would like to convey their gratitude to the Director and the Head of Pediatrics Department of Dhaka Medical College Hospital for providing ethical clearance to carry out the research. Special thanks to the Autism Spectrum School that allowed us to approach their students and also to each and every parents/guardian of the participants for letting their children take part in the research. Authors thank the Center for Natural Science & Engineering Research (CNSER) for her support.

REFERENCES


**Competing Interest:** The authors declare that they have no competing interests.

**Ethical Clearance:** The Director and the Head of Pediatrics Department, Dhaka Medical College Hospital has provided the Ethical Clearance to carry out the research. The Head of the Autism Spectrum School, Dhaka, Bangladesh has allowed the official approval to undergo the research upon the approval of concerned partners.