

A Game-Based Eye Tracking Approach To Measuring Interaction Levels In Children With Autism

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ABSTRACT - This study aims to analyze autism games have been used to facilitate the development of the interaction of children with autism, particularly with regard to emotions. However, these games are unable to gauge how the interaction improves as the player progresses to higher levels. Through the recording of pupil movements, computer technology is able to measure the interaction level of children with autism with accuracy. The game application proposed in this study uses pupil positions and movements to see how well children with autism interact. The method used in this study presents the results of experiments with ten children with autism and ten children without autism. For both groups, we used statistical descriptions to analyze the resulting pupil positions. Two descriptive analyses were performed: a comparison of pupil position modes between children with autism and children without autism from 1 to 120 seconds; and a comparison of pupil positions between children with autism and children without autism from frame one. The results of the experiment showed that children with autism were encouraged to interact using video games. Their pupil movements were measured while playing the games. During the interaction, children with autism had inconsistent pupil movement patterns, while the control group, consisting of children without autism, showed consistent pupil movement patterns. Then the other results show, first, that the TFA application provides pupil position patterns that are highly suitable as a biomarker for measuring the interaction level of children with autism. Second, further research is needed to implement therapies for children with autism to improve their interaction levels based on these measurements. Third, most of the research was conducted using data for level 2 autism ("requires substantial support") so that in the future research may be conducted to further develop the application for level 3 autism ("requires very substantial support"). The conclusion of this study showed that children with and without autism have pupil movement patterns that remain within certain areas. Based on these areas, the severity of autism in children with autism is level 2 (moderate) according to DSM-5, making it possible to divide this level into three sub-levels: low-moderate, moderate-moderate, and high-moderate. **Keyword** - Autism, Eye Pupils, Games, Interaction.

I. INTRODUCTION

The capture of spontaneous facial expressions of children with autism can be performed to detect autism spectrum disorder (ASD) behaviors [1]. The framework proposed in [2] was used to measure the level of impairment of children with autism in terms of social response and engagement. In this framework, the eye movements of children with autism are assessed using three analyses: free viewing, emotion recognition, and comparison of eyebrow and mouth width. Furthermore, the pupil responses of children with autism can be used as an index of emotional reactivity [3]. Gaze patterns have been used to evaluate the social and cognitive functions of children with autism while playing serious games [4]. Assessment of social attention and emotion recognition in children with autism has been done using eye tracking, facial scanning and pupillometry [5].

The present study proposes a method for measuring interaction levels of children with autism by recording eye pupil movements. Eye tracking was used to assess children with autism while playing games. This paper consists of several sections. Section 2 provides a background review, highlighting ASD and the potential use of pupil movements in studying children with autism. Section 3 describes the experimental setup, the human study protocol that was applied, and the proposed framework for coding and analyzing pupil movement data from children with autism. Section 4 presents the experimental results, while Section 5 discusses the findings in the context of typical ASD characteristics. Section 6 concludes the study.

II. BACKGROUND REVIEW

Disorders in children with autism often last for a lifetime [6]. The condition is generally characterized by impaired social interaction. One of the characteristics of children with autism is their difficulty to maintain

eye contact [7]. Researchers have used eye-tracking systems to measure eye position, eye movement, and pupil size in children with autism to identify areas of interest [8].

II.1. PUPIL MOVEMENT

Computer technology can automatically track the movement of eye pupils. This technique was used in [3] to explore conscious and unconscious emotional reactivity in children with autism. The experiment calibrated the eye movements of children with autism using the Tobii Studio eye-tracking platform with five built-in points. Children with autism passively viewed images, interspersed with stimuli to maintain attention. Another study conducted eye tracking with the aim of distinguishing between clinical groups in terms of social attention and emotion recognition using facial scanning and pupillometry [6]. The stimuli consisted of twelve color photographs of adult faces (equal number of males and females), each showing a calm, excited, or fearful facial expression. Pupil movements in children with autism increased relatively more with happy faces than in the typically developing (TD) group. Eye tracking was administered to all participants to assess changes in pupil movement when viewing facial expressions. The eye-tracking data were collected using Tobii. Eye-tracking sampling was done with infrared T120 at a rate of 120 Hz to record the X and Y coordinates of eye position and pupil diameter.

II.2. COMPUTER VISION AND ASD RESEARCH

Children with autism exhibit deficiencies in social interaction [9]. For example, a hallmark of ASD is difficulty in maintaining eye contact [7]. In view of this, eye-tracking technology has become popular for supporting autism research and analysis. This can help psychologists to obtain a correct diagnosis of children with autism, so that they can receive immediate treatment and care.

Many approaches to engage children with autism are based on fun interactions and games, such as games and puzzles, which may have a positive impact [10]. Interactive technology can assist the education of children with autism by enhancing learning experiences and reducing the need for ongoing assistance.

Previously, technology has also played a role in capturing pupil positions [11]. Eye tracking is the process of tracking an individual's eyes to determine their exact position while searching for a target object, as well as the duration of the search [8]. The eye tracking system measures eye position, movement, and pupil size at any given time to detect the user's area of interest. A camera records pupil samples generated from the gaze and the position of the detected marker.

Gaze-generated pupil samples have also been used to detect autism in children [10]. Based on the evaluation results, the technique used provided average gaze estimation accuracy with a visual angle of 0.6° (precision 0.08 degrees) and a pipeline latency of only 0.045 seconds. The software used comprises two primary components: the pupil catcher and the pupil player. The pupil catcher runs in real time to capture and process images from two (or more) video cameras. The pupil player replays the video and gaze data recorded by the pupil catcher.

Researchers have used infants' pupil dilation responses to direct speech, the sound of running water, and other sounds they frequently hear in daily life to detect autism [12]. Infants diagnosed with autism exhibit greater pupil dilation when listening to nonsocial sounds. On a trial-by-trial basis across all conditions and groups, infants with autism experienced more pupil dilation. This data was collected using the Tobii 1750 and Tobii TX300 eye trackers. The study showed that infants with autism respond to nonsocial sounds with greater alertness compared to infants without autism.

II.3. CONTRIBUTIONS

This study proposes a model for assessing the interaction level of children with autism using pupil movement measurement and game media. Current eye-tracking systems can measure eye position, movement, and pupil size to detect areas of interest [8]. We developed a system for automatically measuring the level of interaction in children with autism based on pupil movement, which we call the Tracking for Autism (TFA) game application. The game media uses several categories of subjects, such as music, animals, electronics, atmosphere, and cartoons. Interaction stimulus preferences, such as music, expressions, objects, colors, and intonation, are used to provide motivational effects during task completion.

In the experiment, we investigated the level of focus in children with autism during the execution of a task while using the TFA game application. The participants took a series of tests to determine their level of focus by measuring the movement of their pupils. This process was automated using the eye-tracking system of the proposed application. To the best of our knowledge, this is the first study to use eye tracking to measure interaction levels and to conduct therapy in children with autism.

III. EXPERIMENTAL DESIGN AND STUDY PROTOCOL

The development of the application involved several autism experts and therapists with at least twenty years of experience. The AGCA Center is a school for children with autism, located in the city of Surabaya, Indonesia. It has many therapists, both female and male, who help with the education of children with autism. The AGCA Center has approved the protocol for collecting and analyzing pupil data from children with autism used in this study. The section below describes the protocol and the experimental design.

III.1. PARTICIPANTS

The study invited children with autism at random levels for participation, finally recruiting ten children with autism and ten school-aged children without autism aged between 3 and 13 years [7]. The group of twenty test subjects in total comprised ten male and ten female participants. They and their parents completed a consent process that briefly outlined the purpose and tasks of the study. The AGCA Center confirmed each patient's ASD based on the Autism Diagnostic Observation Schedule (ADOS) [1]. The task proposed in this study required each participant to respond to the given stimuli.

According to DSM-5 (Diagnostic and Statistical Manual of Mental Disorders), autism spectrum disorder (ASD) can be divided into three levels of severity: level 1 ("requiring support"), level 2 ("requiring substantial support"), and level 3 ("requiring very substantial support") [13]. These levels of severity are based on the amount of support a person needs in their daily life related to social interaction, communication, and repetitive behaviors. For example, people with level 2 ASD require substantial support with social interaction, communication, and/or repetitive behaviors. They may have difficulty with some aspects of daily life but can still function independently in some situations. Early diagnosis and implementation of an appropriate therapy for patients with affective and cognitive deficits can accelerate the healing process [14]. All children with autism tested in the experiment were in the range of DSM-5 level 2 (moderate) autism.

III.2. GAME SETTING

Based on our preliminary work, we used the following steps to assess the level of autism in children:

- a. Randomly selection of children with autism without knowing their category of severity.
- b. Each child with autism was given instructions to watch a video on a laptop.
- c. The eye movements of the children were recorded using the eye tracking system in the TFA game application on the laptop.
- d. The researchers or therapists broadcasted the eye tracking measurements to another computer in real time.

The TFA application uses an eye tracking system and installed games. We chose games because they can enhance social interaction in children with autism [15]. Figure 1 shows one of the participants seated on an adjustable chair facing the laptop screen.

The measurement results for children with autism are in the form of numbers (0, 1, 2, 3, 4, 5, 6, 7). The pupil movement measurement uses X and Y coordinate points, as shown in Figure 2. The X and Y coordinates can also be used to measure the pupil diameter [6]. Here, the pupil diameter was measured using Tobii eye tracking.



FIGURE 1. A participant seated facing the laptop with the TFA game application.

Figure 1 illustrates a child with autism participating in the research activity, seated on an adjustable chair and facing a laptop screen running the TFA game application. The child follows the given instructions by focusing attention on the visual content displayed on the laptop screen. The laptop serves as the primary medium for presenting videos and games integrated with an eye-tracking system. During the activity, the child's eye and pupil movements are automatically recorded by the eye-tracking system to capture X and Y

coordinate data as well as information related to pupil diameter. The seating position and viewing distance between the child and the laptop screen are carefully adjusted to ensure optimal and consistent eye movement recording. This figure represents the actual experimental setup, in which the child interacts naturally with a computer-based game while researchers or therapists monitor and record the child's visual responses as part of the autism level assessment process.

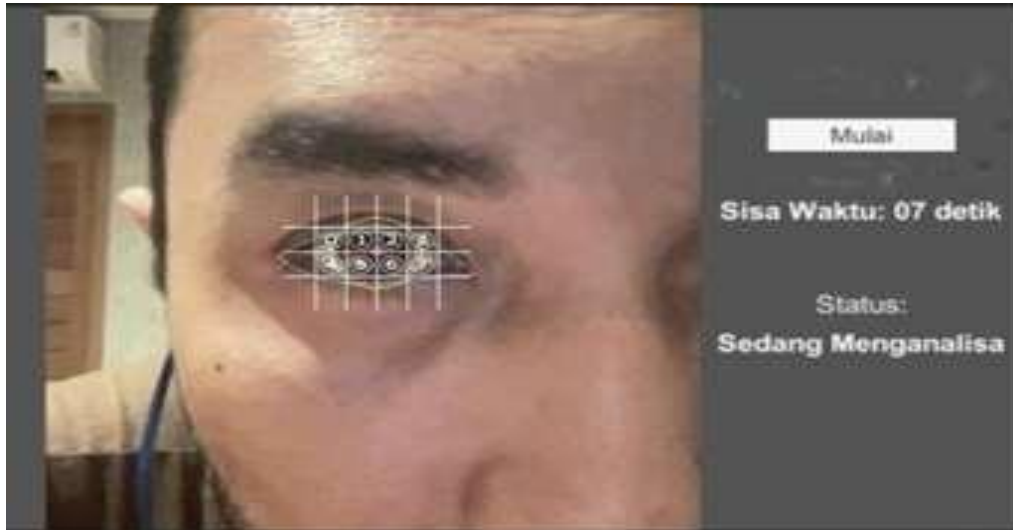


FIGURE 2. Interaction-level measurement design based on pupil movements.

Figure 2 shows the interface of the eye-tracking system used to record and analyze the participant's eye movements. The image displays the eye region overlaid with a grid that serves as a reference for X and Y coordinates. This grid is used to detect gaze direction, fixation points, and detailed pupil movements during the measurement process. On the right side of the screen, system information is displayed, including the "Start" button, the remaining measurement time indicated by "Remaining Time: 07 seconds", and the status "Analyzing", which signifies that the system is performing real-time data analysis. This information assists researchers or therapists in monitoring the duration and condition of the measurement session. This figure 2 represents the technical process of eye-tracking data acquisition, in which pupil movements are automatically recorded and processed by the system to generate numerical data and visual coordinates for subsequent analysis in assessing autism levels.

Figure 3 shows how the pupil movement is categorized by TFA using a diagram with 8 pupil positions. These positions were determined using gradient detection and threshold segmentation in the pupil region of interest, with the reflections recovered directly [16]. We used the centroid method to more precisely calculate the center coordinates.

The diagram with four columns and two rows is based on the more frequent and wider eye movements of children with autism. This categorization was supported by a therapist for children with autism who serves as the AGCA Center's coordinator and has worked with children with autism for twenty years. We conducted an evaluation of children with autism to determine their ability to maintain eye contact and maintain a straight gaze.



FIGURE 3. Template showing different positions for measuring pupil movement.

Figure 3 illustrates the division of the screen into eight distinct areas labeled from 0 to 7. Each number represents an *Area of Interest* (AOI) used in the eye-tracking analysis process. This screen segmentation is designed to identify and classify the direction of gaze and the visual focus points of participants while interacting with the displayed video or game application. Each AOI serves as an indicator of gaze position based on the X and Y coordinates obtained from the eye-tracking system. When the participant's gaze is detected within a specific area, the system records the corresponding numerical value. These numerical data are then used as inputs for further analysis, such as eye movement pattern recognition and the assessment of visual responses in children with autism. This figure represents a method for quantifying eye movements by transforming qualitative visual responses into structured numerical data, thereby facilitating efficient data processing and analysis within the research.

We set a value of 0 for pupil movements in the upper left position. Pupil movements with a value of 1 are located directly to the right of position 0. Pupil movements with a value of 2 occur in the middle. For positions 1 and 2, the head tends to be directed straight toward the monitor. Pupil movements with a value of 3 are in the upper right location. For value 4, the pupil movements occur in the bottom left. Positions 5 and 6 refer to pupil movements at the bottom center. Finally, pupil movements with a value of 7 are out of range, particularly in the lower right corner.

Video data was recorded and analyzed at five frames per second. In one minute, five images were generated. We generated 600 images for each child for a duration of 2 minutes, or 120 seconds, divided by 5. We used three therapists to validate the results. This validation aimed to provide the first label to classify the results of the pupil movement area.

The researchers used a duration of 60 seconds to obtain data validation from the three therapists. Previously, the researchers had provided them with videos with random positions of the pupils of children with autism. The therapists then tried to determine the level of autism of the children based on the videos. The video duration of 60 seconds was decided by the three therapists, after trying a duration of 10 seconds, 20 seconds, 30 seconds, 40 seconds, and 60 seconds. The therapists' consideration for choosing 60 seconds was that the longer duration makes the position of the pupils more clearly visible. For more details, see Table 1.

TABLE I. SELECTION OF DURATION

Second	Therapist 1	Therapist 2	Therapist 3
10	Too fast and unclear	Too fast and unclear	Too fast and unclear
20	Pupil position 2 and low category	Too fast and unclear	Too fast and unclear
30	Too fast and unclear	Pupil position 5 indicates moderate autism	Pupil position 5 indicates moderate autism
40	Pupil position 6 indicates severe autism	Pupil position 6 indicates severe autism	Too fast and unclear
60	Pupil position 2 indicates low autism	Pupil position 2 indicates low autism	Pupil position 2 indicates low autism

Table 1 presents the evaluation results of three therapists in determining the most appropriate video duration for identifying autism levels based on pupils' position and movement. The tested video durations were 10, 20, 30, 40, and 60 seconds, aiming to obtain an observation period that provides clear and consistent visual information. At a duration of 10 seconds, all therapists agreed that the video was too short, making the pupils' position and movement unclear. At 20 seconds, only Therapist 1 was able to identify the pupil position in Area 2, indicating a low autism category, while Therapists 2 and 3 still considered the duration too fast and unclear. At 30 seconds, Therapists 2 and 3 identified the pupil position in Area 5, which indicated a moderate level of autism, whereas Therapist 1 still found the observation insufficiently clear. At 40 seconds, Therapists 1 and 2 identified the pupil position in Area 6, indicating severe autism, while Therapist 3 continued to report that the duration was too fast and unclear. At 60 seconds, all three therapists provided consistent results, identifying the pupil position in Area 2, which indicates a low level of autism. This consistency demonstrates that a longer observation duration allows for clearer and more stable visualization of pupil movements. Based on these findings, a video duration of 60 seconds was selected as the optimal duration for data analysis and validation, as it yields consistent assessments among therapists and provides more reliable visual information for determining autism levels.

III.3. STIMULI

Playing games is a novel approach to improving social interaction in children with autism, for example by using cartoons [15]. Children with autism tend to prioritize attention to the mouth rather than the eyes, which is a challenge for autism therapists and educational experts in helping them. Therefore, we used interaction stimulus preferences of children with autism, such as music, expressions, objects, colors, and intonation, to provide motivational effects during task completion. For example, it is known that music therapy accelerates the development of social behavior in children with autism [17].

Children with autism experience changes in making eye contact when playing games, being able to focus for five minutes on a game and being able to cope with behavioral changes. Audio games help adults with autism express their emotions [18]. Adults with autism often have difficulty expressing and recognizing emotions; thus, social interactions can be difficult for them. Children with ASD show a tendency to enjoy playing with various toys or objects used during therapy sessions, such as cars, puzzles, and balls [19].

Children with autism have a high sensitivity to certain colors, such as blue, dark yellow, and green, which can trigger a strong response from them [20]. For children with autism, these colors are considered positive motivational colors. Particularly, blue is known to enhance brain performance [21]. The games have been

specifically designed to facilitate interaction and cooperation between children with autism using gaze- and voice-based communication [22].

III.4 EXPERIMENTAL RESULTS AND ANALYSIS

This section presents the experimental results for both the ten children with autism and the ten children without autism. For both groups, we used statistical descriptions to analyze the resulting pupil positions. Two descriptive analyses were done, namely, comparison of pupil position modes between children with autism and children without autism from 1 to 120 seconds; and comparison of pupil positions between children with autism and children without autism from frame 1.

III.4.1. SAMPLE DATA

The analysis in this study was based on video recordings taken during the experiments. The 120-second video footage was converted to frames per second, resulting in a total of 600 images (assuming 5 frames per second). We used two data sets: children with autism and children without autism, each lasting 120 seconds. Therefore, each data set comprised 600 images with a breakdown of 120 seconds x 5. Integer values between 0 and 7 represent the measured pupil positions. Figures 4 and 5 present illustrations of frame-per-second data for children with autism and the children without autism.

We employed two separate screens: a laptop screen used by the participants and a computer screen used by the researchers to execute the testing procedure. During the test, the researchers supervised the children as they played the game. Three therapists also assisted the researchers.



FIGURE 4. Examples of data frames per second for a child with autism.

Figure 4 presents examples of extracted frames from the experimental video recordings used in the analysis process. Each image represents a sequential frame-per-second (fps) segment taken from the video, with file names such as *ezgif-frame-046* to *ezgif-frame-067*, indicating the chronological order of frame extraction. These images illustrate variations in facial expressions and gaze direction of the participant over time. Each frame serves as an individual data unit for analyzing eye movements and pupil positions detected by the eye-tracking system. By converting video recordings into a series of frames, the analysis can be conducted in a more detailed and structured manner based on specific time intervals. This figure demonstrates how continuous video data are transformed into static image data, which are subsequently used as inputs for data processing, eye movement pattern recognition, and comparative analysis between children with autism and children without autism.



FIGURE 5. Examples of data frames per second for a child without autism.

Table 2 shows examples of pupil movement position data measured in children with autism and without autism. The children with autism tended to have inconsistent pupil movement positions, with a particular emphasis on value 6. Meanwhile, the pupil movement positions of the children without autism were highly consistent, with a predominance of value 1. Figure 6 provides more detailed information.

TABLE 2. SNAPSHOT OF PUPIL MOVEMENT POSITION DATA FOR A CHILD WITH AUTISM AND A CHILD WITHOUT AUTISM

Second	Image	With Autism	Without Autism
1	1	1	1
	2	6	1
	3	1	1
	4	1	1
	5	1	1
2	1	6	1
	2	6	1
	3	6	1
	4	1	1
	5	1	1
.....			
120	1	2	1
	2	6	1
	3	6	1
	4	2	1
	5	2	1

Table 2 provides a comparative snapshot of pupil movement position data between a child with autism and a child without autism, observed across multiple seconds and image frames. The data clearly show that the child with autism demonstrates irregular and fluctuating pupil positions, with frequent shifts and a strong predominance of value 6 appearing repeatedly throughout the observation. This variability indicates instability in gaze direction and difficulty in maintaining consistent visual focus. In some instances, other values such as 2 also appear, further emphasizing the inconsistency of the pupil movement pattern. In contrast, the child without autism exhibits highly consistent pupil positions, with value 1 dominating almost all frames across the observation period. This consistency reflects stable gaze control and the ability

to sustain visual attention over time. Overall, the table highlights a fundamental difference in visual attention regulation: children with autism tend to show variability and instability in pupil movements, while children without autism maintain steadiness and uniformity.

III.4.2. RESULTS AND ANALYSIS

The chart illustrates the comparison between the number of correct words and word errors across 100 trials. The blue line, representing correct words, remains relatively low and stable, indicating limited improvement or consistency in correct responses. In contrast, the orange line, representing word errors, shows significant fluctuations with frequent peaks, suggesting variability and instability in performance. This visualization highlights a clear imbalance between accuracy and errors, where errors dominate the overall trend. Such a pattern provides important insights into performance dynamics, emphasizing the need to analyze underlying factors that contribute to the high frequency of mistakes compared to correct responses.

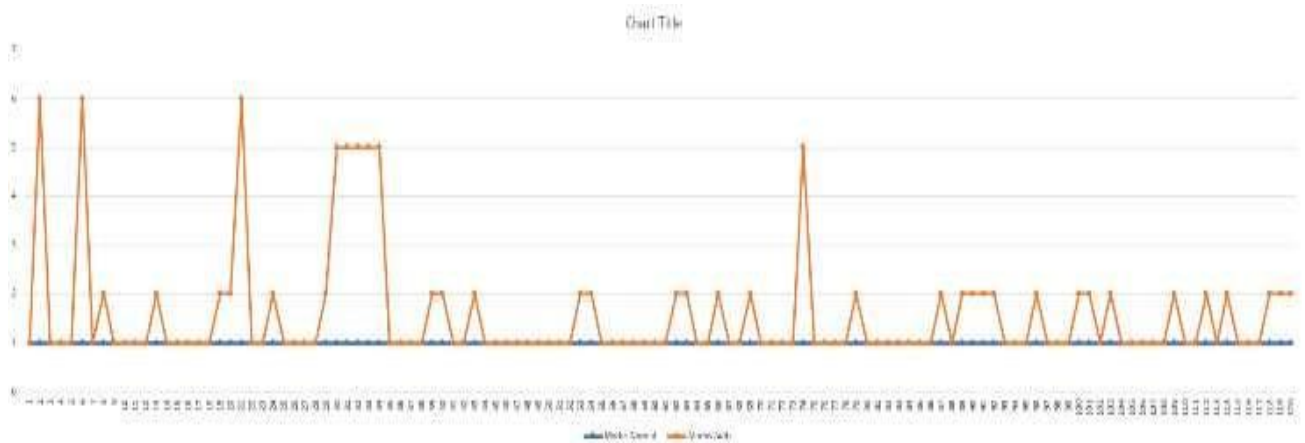


FIGURE 6. Mode at seconds 1-120 for children with autism.

Figure 6 provides a detailed visualization of the relationship between correct word responses and word errors across 100 trials. The blue line, which represents correct words, remains consistently low and relatively flat throughout the observation, indicating that the number of accurate responses is limited and shows little improvement over time. In contrast, the orange line, representing word errors, fluctuates sharply with frequent peaks, reflecting instability and variability in performance. This pattern suggests that errors occur far more frequently than correct responses, and the inconsistency of the error line highlights difficulties in sustaining accuracy and focus across repeated trials. The dominance of errors over correct responses underscores a performance imbalance, where the ability to produce accurate words is overshadowed by recurring mistakes. Overall, Figure 6 emphasizes the persistence of errors as a defining characteristic of the observed trend, offering important insights into the challenges of maintaining consistent accuracy in word production tasks.

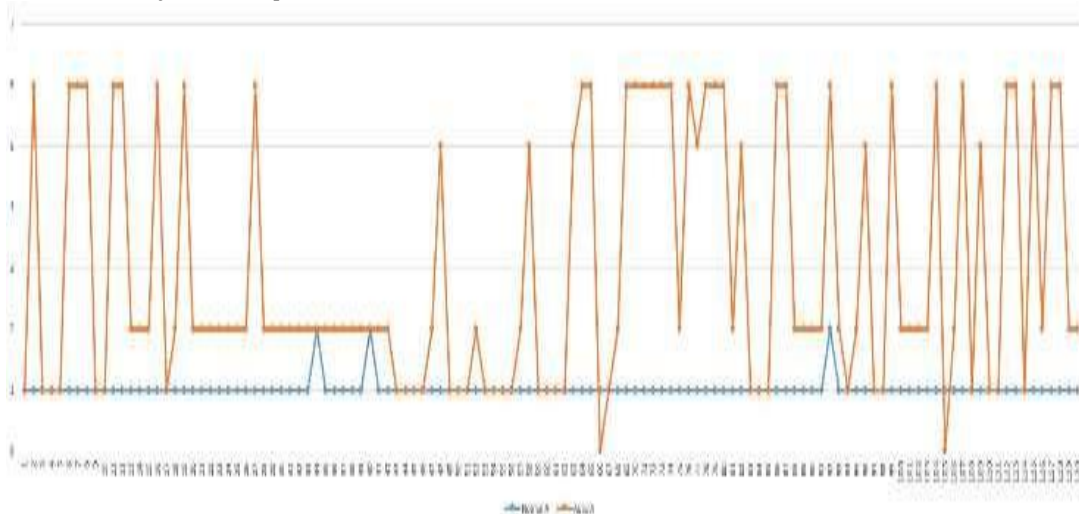


FIGURE 7. Pupil positions from frame 1 for a child with autism.

Figure 7 shows representative pupil positions for a child with autism (1 of 10 children with autism who participated in the test) in frame 1. The graphic representation makes it easier to see the inconsistent movements of children with autism. Orange is the color for children with autism, while blue is the color for children without autism.

Next, Tables 3 and 4 explain in more detail the pupil positions in frame 1. Table 3 shows the pupil positions in frame 1 for a child with autism. Meanwhile, Table 4 shows the pupil positions in frame 1 for a child without autism. Below we also include a table of the pupil positions in frames 1-5 for all the tested children with autism. Tables 5-9 show the total number of pupil positions for the children with autism in frames 1-5. Table 10-14 shows the total number of pupil positions for the children without autism in frames 1-5.

TABLE 3. PUPIL POSITIONS IN FRAME 1 FOR A CHILD WITH AUTISM

Sec	Pupil Position							
	0	1	2	3	4	5	6	7
1		v						
2							v	
3		v						
4		v						
5		v						
6							v	
7							v	
8							v	
9		v						
10		v						
11							v	
12							v	
13			v					
14			v					
15			v					
16							v	
17		v						
18			v					
19							v	
20			v					
21			v					
22			v					
23			v					
24			v					
25			v					
26			v					
27							v	
28			v					
29			v					
30			v					
31			v					
32			v					
33			v					
34			v					
35			v					
36			v					
37			v					
38			v					
39			v					
40			v					
41			v					
42			v					
43		v						
44		v						
45		v						
46		v						
47			v					
48						v		
49		v						
50		v						
51		v						
52			v					
53		v						
54		v						
55		v						
56		v						
57			v					
58						v		
59		v						
60		v						

Sec	Pupil Position							
	0	1	2	3	4	5	6	7
61		v						
62		v						
63						v		
64							v	
65							v	
66	v							
67		v						
68			v					
69							v	
70							v	
71							v	
72							v	
73							v	
74							v	
75			v					
76							v	
77						v		
78							v	
79							v	
80							v	
81			v					
82						v		
83		v						
84		v						
85		v						
86							v	
87							v	
88			v					
89			v					
90			v					
91			v					
92							v	
93			v					
94		v						
95			v					
96						v		
97		v						
98		v						
99							v	
100			v					
101			v					
102			v					
103			v					
104							v	
105	v							
106			v					
107							v	
108		v						
109						v		
110		v						
111		v						
112							v	
113							v	
114		v						
115							v	
116			v					
117							v	
118							v	
119			v					
120			v					

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Table 3 presents the pupil positions in frame 1 for a child with autism and highlights the irregularity of gaze movement compared to typical patterns. The data show that the pupil positions are distributed across several values rather than remaining fixed at one dominant position. This variation reflects a lack of

stability in visual orientation, suggesting that the child experiences difficulty maintaining consistent focus. The repeated shifts in pupil position indicate fluctuating attention and possible challenges in visual tracking, which are often associated with autism spectrum conditions. Overall, Table 3 emphasizes that the pupil movement of a child with autism in frame 1 is characterized by inconsistency and variability, underscoring differences in visual attention regulation when compared to children without autism.

TABLE 4. PUPIL POSITIONS IN FRAME 1 FOR ONE CHILD WITHOUT AUTISM

Sec	Pupil Position							
	0	1	2	3	4	5	6	7
1	v							
2	v							
3	v							
4	v							
5	v							
6	v							
7	v							
8	v							
9	v							
10	v							
11	v							
12	v							
13	v							
14	v							
15	v							
16	v							
17	v							
18	v							
19	v							
20	v							
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45	v							
46	v							
47	v							
48	v							
49	v							
50	v							
51	v							
52	v							
53	v							
54	v							
55	v							
56	v							
57	v							
58	v							
59	v							
60	v							

Sec	Pupil Position							
	0	1	2	3	4	5	6	7
61	v							
62	v							
63	v							
64	v							
65	v							
66	v							
67	v							
68	v							
69	v							
70	v							
71	v							
72	v							
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119	v							
120	v							

Table 4 presents the pupil positions in frame 1 for a child without autism and demonstrates a clear pattern of stability and consistency. The data show that the pupil positions remain predominantly fixed at a single value, with minimal variation across the recorded points. This uniformity reflects a steady gaze direction and indicates that the child is able to maintain visual focus effectively. Unlike the irregular and fluctuating movements observed in children with autism, the pupil positions in Table 4 highlight a strong ability to regulate attention and sustain concentration. Overall, the table emphasizes that children without autism exhibit consistent and controlled pupil movements, which serve as an indicator of stable visual attention.

TABLE 5. PUPIL POSITIONS IN FRAME 1 – WITH AUTISM

Participant Frame 1	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	2	33	46	0	0	7	32	0
B	12	37	56	0	0	8	7	0
C	0	97	12	0	0	3	8	0
D	7	82	20	0	0	8	3	0
E	1	58	46	0	0	11	4	0
F	0	53	45	0	0	9	13	0
G	0	53	43	0	0	6	18	0
H	5	79	22	0	0	8	6	0
I	0	60	39	0	0	9	12	0
J	4	36	42	0	0	14	24	0
Total	31	588	371	0	0	83	127	0

TABLE 6. PUPIL POSITIONS IN FRAME 2 – WITH AUTISM

Participant Frame 2	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	2	33	43	0	0	12	30	0
B	7	39	60	0	0	6	8	0
C	0	101	10	0	0	4	5	0
D	4	79	23	0	0	12	2	0
E	1	54	45	0	0	12	8	0
F	0	50	46	0	0	12	12	0
G	0	48	45	0	0	9	18	0
H	3	78	24	0	0	11	4	0
I	0	55	41	0	0	11	13	0
J	1	34	40	0	0	23	22	0
Total	18	571	377	0	0	112	122	0

TABLE 7. PUPIL POSITIONS IN FRAME 3 – WITH AUTISM

Participant Frame 3	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	3	35	51	0	0	10	21	0
B	8	38	60	0	0	6	8	0
C	0	98	12	0	0	5	5	0
D	6	82	16	0	0	12	4	0
E	1	55	49	0	0	8	7	0
F	0	50	49	0	0	8	13	0
G	0	48	48	0	0	5	19	0
H	5	76	19	0	0	12	8	0
I	0	56	43	0	0	8	13	0
J	3	40	43	0	0	17	17	0
Total	26	578	390	0	0	91	115	0

TABLE 8. PUPIL POSITIONS IN FRAME 4 – WITH AUTISM

Participant Frame 4	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	2	35	42	0	0	11	30	0
B	8	41	54	0	0	8	9	0
C	0	97	11	0	0	5	7	0
D	7	79	14	0	0	14	6	0
E	1	66	37	0	0	11	5	0
F	1	61	37	0	0	12	9	0
G	1	60	37	0	0	8	14	0
H	6	76	14	0	0	15	9	0
I	1	65	34	0	0	11	9	0
J	2	38	37	0	0	20	23	0
Total	29	618	317	0	0	115	121	0

TABLE 9. PUPIL POSITIONS IN FRAME 5 – WITH AUTISM

Participant Frame 5	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	2	32	49	0	0	12	25	0
B	7	45	50	0	0	12	6	0
C	0	93	16	0	0	7	4	0
D	7	78	22	0	0	9	4	0
E	2	59	41	0	0	12	6	0
F	1	56	40	0	0	11	12	0
G	1	56	40	0	0	8	15	0
H	6	77	21	0	0	10	6	0
I	1	59	37	0	0	11	12	0

J	1	35	42	0	0	20	22	0
Total	28	590	358	0	0	112	112	0

TABLE 10. PUPIL POSITIONS IN FRAME 1 – WITHOUT AUTISM

Participant Frame 1	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	0	117	4	0	0	0	0	0
B	0	119	0	0	0	1	0	0
C	0	116	4	0	0	0	0	0
D	0	116	4	0	0	0	0	0
E	0	115	5	0	0	0	0	0
F	0	115	5	0	0	0	0	0
G	0	116	4	0	0	0	0	0
H	0	118	2	0	0	0	0	0
I	0	115	5	0	0	0	0	0
J	0	116	4	0	0	0	0	0
Total	0	1163	37	0	0	0	0	0

TABLE 11. PUPIL POSITIONS IN FRAME 2 – WITHOUT AUTISM

Participant Frame 2	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	0	115	5	0	0	0	0	0
B	0	119	0	0	0	1	0	0
C	0	116	4	0	0	0	0	0
D	0	116	4	0	0	0	0	0
E	0	115	5	0	0	0	0	0
F	0	115	5	0	0	0	0	0
G	0	117	3	0	0	0	0	0
H	0	118	2	0	0	0	0	0
I	0	116	4	0	0	0	0	0
J	0	113	4	0	0	0	0	0
Total	0	1160	40	0	0	0	0	0

TABLE 12. PUPIL POSITIONS IN FRAME 3 – WITHOUT AUTISM

Participant Frame 3	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	0	117	3	0	0	0	0	0
B	0	119	0	0	0	1	0	0
C	0	115	5	0	0	0	0	0
D	0	117	3	0	0	0	0	0
E	0	115	5	0	0	0	0	0
F	0	116	4	0	0	0	0	0
G	0	118	2	0	0	0	0	0
H	0	118	2	0	0	0	0	0
I	0	116	4	0	0	0	0	0
J	0	116	5	0	0	0	0	0
Total	0	1167	33	0	0	0	0	0

TABLE 13. PUPIL POSITIONS IN FRAME 4 – WITHOUT AUTISM

Participant Frame 4	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	0	116	4	0	0	0	0	0
B	0	118	2	0	0	1	0	0
C	0	116	4	0	0	0	0	0
D	0	117	3	0	0	0	0	0
E	0	115	5	0	0	0	0	0
F	0	116	4	0	0	0	0	0
G	0	117	3	0	0	0	0	0

H	0	118	2	0	0	0	0	0
I	0	115	5	0	0	0	0	0
J	0	116	4	0	0	0	0	0
Total	0	1164	36	0	0	0	0	0

TABLE 14. PUPIL POSITIONS IN FRAME 5 – WITHOUT AUTISM

Participant Frame 5	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
A	0	116	4	0	0	0	0	0
B	0	118	1	0	0	1	0	0
C	0	116	4	0	0	0	0	0
D	0	116	4	0	0	0	0	0
E	0	115	5	0	0	0	0	0
F	0	116	4	0	0	0	0	0
G	0	107	13	0	0	0	0	0
H	0	118	2	0	0	0	0	0
I	0	116	4	0	0	0	0	0
J	0	116	4	0	0	0	0	0
Total	0	1154	45	0	0	0	0	0

Noting that all the children with autism tested in the experiment had moderate (level 2) autism based on the DSM-5 scale, the results presented in Tables 5-14 allow us to distinguish the following three sublevels of moderate autism: low-moderate autism, medium-moderate autism, and high-moderate autism. Autism is in the low-moderate category when the majority of values are in the lowest range, namely pupil position 1, which is the tendency for children without autism, and pupil positions 2 and 3, which is the tendency for children with low-moderate autism. The graph pattern of children with low-moderate autism shows that the pupil positions are more stable and there are rarely spikes, see Figure 8. Low-moderate autism was seen in participants C, D, and H.

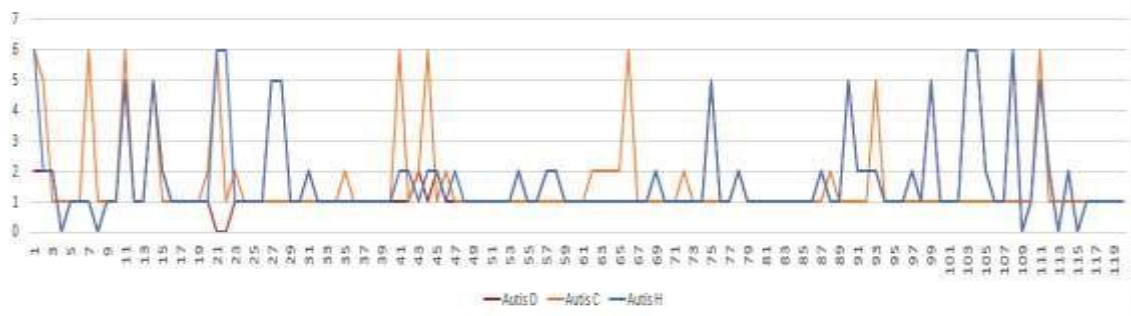


FIGURE 8. Category of children with low-moderate autism.

The graph pattern of children with medium-moderate autism has many fluctuations but not consistently high values. The pattern of fluctuation is not as strong as in children with severe autism. In children with medium-moderate autism, the graph pattern appears more balanced. Children with medium-moderate autism were participants B, E, F, G, and I, see in Figure 9. The pupils were mostly positioned in positions 4 and 5.

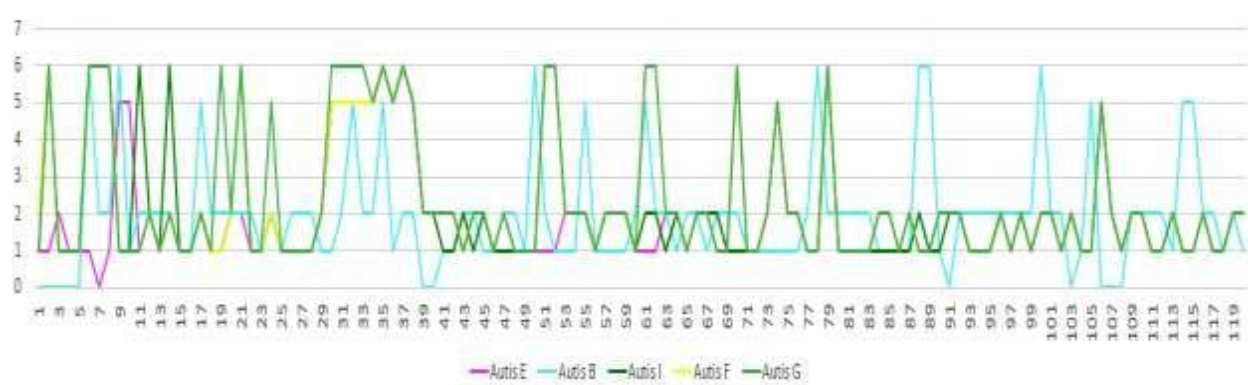
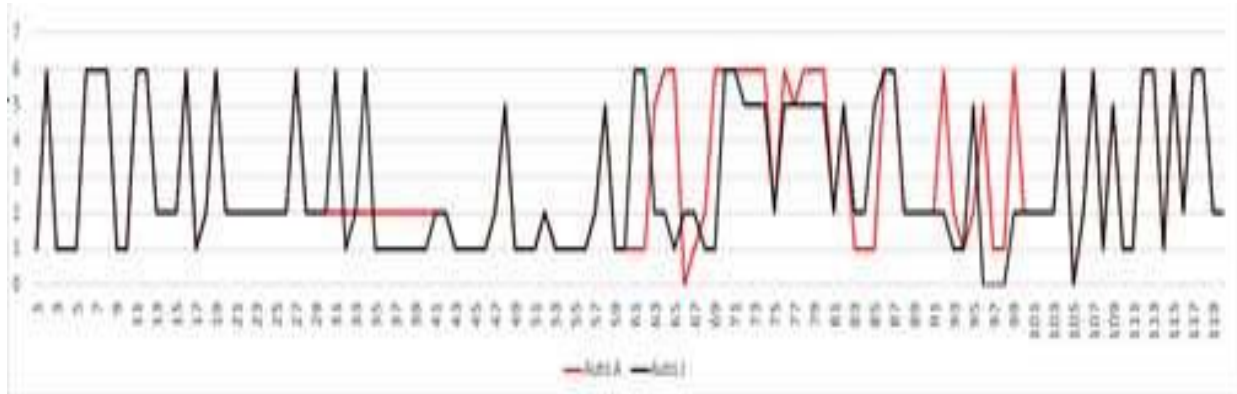


FIGURE 9. Category of children with medium-moderate autism.

The high-moderate autism pattern shows instability in the graph. This pattern is unstable and occurs in the low pupil position category. There are many sharp, zigzag-like patterns that move from low to high values, and vice versa. High-moderate autism was seen in A and J, see Figure 10. The frequency of pupil positions 6 and 7 is very high.

**FIGURE 10. Category of children with high-moderate autism.**

IV. RESULTS

The researchers conducted a retest with two children with autism and two children without autism. In this test, the researchers wanted to determine whether the scores for children with and without autism were consistent with the previous test. Tables 15-19 show the validation for the assessment of children with autism in frames 1-5 for the low-moderate and high-moderate autism categories. We used the letters K and L, as they fall outside the category of children with autism (A-J). Validation for children with low-moderate autism is represented by K, while validation for children with high-moderate autism is represented by L. The results for K showed that the pupils were predominantly in the positions 1, 2, and 3, which indicates low-moderate autism. Meanwhile, the pupils of L were predominantly in the positions 6 and 7, which indicates high-moderate autism.

TABLE 15. VALIDATION OF PUPIL POSITIONS IN FRAME 1 OF CHILDREN WITH AUTISM

Participant Frame 1	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	94	20	0	0	2	4	0
L	0	51	30	0	0	10	25	4
Total	0	145	50	0	0	12	29	4

TABLE 16. VALIDATION OF PUPIL POSITIONS IN FRAME 2 OF CHILDREN WITH AUTISM

Participant Frame 2	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	95	19	0	0	4	2	0
L	0	40	31	0	0	22	23	4
Total	0	135	50	0	0	26	25	4

TABLE 17. VALIDATION OF PUPIL POSITIONS IN FRAME 3 OF CHILDREN WITH AUTISM

Participant Frame 3	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	101	11	0	0	5	3	0
L	3	49	25	0	0	18	21	4
Total	3	150	36	0	0	23	24	4

TABLE 18. VALIDATION OF PUPIL POSITIONS IN FRAME 4 OF CHILDREN WITH AUTISM

Participant Frame 4	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	103	10	0	0	4	3	0
L	0	44	34	0	0	18	24	0
Total	0	147	44	0	0	22	27	0

TABLE 19. VALIDATION OF PUPIL POSITIONS IN FRAME 5 OF CHILDREN WITH AUTISM

Participant Frame 5	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	95	17	0	0	6	2	0
L	1	51	35	0	0	14	15	4
Total	1	146	52	0	0	20	17	4

Tables 20-24 below show the validation for the assessment of children without autism in frames 1-5. The results indicate that the pupil positions were dominantly in position 1. The letters K and L were used to represent children without autism in the validation, because they fall outside the category for children without autism (A-J).

TABLE 20. VALIDATION OF PUPIL POSITIONS IN FRAME 1 OF CHILDREN WITHOUT AUTISM

Participant Frame 1	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	117	3	0	0	0	0	0
L	0	117	3	0	0	0	0	0
Total	0	234	6	0	0	0	0	0

TABLE 21. VALIDATION OF PUPIL POSITIONS IN FRAME 2 OF CHILDREN WITHOUT AUTISM

Participant Frame 2	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	116	4	0	0	0	0	0
L	0	117	3	0	0	0	0	0
Total	0	233	7	0	0	0	0	0

TABLE 22. VALIDATION OF PUPIL POSITIONS IN FRAME 3 OF CHILDREN WITHOUT AUTISM

Participant Frame 3	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	115	5	0	0	0	0	0
L	0	117	3	0	0	0	0	0
Total	0	232	8	0	0	0	0	0

TABLE 23. VALIDATION OF PUPIL POSITIONS IN FRAME 4 OF CHILDREN WITHOUT AUTISM

Participant Frame 4	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	116	4	0	0	0	0	0
L	0	117	3	0	0	0	0	0
Total	0	233	7	0	0	0	0	0

TABLE 24. VALIDATION OF PUPIL POSITIONS IN FRAME 5 OF CHILDREN WITHOUT AUTISM

Participant Frame 5	Total Number of Pupil Positions							
	0	1	2	3	4	5	6	7
K	0	116	4	0	0	0	0	0

L	0	117	3	0	0	0	0	0
Total	0	233	7	0	0	0	0	0

Based on the results in Tables 15-19, the researchers then compared the results with the categories of children with autism, namely children with low-moderate autism and children with high-moderate autism. Child with autism K was compared with the low-moderate autism category, while child with autism L was compared with the high-moderate autism category. The results show many similarities in the respective graphs. For more details, see Figures 11 and 12.

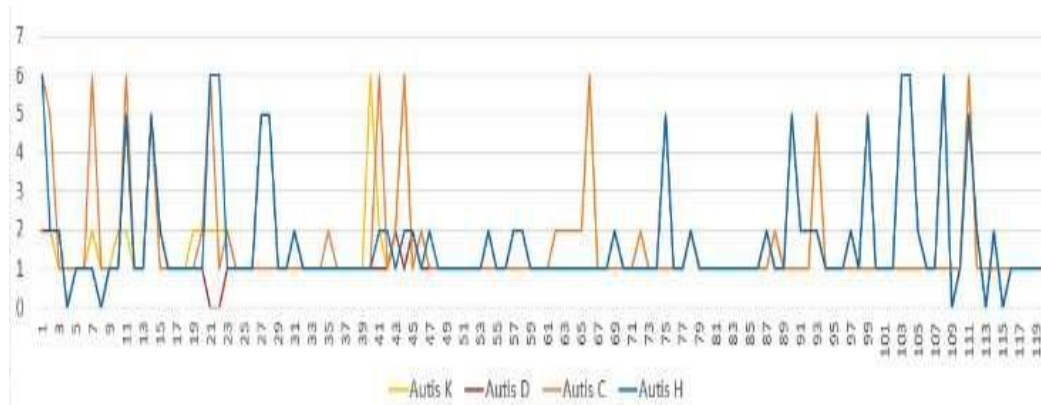


FIGURE 11. Comparison of the graphs of children with low-moderate autism.

Figure 11 presents a comparison of the graphs of children with low to moderate autism, showing distinct variations in pupil movement patterns across different individuals. Each line represents a child, and the fluctuations indicate differences in the stability and consistency of their visual focus. For example, some children display frequent and sharp peaks, suggesting irregular and unstable pupil positions, while others show relatively flatter lines, reflecting more consistent gaze control. The child represented by the blue line demonstrates the highest frequency of peaks, indicating greater variability in attention regulation, whereas the red line remains relatively low, suggesting more stable visual orientation. Overall, the figure highlights the heterogeneity among children with low-moderate autism, emphasizing that while some exhibit pronounced instability in pupil movements, others maintain steadier patterns. This comparison underscores the importance of recognizing individual differences in visual attention and gaze behavior within the autism spectrum.

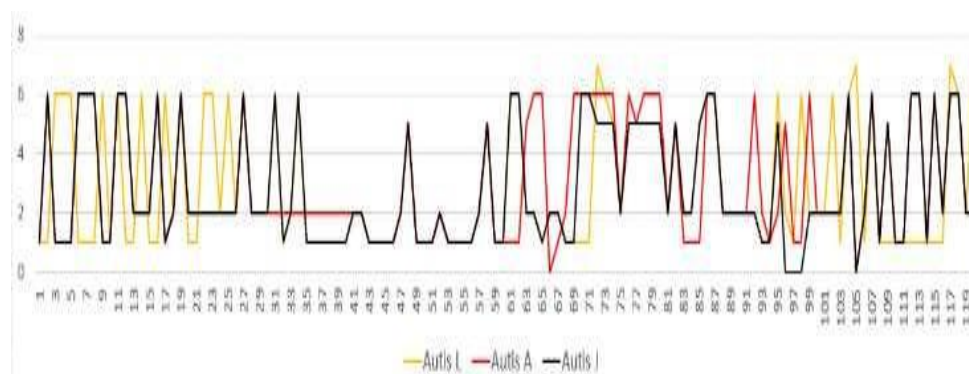


FIGURE 12. Comparison of the graphs of children with high-moderate autism.

Figure 12 presents a comparison of the graphs of children with high-moderate autism, highlighting the variability in their pupil movement patterns across time. The three lines, each representing different children, show noticeable fluctuations in values, indicating differences in the stability and regulation of visual focus. Some children display frequent peaks and irregular shifts, suggesting greater instability and inconsistency in gaze control, while others exhibit relatively flatter trends, reflecting more stable but still variable attention. The overlapping segments of the lines reveal moments of similarity in pupil positions, yet the divergence at other points underscores the heterogeneity of visual behavior within this group. Overall, the figure emphasizes that children with high-moderate autism tend to experience more pronounced variability in pupil movements compared to those with lower levels of autism, reinforcing the idea that attentional regulation and visual tracking differ significantly across the spectrum.

V. DISCUSSION

The aim of this research was to develop a game application to measure the interaction level of children with autism. The proposed application is called Tracking for Autism (TFA). Existing game applications only support interaction with children with autism, not usage as a measurement or therapy tool.

Testing with the TFA application directs the children to focus on the screen. During the testing process, the children's pupil movements are recorded by Tobii eye tracking. Based on the recorded values, it was discovered that the interaction levels of children with autism can be categorized by analyzing their pupil position patterns.

The findings suggest that eye tracking may also be integrated into other game applications to measure the interaction level of children with autism from one point to another, thereby assisting therapists in determining a child's autism developmental stage. Currently, determining a child's autism class is done manually, requiring significant time and concentration. With the TFA application, results can be displayed automatically and in real time.

Several previous studies have discussed gaming platforms that support interaction for people with autism. These platforms also include interactive and collaborative games for adults with autism [18]. The social interaction skills involve peer engagement, allowing them to better express and recognize emotions. One game platform, Collaborative Virtual Environment (CVE), encourages children with autism to collaborate with peers [22]. This game allows children with and without autism to play a series of interactive games in a virtual reality environment. Both groups use simple hand gestures to move virtual objects that are tracked live through a camera. The game is designed to encourage natural communication and cooperation between users. The game application allows users to share information and discuss game strategies using gaze- and voice-based communication.

The TFA game application could also be used as a therapeutic tool in the future. Children can participate in testing according to their age and ability. Implementing multiple difficulty levels is an important step in improving the interaction level of children with autism. Being able to measure their interaction level in real time while playing provides essential information for the therapist.

Previous research has found that most systems for diagnosing autism adopt the DSM-5 criteria [23]. Existing assessment tools use augmented reality. Previously, no tool or system was available that could measure the level of interaction in children with autism based on the DSM-5 diagnosis. The findings of the present study regarding eye tracking with the TFA application to measure interaction levels in children with autism show that pupil movement patterns can be used as a biomarker.

In this study, the researchers only measured interaction based on data from children with DSM-5 level 2 autism ("requires substantial support"). This is the main limitation of this study. Thus, this study claims that individuals with ASD can have three levels of autism within level 2: low-moderate, medium-moderate, and high-moderate. This can be used as a therapeutic benchmark for children with autism, allowing for appropriate treatment. However, children with severe autism (DSM-5 level 3) may have difficulty understanding games designed for their group. Another factor is that the level of attention of children with level 3 autism is affected by many things, such as hand and foot movements and unstable sitting positions. Therefore, it is difficult to test them using eye tracking. In contrast, children with level 1 autism ("needing support") are considered more independent, generally approaching typical children, and hence are expected to be able to use TFA without difficulty.

VI. CONCLUSION

The conclusion from the results of this study shows that found that most systems were developed to diagnose children with autism based on DSM 5. Several systems utilize computer technology to support the interaction development of children with autism. This includes learning methods, peer interaction apps, and even apps designed to help children with autism to focus. However, none of the existing apps use eye tracking to measure interaction levels in children with autism; most of them were designed to diagnose children with autism. We also observed that most tools/apps are used as a medium to encourage interaction in children with autism. With the proposed TFA game application, the level of interaction of children with autism can be measured in real time. Based on the results in Tables 5-14, three categories of children with level 2 autism were identified: children low-moderate autism, medium-moderate autism, and high-moderate autism. Tables 15-19 show the validation of the assessment of children with autism tested in the experiment. Pupil positions predominantly at position 1 indicates no autism and pupil positions predominantly at 2 or 3 indicate low-moderate autism. Meanwhile, pupil positions predominantly at 6 or 7 indicates high-moderate autism. Based on the results in Tables 15-19, the researchers then compared these results with the children with low-moderate and high-moderate autism.

For validation in this study, the results of K were compared with those of the low-moderate autism category. Meanwhile, the results of L were compared with the high-moderate autism category. The results showed many similarities in the graphs of both categories with those of K and L. Therefore, we conclude, first, that the TFA application provides pupil position patterns that are highly suitable as a biomarker for

measuring the interaction level of children with autism. Second, further research is needed to implement therapies for children with autism to improve their interaction levels based on these measurements. Third, most of the research was conducted using data for level 2 autism (“requires substantial support”) so that in the future research may be conducted to further develop the application for level 3 autism (“requires very substantial support”).

REFERENCES

- [1] M. D. Samad, N. Diawara, J. L. Bobzien, C. M. Taylor, J. W. Harrington, and K. M. Iftekharruddin, “A pilot study to identify autism related traits in spontaneous facial actions using computer vision,” *Res. Autism Spectr. Disord.*, vol. 65, no. September 2018, pp. 14–24, 2019, doi: 10.1016/j.rasd.2019.05.001.
- [2] M. Ewa, “Neuropsychologia. A novel machine learning analysis of eye-tracking data reveals suboptimal visual information extraction from facial stimuli in individuals with autism,” vol. 129, no. February, pp. 397–406, 2019, doi: 10.1016/j.neuropsychologia.2019.04.022.
- [3] H. J. Nuske, G. Vivanti, K. Hudry, and C. Dissanayake, “Pupillometry reveals reduced unconscious emotional reactivity in autism,” *Biol. Psychol.*, vol. 101, no. 1, pp. 24–35, 2014, doi: 10.1016/j.biopsycho.2014.07.003.
- [4] Y. Lin, J. Wong, and Y. Tseng, “Game-Based Social Interaction Platform for Cognitive Assessment of Autism Using Eye Tracking,” *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 31, pp. 749–758, 2023, doi: 10.1109/TNSRE.2022.3232369.
- [5] D. L. Reisinger et al., “Atypical Social Attention and Emotional Face Processing in Autism Spectrum Disorder : Insights From Face Scanning and Pupillometry,” vol. 13, no. February, pp. 1–14, 2020, doi: 10.3389/fnint.2019.00076.
- [6] R. Carette, M. Elbattah, G. Dequen, J. L. Guerin, and F. Cilia, “Visualization of Eye-Tracking Patterns in Autism Spectrum Disorder: Method and Dataset,” 2018 13th Int. Conf. Digit. Inf. Manag. ICDIM 2018, pp. 248–253, 2018, doi: 10.1109/ICDIM.2018.8846967.
- [7] M. K. Kwon, A. Moore, C. C. Barnes, D. Cha, and K. Pierce, “Typical Levels of Eye-Region Fixation in Toddlers with Autism Spectrum Disorder Across Multiple Contexts,” *J. Am. Acad. Child Adolesc. Psychiatry*, vol. 58, no. 10, pp. 1004–1015, 2019, doi: 10.1016/j.jaac.2018.12.011.
- [8] A. A. Magableh, “Eye Tracking Algorithms, Techniques, Tools, and Applications with an Emphasis on Machine Learning,” *Expert Syst. Appl.*, p. 114037, 2020, doi: 10.1016/j.eswa.2020.114037.
- [9] Z. A. Taha Ahmed and M. E. Jadhav, “A Review of Early Detection of Autism Based on Eye-Tracking and Sensing Technology,” *Proc. 5th Int. Conf. Inven. Comput. Technol. ICICT 2020*, pp. 160–166, 2020, doi: 10.1109/ICICT48043.2020.9112493.
- [10] S. Alarcon-Licon, L. Loke, and N. Ahmadpour, “From Autism Educators to Game Designers Integrating Teaching Strategies into Game Design for Autism Education Support,” *ACM Int. Conf. Proceeding Ser.*, pp. 58–62, 2018, doi: 10.1145/3292147.3292208.
- [11] M. Kassner, W. Patera, and A. Bulling, “Pupil: An Open Source Platform for Pervasive Eye Tracking and Mobile Gaze-based Interaction,” *UbiComp 2014 – Adjunct Proc. 2014 ACM Int. Jt. Conf. Pervasive Ubiquitous Comput.*, pp. 1151–1160, 2014, doi: 10.1145/2638728.2641695.
- [12] M. Rudling, P. Nyström, S. Bölte, and T. Falck-Ytter, “Larger Pupil Dilation to Nonsocial Sounds in Infants with Subsequent Autism Diagnosis,” *J. Child Psychol. Psychiatry Allied Discip.*, vol. 63, no. 7, pp. 793–801, 2022, doi: 10.1111/jcpp.13520.
- [13] M. Of and M. Disorders, *DSM-5*.
- [14] C. Linnemann et al., “Predictive Value of Serum Neurofilament Light Chain for Persistent Cognitive Deficits in Elderly Depressive Patients,” *J. Affect. Disord. Reports*, vol. 4, no. December 2020, p. 100095, 2021, doi: 10.1016/j.jadr.2021.100095.
- [15] K. Zhang, L. Gao, J. Chen, X. Liu, G. Wang, and M. Liao, “Eye-Tracking Analysis of Autistic Children’s Attention to Social Stimuli,” *Proc. – 2020 Int. Symp. Educ. Technol. ISET 2020*, pp. 268–272, 2020, doi: 10.1109/ISET49818.2020.00065.
- [16] J. Zou, H. Zhang, and T. Weng, “New 2D Pupil and Spot Center Positioning Technology under Real-Time Eye Tracking,” *ICCSE 2017 – 12th Int. Conf. Comput. Sci. Educ.*, no. Iccse, pp. 110–115, 2017, doi: 10.1109/ICCSE.2017.8085473.
- [17] M. Pater, M. Spreen, and T. Van Yperen, “The Developmental Progress in Social Behavior of Children with Autism Spectrum Disorder Getting Music Therapy. A Multiple Case Study,” *Child. Youth Serv. Rev.*, vol. 120, no. July 2020, p. 105767, 2021, doi: 10.1016/j.chilcyouth.2020.105767.
- [18] Y. Ng and M. S. Pera, “Recommending Social-Interactive Games for Adults with Autism Spectrum Disorders (ASD),” pp. 209–213.
- [19] C. Crowell, J. Mora-Guiard, and N. Pares, “Structuring Collaboration: Multi-user Full-Body Interaction Environments for Children with Autism Spectrum Disorder,” *Res. Autism Spectr. Disord.*, vol. 58, no. July 2017, pp. 96–110, 2019, doi: 10.1016/j.rasd.2018.11.003.

- [20] A. F. Azizah, A. Djunaidy, D. Siahaan, and F. Suhariadi, "Improving the Interaction of Autistic Children through Eye Tracking using Gamification Design Framework," 2021 Int. Conf. Comput. Syst. Inf. Technol. Electr. Eng. COSITE 2021, pp. 57–62, 2021, doi: 10.1109/COSITE52651.2021.9649613.
- [21] A. F. Azizah and T. D. Susanto, "Conceptual Model Cognitive, Affective, Physical, and External Factor for Individual Information Technology Acceptance," IPTEK J. Proc. Ser., vol. 2, no. 1, pp. 171–172, 2016, doi: 10.12962/j23546026.y2015i1.1169.
- [22] H. Zhao, A. R. Swanson, A. S. Weitlauf, Z. E. Warren, N. Sarkar, and S. Member, "Hand-in-Hand: A Communication-Enhancement Collaborative Virtual Reality System for Promoting Social Interaction in Children With Autism Spectrum Disorders," pp. 1–13, 2018.
- [23] ADAMU, Amina Sani; ABDULLAHI, Saleh El-Yakub. A Review of Autism Diagnosis/Screening Expert System and Mobile Application. In: 2020 IEEE 2nd International Conference on Cyberspace (CYBER NIGERIA). IEEE, 2021. p. 80-84.