An Eye Tracking Study of the Visual Behavior of Children in Social Interaction

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Abstract— **The paper presents an eye tracking analysis study to help us understand the visual behavior and pattern of normal developing children and autistic children while viewing a socially rich stimulus consisting of human and social interactions, as well as the factors that influence their behavior. Eye tracking is a technology that allows the assessment of one's spontaneous visual attention and eye gaze preference and pattern. An eye tracking experiment consists of displaying different images with social stimuli (containing human faces) to the child. The eye tracker captures and tracks the child's eye gaze movements, then analyzes the data to identify where specifically in the stimulus is the child looking at. Sixty-four participants (normal and autistic) were divided into two groups. The participants were asked to view a socially rich information stimulus for a limited and set time. Based on the data analysis conducted in the study, the findings show a significant difference between the two groups viewing patterns and behavior when the subjects were presented with a scene included material with human and social interaction content. The study also reveals that a large percentage of autistic participants expressed minimum interest and time looking at the face area, evident by a significant time spent fixating on non-face regions. This is linked to a lack of interest in socially relevant information, especially the two small areas of interest which are the eyes and the mouth regions, when compared to the normal developing children. The results can be used to help improve the life style of other children who have a potential to develop autism as well as discover earlier signs of autism spectrum disorder.**

Keywords- Autism Spectrum Disorder; Eye Tracking; Socially relevant information; Visual behavior.

I. INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition defined by impairments in reciprocal social-emotional interaction and non-verbal communication, alongside with restrictive/repetitive patterns of behavior [1]. Research shows that early diagnosis of ASD enhances the possibility of improving psychosocial functioning in the following developmental years. Furthermore, recent experiments have proved that eye movements and reactions to verbal/visual cues can be used to identify signs of ASD, through an eye tracking software, allowing an early diagnosis.

An eye-tracker is a software system that allows the assessment of one's spontaneous attention and eye gaze preference [2]. In other words, it tracks and captures what the users are looking at. One of the most common signs of ASD is the specific patterns of eye movements and reactions to verbal and non-verbal cues. That is why, in the recent years, many medical researchers turned to eye tracking techniques, as they have the potential to characterize ASD non-invasively and does not require advanced motor responses or language when studying young children and infants [3]-[8].

This research aims to utilize the eye tracking technology combining different stimuli (pictures, films, interpersonal and social interactions) and enlarging computational and analytical capabilities in terms of results – i.e. gaze readings and plots, heat maps, bee swarm. In collaboration with Dubai Autism Centre and other UAE national autism related centers, we have used eye tracking technology in an experimental group and in a control group, aiming to significantly contribute to early ASD diagnosis in UAE and worldwide. The findings may be used to help improve the life of other children who have a potential to develop autism. Furthermore, the research will aid in an earlier diagnosis through an experiment that involves analysis of a child's gaze with an eye-tracker system. The paper is organized as follows: Section 1 presents a broad overview of previous research studies related to ASD and eye tracking technology; Section 2 describes the research motivation and objectives, Section 3 outlines the research methodology; Section 4 presents the data analysis and results; Section 5 discusses the results and findings; and Section 6 presents the conclusion and future work.

II. RELATED WORK

ASD is a neurodevelopmental condition characterized by impaired social interaction, problems with verbal and non-verbal communication, unusual, repetitive, or severely limited activities and interests [9]. The number of children being diagnosed with ASD in the US has risen by 23% since 2009, with one in 88 children affected, according to a report from the US Centre for Disease Control and Prevention [9].

The number of children with ASD in the UK has also risen by twelve-fold in the past 30 years and may be 50% higher than previously suspected, according to a report by the Autism Research Centre at Cambridge University [2]. In the UAE, the head of the community service unit, Dubai Autism Centre [10][11] reported that the UAE is heading in the same direction and autism is on the rise. She also

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mentioned that Dubai and Abu-Dhabi centers are not coping with the large numbers and several hundreds of patients are on waiting lists. Symptoms are present since early childhood, but the complex nature of this disorder, coupled with a lack of biologic markers for diagnosis and changes in clinical definitions over time, create challenges in monitoring the prevalence of ASD. Furthermore, the evaluation of symptoms involves a multi-disciplinary team of doctors including a pediatrician, a psychologist, a speech and language pathologist, and an occupational therapist.

Fortunately, it is widely reported that early detection is essential for early treatment and symptoms' control and that is why, in recent years, a large number of medical researchers are investigating early symptoms of autism [12][13]. However, most of the research undertaken by medical researchers were not comprehensive, considering only a few aspects of the problem and did not go into deep computational analysis of the data and videotapes recorded on the behavior of early aged children who were later diagnosed with autism. Eye tracking research plays a key role in understanding how individuals view and perceive the world around them. The scientific study of human eye movements provides an insight into the cognitive thought processes and has been established in research domains such as developmental psychology, psycholinguistics, reading research and HCI [14].

Eye tracking is an advanced technology that uses high precision to measure exactly where a user is looking and for how long. It is used to study the relationships between eye movement data and cognitive activity of the user. Frequency of fixations and duration of fixations are two important factors used to decide different aspects of the quality of screen contents. Eye movements are tracked and classified using various significant indicators of ocular behaviors, namely fixations, saccades, pupil dilation, and scan paths [9]. Eye fixations are considered the most relevant indicator for evaluating information acquisition and processing in online search and visualization environment [15]. Fixations are defined as spatially stable gaze which last for approximately 200-300 milliseconds during which visual attention is directed to a specific area of content display [16].

III. RESEARCH OBJECTIVES

Eye tracking technology has been used in many autism studies [4]-[8]. The research in [8] found no differences between gaze behaviors of children with autism and their age and IQ-matched typically developing peers when viewing cartoon like scenes that include a human figure. The research in [4]-[6] contradicted with [7] result as both research studies reported that individuals with autism fixated less on the eye region and more on the mouth, body, and object regions than individuals in the comparison group.

The aim of our research is to exploit the eye tracking technology by analyzing and comparing autistic and normal developing children gaze patterns while viewing a human and social interaction rich material. We have used and combined different stimuli with four still images, each one involving a human and social interaction situation including children and adults, both male and female. The eye tracking technology has significantly improved over the last decade. Our research subjects are based in the Gulf Area and they are a mixture of Emirati and expatriate children. The purpose of this paper is to present the initial study findings and compare it with the previous studies. We have used four different social scenes (each has socially relevant information and human interaction). The long term objective of the project is to design and develop an eye-tracker-based computing model that aims to contribute to early ASD diagnosis. The immediate aim of this research is to address the following research questions:

- How do autistic children (AC) and normal developing children (NDC) eye movement visual patterns differ when processing human faces in a socially rich context?
- What is the first area of the face for the eye gaze fixation of AC and NDC that grab their attention when presented with human and social interaction image situation?
- How fast (fixation time) NDC and AC groups spot the face region?
- Are areas of interest in fixating gaze different between NDC and AC (eye, mouth, ears, body, and off zones)?
- Within the AC group, what are the preferred areas of fixation on a face/person? (duration time).

IV. STUDY DESIGN AND METHODOLOGY

A. Participants

Sixty-five children (34 autistic children and 31 normal developing children) participated in this study. The average age of participants was eight years old (max=16 and min = 4). The gender representation is (73%) females and (27%) males. The participants come from different groups, Expatriates (60%) and Emirati nationals (40%) and come from families with different ethnic background and various social and economic classes.

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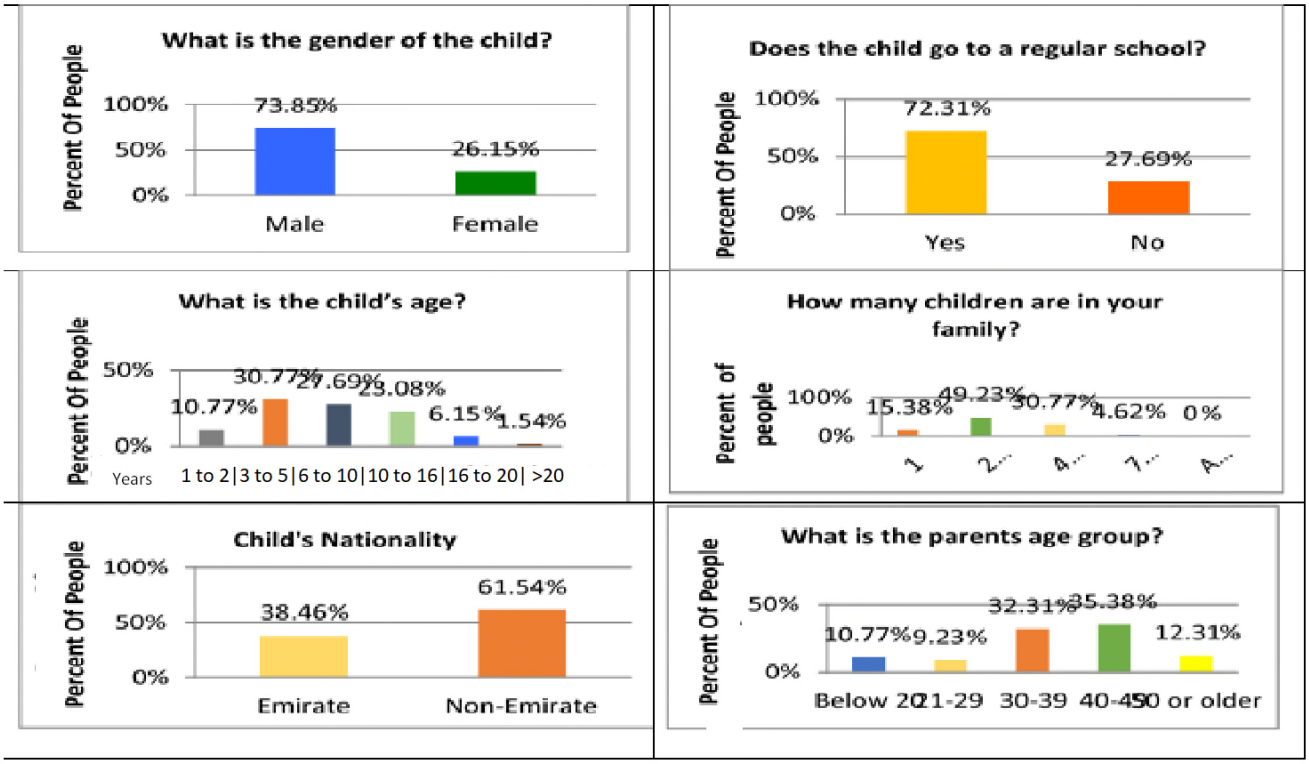

Figure 1. Participants' demographic information and background.

In terms of schooling system, 72% go to a regular school (inclusive education system) and (28%) go to special needs schools. Most participants (80%) come from small to mid-size families, almost (70%) of children parents' age between 30 to 50 years old. Participants were selected from three different Emirates: Dubai, Sharjah and Abu Dhabi. All participants' parents signed a consent form stating the purpose of the study, risks involved, confidentiality and their rights as study participants. See Figure 1 for the details of the participants' demographic and background information.

B. *Materials and Tasks*

An eye tracking experiment was designed using a Tobii studio environment which consists of a stimulus with four still images each one involving a human and social interaction situations including children and adults and both male and female, as represented in Figure 2. The focus of this research was to study and analyze the eye gaze pattern and visual behavior of autistic and normal developing children while viewing these images. On each image, we created three areas of interest (AOIs) namely: full human face, mouth and eyes, which are the focus of human, and social interactions.

C. *Procedure*

The experiment started with the moderator explaining the main purpose of the study. An unobtrusive eye-tracking mobile technology and system was used in the experiment,

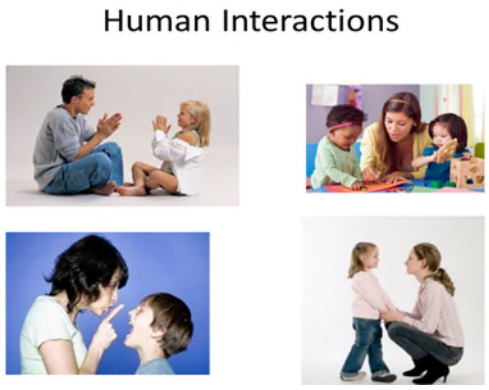

Figure 2. A stimulus involves human and social interaction.

mobile Tobi X2 model, to collect the eye movement data of the children participants. The mobile eye tracker provides the researchers with the flexibility to set up the experiment anywhere off campus, such as homes, schools, and special needs centers to meet the situational needs of the children participants. The eye tracker was calibrated for each participant by the test moderator before the test and collected data covering all the tasks during the experiment, as demonstrated by Figure 3. The experiment consisted of three sections. The three sections of the experiment and type of data collected from each section are outlined and described in Table I. Due to space limitations, this paper will discuss the results from Test 1 only.

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TABLE I. COLLECTION OF TESTS USED IN THE STUDY

Sections	Instrument used for data collection
Test 1	Eye tracking test to collect quantitative data while viewing tasks in a sequence of static colored stimuli created by authors
Test 2	Eye tracking test to collect quantitative data while viewing a sequence of 28 static black and white stimuli used in a previous research study in UK
Test 3	Eye tracking test to collect quantitative data while viewing a sequence of static black and white dynamic stimuli used in a previous research study in the US. Each stimulus expressed a different emotion, followed by a question to determine the type of emotion presented in the motion stimulus
Post -test Questionnaire	To collect qualitative data on the participants' demographics, social status and their physical conditions

Studio software version 3.6 was used to record all eye tracking data for later data visualization and data analysis. This experiment requires the participants to look at a picture (face, banana, football and tomato). During this time, the eye tracker will trace the child's eye gaze, analyzing where specifically the child looks at in the picture. As so, the child only needs to be seated at the computer looking at the different pictures (and can be accompanied by a parent if necessary). The length of the experiment will take approximately between 20 to 30 minutes. For each test, the participant must also complete an eye tracking calibration, so a total of 3 calibrations per experiment/participant are needed.

Figure 3. Experiment environment.

The experiment was conducted in a controlled environment as throughout the study. The participants had control of their environment, allowing them to click and to continue to the next stimulus. Once the test session was completed, the participants were thanked for their participation. At the end of the 3rd test, the parents of the participants were asked to answer 12 demographic, social, financial, educational level, and physical health status questions related to them and their child (questions are not discussed in this paper). For convenience, the questions were presented on the screen in both languages Arabic and English, whereby parents choose their preferred language. The experiment was conducted and eye tracking data were collect between November 2016 and September 2016.

V. DATA ANALYSIS AND DISCUSSION

In this section, we analyze and discuss the visual behavior of autistic and normal developing children when the stimulus contains four still images each one involving a human and social interaction situation including children and adults and both males and females (see Fig 1.). We will discuss and analyze the gaze behavior when the stimulus contained all images. We will then discuss the gaze behavior when the stimulus contained the human's face only. Within the human's face, we have defined three areas of interest (AOI) which includes the full face, face-eyes and face-mouth. Various metrics are used to analyze the difference in the behaviors between the two groups. As mentioned before, we refer to Autistic Participants as AP and Normal Developing Participants as NDC. The collected eye tracking data were analyzed using three data analysis and visualization tools to understand and describe the children's visual and eye gaze behavior.

A. Eye Gaze Analysis

The analysis of eye gaze behavior has been used in this research. Gaze plots showing location, order, time spent looking (fixation time) at different areas (zones) on the stimulus are mostly used for a single eye tracking participant looking at a fixed and dynamic content. It contains a sequence of numbered circles, each one representing a point that the children's eyes fixated on; the larger the circle, the longer the fixation. The numbers represent the order in which children look at various items (areas) on the stimulus that involves human and social interaction used to study. Social interaction stimulus consists of mainly human faces, marked by the two most important areas, namely mouth and eyes. Eye gaze indicates the level of visual activity taking place on certain areas, especially the face area which is the focus of the human and social interaction. It is assumed that more visual activity means higher interest and less visual activity indicates less interest in the content.

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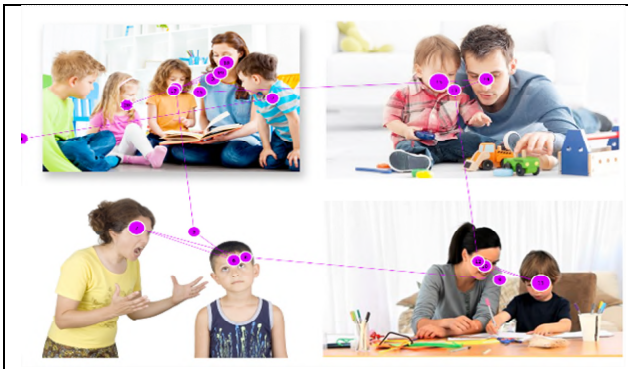
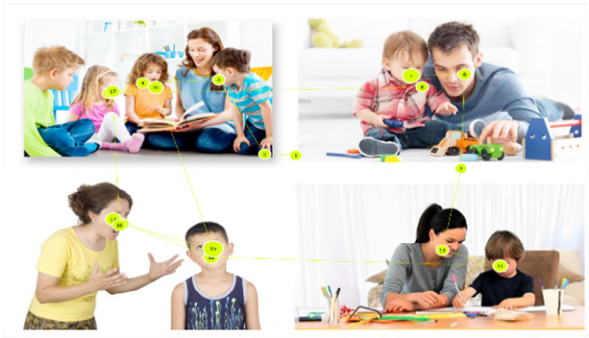


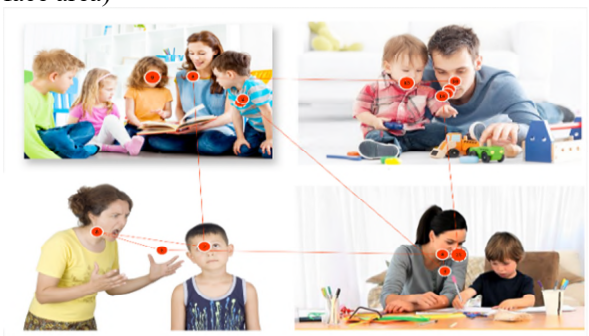
Intensive visual attention (20 fixations most of them on face area)

Low visual attention (2 out of 10 fixations on face area)



Moderate visual attention (14 out of 18 fixations on face area)

Extremely low visual attention (1 out of 10 fixations on face area)



Low visual behavior (9 fixations on face area)

No visual attention (0 out of 15 fixations on face area)

Figures 4a and 4b. Eye gaze behavior for normal developing children group vs. autistic children group.

An interesting result has been revealed from the scenes that involve human and social interactions between two or more individuals, including children. It was clear that more visual activity and eye gaze fixations are on areas that are relevant to human interaction, such as the face represented by the eyes and mouths. Normal developing children expressed very high interest in looking and spending more fixation time at the human face, which is the core element for human social interaction. Even within the normal group, there were different levels of fixation intensity on the face area. It ranged from highly intensive fixation, which demonstrated strong interest, to minimum fixation, which indicated low interest in social interaction, as depicted in Figures 4a and 4b. On the other hand, Autistic children have expressed minimal interest in looking at the human face as a result have much lower fixations with extremely no fixations, as indicated by the Figures 4a and 4b. The interest was measured in how many fixation points resulted from the eye gaze behavior spent looking at various images involving human and social interaction. It is worth noting that this pattern of visual attention is evident in all four images

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regardless of ages and genders of the persons in the picture. The results indicate that autistic children avoid looking at the human faces, including mouth and eyes.

B. *Heat Maps Analysis*

Heat maps show how the viewing and looking is distributed over the given stimulus. Heat maps are a visualization tool that can effectively reveal the focus (hot spots) of visual attention and viewing behavior for a group of participants. Children's visual attention to socially relevant information stimulus can be represented with heat maps. Four heat maps are presented for each group, see Figures 5a and 5b. Figures 5a and 5b show the heatmap analysis with the hot spot and fixation areas and patterns on the social interaction stimulus for the Normal Developing group and Autistic group. There are 11 different human faces presented on the social stimulus, which include 3 girl faces, 4 boy faces, one man face and 3 women faces.

The heat maps show that the two boy faces looking sideways did not receive any visual attention from both groups. A close look at the heat maps in Figure 5a shows what areas of the stimulus attracted children's attention during the entire time that they viewed the content. The results in Figure 5a reveal that the Normal Developing Children group was more visually engaged (they tended to spend more time looking at the eyes) with the social content, especially at the human faces compared to the Autistic group. The finding indicates that the majority of ND children focused their visual attention on the eyes of the human face. Figure 5b exhibits more fixation activities on areas away from the faces. Autistic children tended to spend more time looking at areas other than the eye regions. This visual behavior demonstrate that autistic children lack interest in looking at socially relevant information represented by the human eyes, evident by the time spent fixating mostly on the mouth region.

Figure 5a. Heat maps of visual attention for the NDC group.

Figure 5b. Heat maps of visual attention for AC group.

C. *Descriptive Statistical Data Analysis*

Eye movement analysis was conducted in the study to analyze the children's visual attention. The average total viewing time (fixation duration) and the average number of fixations in each social image were calculated and compared across the two groups. Statistical analysis tools using AOIs and various metrics data, like time for first fixation, no. of fixations, fixation duration on specific content area, no. of visits, etc. were used to measure the child dwelling time and decision-making behavior activities. To quantify visual fixations, four regions of interest (eye, mouth, face and non-face) were created. The areas of interest (AOIs) were defined on the stimulus and include all human faces for all people shown on the human and social interaction image. For this research, we use five different metrics. The types of metrics and their meaning and description are outlined in Table II.

A minimal difference was found in the time taken by the AC and NDC groups to have their first fixation on all human face regions. The average mean time for the first fixation looking at any of the faces, all combined for the AC group

TABLE II. LIST OF METRICS USED IN THE STATISTICAL ANALYSIS.

Metric name	Meaning/Description
Time to First Fixation	This metric measure how long it takes before a participant fixates on an AOI or object for the first time.
Total Fixation Duration Mean	This metric measures the sum of the duration for all fixations within an AOI or object
Visit Counts Mean	A visit is defined as the time interval between the first fixation on the active AOI and the end of the last fixation within the same active AOI (Area of Interest)
Total Visits Duration Mean	Total visit duration is defined as the sum of visit durations of an active AOI
Percentage Fixated Mean	This metric measures the number of recordings in which participants have fixated at least once within the AOI and expresses it as a fraction of the total number of recordings

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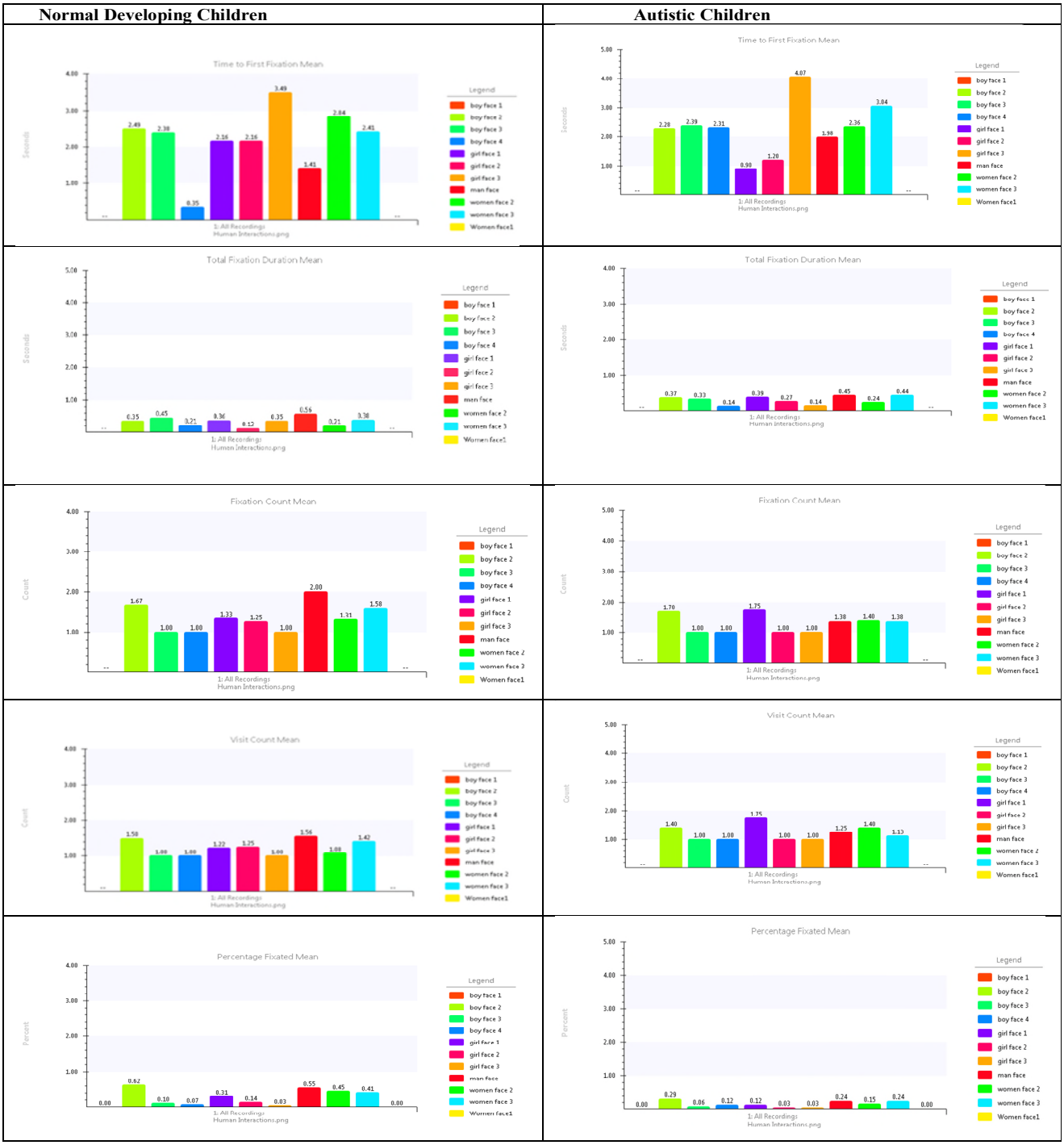

Figures 6a and 6b. Metrics analysis for normal developing children group vs. autistic children group.

was 2.28 sec whilst it was 2.15 sec for the NDC group. It indicates that, on average, there was an 0.13 second delay in the first fixation by the AP group. Another interesting observation, the first face among the 11 faces that grabbed the attention of the NDC group was a boy face with 0.35 sec. mean time to first fixation, while the AP group got fixated first at a girl face with average of first fixation time 0.90 sec (see Figures 6a and 6b). It means that there are more boys in the NDC group than the AP and vice versa. Another area of minimal difference is that the NDC group expressed slightly more interest in looking at all faces combined than the AC group, as demonstrated by the mean total fixation duration time 0.34 sec vs. 0.30 sec (Figures 6a and 6b).

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In addition, the NDC group made on average more fixations on human faces compared to the AC group. The average fixation counts were 1.34 fixations for the NDC group vs. 1.28 for the AC group (see Figures 5a and 5b). These results support the fact that NDC children expressed more interest in looking at human faces than the AC children, within a social context. The number of visits to human face AOIs were also analyzed. The results show no significant difference in the average of visits counts on all faces for both groups, with an average of 1.22 visits for NDC and 1.21 visits for AC children. The percentage of participants of both groups who had at least one fixation within the faces regions were also analyzed. A significant difference was noticed between the two groups. The results show that 30% of the NDC children got fixated at least once on one of the human faces comparing to only 14% of the AC children (see Figures 5a and 5b). This indicates that even though there is a small difference in average fixations duration on human faces combined between the two groups, the interest among the NDC group is almost twice that of the AC group. It also means that a large percentage of the AC children were not attracted and did not pay any attention to the human faces in the social stimulus, and that is linked to a lack of interest in socially relevant information, especially the face and, more specifically, the eyes.

V. CONCLUSION

The paper presents a research analysis study using eye tracking technology in ASD diagnosis which, is the first of its kind in the region. The aim of the study was to help us understand the visual behavior and pattern of Normal Developing children and Autistic children while viewing a static social stimulus consisting of human and social interaction. Eye tracking was employed to record children's visual attention. An eye tracking experiment was designed and conducted using social interaction content (human faces) to collect an eye tracking data on children's visual behavior. Sixty-four participants (normal and autistic) were divided into two groups. The participants were asked to view a static stimulus for a limited and set time.

Based on the data analysis conducted in the study, the finding shows a significant difference between the two groups (NDC vs. AC) viewing patterns and behavior when presented with a situation including material with human and social interaction content. The study reveals that a large percentage of autistic participants expressed minimum interest and time viewing the face area, especially the two Areas of Interests (AOIs) eyes and mouth regions comparing to the normal developing children. The findings revealed a significant difference between the two groups which is in line with the research results found in [4][6]. Autistic children fixate less on eyes (strong tendency to avoid fixation on the eyes) and expressed more interest in looking at the mouth than the normal developing children. The finding of this study is in line with the majority of international eye tracking studies indicating that individuals with ASD exhibited decreased visual attention to social stimuli relative to NDC. The results also provide quantitative assessment of how children with potential ASD process facial regions information when presented with socially rich context.

The study also provided practical evidences with respect to the speed of human face visual scanning and recognition. It appears that autistic children need more time to recognize and process facial and social information compared to normal developing children. The findings can be used to help improve the life style of other children who have a potential to develop autism as well as earlier ASD diagnosis. As future research, the results from the study can be used to develop an eye tracking-based framework to assist specialists to look for some early signs of potential children with ASD. As a future work, it would be worth pursuing to include other facial expression data such as human emotions in the data collection and analysis to investigate their impact on the children's' visual behavioral patterns in a social context that were not addressed by this study.

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