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Analysis of visual perception in children using an eye tracker – A pilot study

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ABSTRACT

The technology of tracking eye movements, known as oculography, has become an incredibly innovative research tool, gaining increasing popularity in the field of developmental cognitive neuroscience. This article presents an assessment of the ability to differentiate and interpret visual stimuli in a group of children, both healthy and with diagnosed developmental issues such as Asperger's syndrome. Dedicated computer games, operated using an eye tracker, were utilized for the study. During the research, eye tracking technology was utilized, enabling real-time measurement of eye movements. This technology employs a specialized device called an eye tracker, which consists of an integrated camera recording infrared radiation and emitting it towards the child being examined. The eye tracker records the reflection of radiation from the eye's fundus, allowing precise measurement of eye movements, pupil position, and duration of observation. This facilitated tracking of gaze during interactions with various stimuli such as images, text, or game animations. This method ensured accurate and non-invasive recording of children's visual reactions during interactions with dedicated computer games. The assessment of visual perception in each child was conducted using behavioral paradigms, including tasks involving gaze tracking, concentration, and memorization of moving or stationary objects. To successfully achieve the objectives of the study, data analysis, extraction, and feature selection were performed on the obtained behavioral paradigms. This analysis was based on oculographic data such as saccades, fixations, and pupillometric data. Studies employing oculography among both healthy children and those with autism spectrum disorders. The analysis of gaze and fixation values indicated significant visual preferences and reactions to stimuli present in the examined games, allowing for a better understanding of cognitive processes and the child's interaction with visual content. Observed differences in parameter values, such as saccade duration and the number of outliers, suggest varying levels of visual skills and visual reactions among the studied children. The existence of differences among individual children in their ability to react quickly and focus during interactions with computer games may have significant implications for the design of user interfaces and digital content accessible to this age group. Furthermore, the research results may have practical applications in tailoring intervention strategies and supporting perceptual development in children.

Keywords: oculography, saccades, fixations, eye movement analysis, visual perception analysis.

INTRODUCTION

Seeing the world through the eyes of a child, though physically impossible, has become achievable through advanced methods such as eye tracking. In the past decade, eye tracking has emerged as a key research tool, allowing for the objective measurement of gaze location in children at various stages of development. For instance, a study conducted by Oakes et al. [24], published in the journal Child Development, examined how infants and toddlers track objects using eye-tracking technology.

Their findings indicated that younger children displayed varying fixation patterns when tracking both stationary and moving objects, reflecting developmental differences in visual processing abilities. In another study by Gredebäck et al. [25], published in Developmental Science, the authors explored gaze patterns in infants during social interactions, revealing that infants are more likely to follow gaze cues from adults, which highlights the role of social context in visual attention development. Similarly, research by von Hofsten et al. [26] in Cognitive Development demonstrated that children as young as three years old exhibit significant differences in visual attention to dynamic versus static stimuli, underscoring the evolving nature of visual perception as children grow. These studies emphasize the variability in visual processing based on developmental stages and the need to consider age as a critical factor in research design. Therefore, it was crucial to appropriately qualify children for the study based on various criteria, including age, to ensure homogeneity within the research group. Special attention was given to ensuring similar ages among children in the control group and those with Asperger's syndrome, which allowed for the elimination of potential differences arising from cognitive and emotional development associated with age.

Children do not follow instructions in the same way as adult research participants. Moreover, the quality of data obtained from eye tracking studies in children is often lower compared to studies in adults, raising questions about the quality of data analysis and its impact on the validity of conclusions. In this context, this article adopts a data quality perspective, proposing an analysis of the entire eye tracking research process. This approach addresses challenges related to practical aspects of eye tracking research, often overlooked in experimental design but crucial for the proper interpretation of visual perception development in children [2].

This paper focuses on the topic of eye tracking. The aim of the paper is to present results of a pilot study related to research is the hypothesis of a connection between mental processes and eye movements. An essential task was to conduct research, process, and analyze visual activity. The obtained results allowed for the assessment of visual perception in children using an eye tracker. In the process of participant selection, particular attention was paid to ensuring a similar age among children in both the control group and the group with Asperger's syndrome, in order to eliminate potential differences arising from cognitive and emotional development related to age. Only children with stable mental health who were not taking any medications affecting cognitive functions were included, minimizing additional factors that could interfere with the results. This approach allowed for the acquisition of consistent data, as any observed differences could be attributed to the characteristics of Asperger's syndrome rather than demographic or medical differences. Thus, this selection was crucial for the credibility of the results, enabling accurate comparisons of visual perception between healthy children and those with Asperger's, without interference from other variables. Consequently, the study provided valuable data on the specific characteristics of visual perception associated with Asperger's syndrome, allowing for a more precise analysis of differences in social signal interpretation among children in this group.

To delve into the subject of oculography, the paper presents issues connecting it with common usage and the possibilities it offers. Surely, one of the key elements in the analysis of visual perception in children was the use of behavioral paradigms. These tasks were related to directing and maintaining visual attention, involving both focusing on moving objects and stationary ones during gameplay. These paradigms formed the structural basis for experimental situations in which children were studied, enabling precise monitoring of their visual behaviors. To effectively utilize behavioral paradigms related to eye movement, study participants had to be aware of generating these movements, allowing for intentional use of eye tracking capabilities [1]. A unique aspect of this study is the use of personalized tasks within a gaming environment, allowing for the examination of specific patterns of visual attention and stimulus processing in dynamic situations. Unlike previous research, which primarily focused on simple perceptual tasks, our approach enables a deeper understanding of how children of different ages and cognitive abilities respond to complex and interactive visual stimuli. Moreover, the study's findings have potential practical applications in education and therapy—the data obtained can aid in designing educational tools that support children's learning by tailoring content to their individual visual perception patterns. For example, the results may contribute to the development of educational programs and applications that address the specific needs of children with developmental disorders, enabling them to acquire knowledge and develop cognitive skills more effectively and engagingly. Thus, this study not only advances knowledge in the field of eye-tracking but also represents a step towards practical solutions that support children's development through personalized education.

The paper presents key results of oculographic research conducted in the field of eye tracking among children. These results were referenced for analysis and comparison with the obtained results during the studies conducted for the purpose of this work. Additionally, the main indicators of human eye activity, which play a significant role in the analysis of oculographic research results, were presented. The described content related to eye tracking studies is essential for understanding the significance of the conducted research [1, 11, 12].

METHODOLOGY

Eye tracking

Eye tracking, also known as oculography, investigates visual perception by recording the eye movements of participants. It is a non-invasive method that focuses on measuring the subject in real-time. The process involves converting the eye movements of the subject into a stream of data. Through eye tracking, information can be obtained about where the subject is looking, the sequence in which their gaze moves, and how long their attention is focused on specific elements of the screen. Eye tracking studies emphasize the unconscious reactions of users rather than their declarations, making it considered an objective measurement. Furthermore, eye tracking research has shown that where a respondent looks is often associated with what they are thinking and paying attention to [3–5].

Eye tracker is a device based on video technology that utilizes infrared radiation for non-contact and optical measurement of eye movement. It operates by reflecting infrared rays off the eyes of the subject, directed towards the center of the eye (the pupil) in the form of near-infrared light. This results in detectable reflections in the pupil and the cornea of the eye. The reflection between the pupil and the cornea is captured by an infrared camera, and the obtained data is then transmitted to a computer workstation with dedicated software for result analysis. The analysis was supported by iMotions software, which provides a comprehensive suite of algorithms for the automatic processing of eye-tracking data. Specific formulas were utilized, such as calculating fixation duration as the difference between the start and end points of a fixation and measuring saccade amplitude as the angular distance between two consecutive fixation points. With these tools, we were able to track fixation and saccade parameters in detail, allowing for the segmentation of areas of interest (AOI) and the quantitative assessment of metrics such as fixation frequency, average duration, and saccade speed. Additionally, iMotions facilitated the calculation of statistical measures for saccades, including average speed and amplitude, and enabled the creation of heatmaps and sequence maps to visualize attention patterns. This comprehensive approach provided insights into the participants' visual attention and processing efficiency.

During the analysis of the camera image, algorithms are used to detect and track the position of the pupil based on its location, orientation, and reflection on the cornea of the eye. The device records the position of the pupil in real-time, allowing for the determination of the gaze direction of the subject. During data analysis, changes in the signal are identified, corresponding to eye movements. This enables the determination of the time spent looking at a specific area, the number of gazes on particular elements, as well as the average length of gaze [5, 13–15].

Eye movements

Studying visual attention activity contributed to the discovery of certain recurring features of human gaze positions, such as saccades, fixations, and pupillometric data. These constitute fundamental characteristics of eye movements that can undergo further transformations to gather information about the time and number of visual fixations. Their observation occurs in specific areas of the visual scene determined by the researcher – in our study, it was a specific segment of the game played by the participant. During the static observation of the visual scene, fixations and saccades occur alternately. Fixations can be defined as relative stability of the eyes, while saccades involve rapid, jerky eye movements. Attention data are collected during fixations, whereas it is inhibited during saccades. The prevention of data collection during saccades is referred to as saccadic suppression.

Saccadic suppression is associated with a reduction in human perceptual awareness and decreased visual sensitivity both before and during the occurrence of saccades [6–8].

Fixations are brief and frequent moments of gaze stabilization on a specific element, during which visual information is sought. Visual information is determined by the location and sequence of fixations. The phase of visual attention immobility lasts for 0.15–1.5 seconds. In eye tracking studies, a fixation indicates the focus of the participant on a specific object and how long they maintain their gaze on a particular element [6–8]. Saccades are rapid eye movements that occur between fixation points. They are very fast eye movements lasting 20–40 milliseconds. They can be reflexive or intentional. They stand out as the fastest movement possible to be generated by the human body, and during their occurrence, there is a decrease in visual sensitivity. As a result, the image on the retina during a saccade is of lower quality; therefore, data acquisition occurs during fixations [6, 7, 16].

Research scenario – games

For the purposes of this study, we used a set of therapeutic games designed to train visual perception. These games were developed by Kinka [10] in collaboration with experts in psychology, occupational therapy, and interaction design. Each game focused on different aspects of visual perception, such as shape recognition, object tracking, and hand-eye coordination. Two games from different groups were used during the study. Each selected game targets specific aspects of visual perception relevant to the study's goals, focusing on how children process, remember, and respond to visual stimuli in various contexts. Tasks with static objects were chosen specifically to measure sustained attention, a key element of visual perception and concentration. In contrast, tasks with moving objects allowed us to assess eye-tracking and smoothness of eye movement, providing insights into the children's ability to coordinate visual attention while in motion. These tasks form the basis for visual-motor skills and spatial awareness, as emphasized by Kinka's game developers, who designed these games based on psychological and therapeutic insights into perceptual skill development. Additionally, tasks involving memory and recognition of objects were selected to assess visual working memory, as they required children to recall and recognize elements seen earlier in the game. The games focused on the following abilities:

- focusing visual attention on a static object, assessing participants' ability to keep attention on a single point,
- focusing visual attention on a moving object, allowing us to assess flexibility and smoothness of eye movements in a dynamic game environment,
- maintaining gaze on a selected object, testing the ability to keep attention on a chosen element under different game conditions,
- tracking an object, which allowed us to examine precision and control of eye movements in various directions,
- memorizing and recognizing objects during gameplay.

Each game was carefully adapted to the age and skill level of the study participants, and the diversity of tested abilities across different game groups enabled a comprehensive analysis of visual perception. This varied approach to assessing visual skills allowed for a fuller understanding of children's specific responses in different behavioral contexts. The selected tasks and computer games were chosen to evaluate various aspects of visual perception: tasks involving stationary objects assess visual attention concentration, while tasks with moving objects evaluate saccadic smoothness and precision in gaze control (Figure 1). Each task provides unique data on fixation durations, saccade amplitude, and blink frequency, enabling a detailed understanding of perceptual mechanisms under different conditions [1, 17].

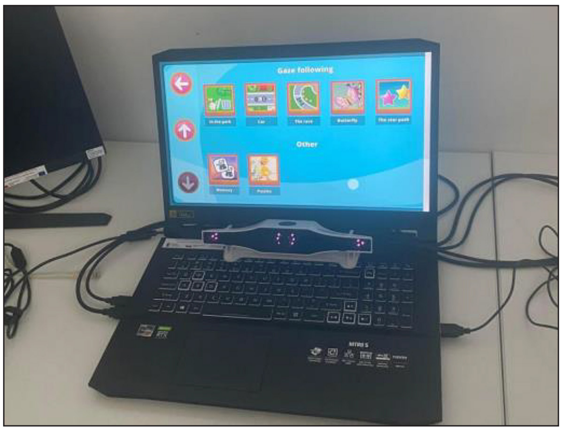

Figure 1. Computer games used during the experiment

Research procedure

The research procedure, during which eye tracking studies were conducted, involved a careful selection of the appropriate research object. In our study, therapeutic computer games specifically designed for eye tracking research in children were chosen. The studies were conducted on a group of 30 children aged 5 to 12 years. In the healthy group, none of the children had psychological disorders, epilepsy, or were taking any medication. In the second group, there were children diagnosed with disorder such as Asperger's syndrome. Recruitment of participants for eye tracking studies was carried out through announcing planned research on visual perception in children. Information was made publicly available on internet platforms and through local communities. Parents of children interested in participating in the study had the opportunity to register their offspring by completing a registration form, which was available online on the research announcement website. The registration form contained key information about the study objectives, procedures, and potential benefits and risks associated with the child's participation in the experiment. Additionally, the form included contact details that allowed researchers to directly communicate with parents for further correspondence and obtaining additional information. All registrations were carefully reviewed for compliance with inclusion criteria for the study, such as the child's age, mental and physical health. Subsequently, parents of children meeting the qualification criteria were informed of their offspring's acceptance to participate in the research and further steps, such as scheduling the experiment date and location, were arranged. The research procedure included the presentation of different computer games, each designed to explore various aspects of eye activity. Each participant was required to maintain maximum focus during gameplay, which constituted a crucial element of the research procedure [1].

Preparation for the research procedure

Before commencing the study, participants were briefed on the rules applicable in the research laboratory. Detailed information about the purpose and course of the study was provided. Additionally, participants signed consent forms to participate in the study. The research was approved by the Ethics Committee of the Lublin University of Technology [1]. Study participants were instructed not to make vigorous head movements and to remain in a stable body position. The use of a specialized chair minimized unwanted behaviors during the study. The room where the study was conducted was dimly lit, allowing participants to focus their visual activity fully on the monitor screen without distractions. The low-light conditions facilitated better eye tracking results than in a strongly illuminated room. Gazepoint Control software assisted in determining the appropriate position and distance from the eye tracker. Upon activation, the software displayed a real-time image from the camera mounted on the eye tracker, showing the participant their own eyes and face. This allowed for the adjustment of the chair and the participant's head position (Figure 2). Subsequently,

Figure 2. Proper positioning of the participant child during the experiment

the calibration process was conducted. The calibration process involves measuring individual characteristics, such as the position of the pupil relative to the cornea and the yellow spot on the back of the eye. The goal of this process is to achieve the highest possible accuracy in the study. Calibration was performed according to the appropriate calibration procedure for the GP3 eye tracker device [1, 18, 19].

There were also limitations in the calibration process due to the age differences among participants. Younger children often found it challenging to understand the calibration process and to remain still, particularly during their first encounter with the equipment. To address this, additional calibration checks and significantly shorter calibration sessions were employed to prevent fatigue. These adjustments included reducing the number of calibration points and incorporating brief breaks, making the calibration process more manageable for younger participants. By implementing these age-appropriate modifications, we aimed to enhance data accuracy while accommodating the attention spans and cooperation levels of younger children.

Study participants

The study was conducted on a group of children aged 5 to 12 years. Children from the healthy group were 11 years old, while the child from the Asperger's group was 10 years old. This diverse age spectrum considered developmental differences crucial for understanding potential changes in visual perception. Among the studied children, a division was made into two main categories: healthy and those with mild psychological disorders, such as Asperger's syndrome. In the first group, consisting of healthy children, none of the participants exhibited psychological disorders, epilepsy, or took any medication. This ensured that the analysis of visual perception was conducted on a group with homogeneous mental and physical health. In the second group, focusing on children with mild psychological disorders, specific needs of the participants were taken into account. Children with Asperger's syndrome or autism were an integral part of the studied population, allowing for the analysis of visual perception in the context of these disorders. The caregivers of the participating children in the experiment provided written consent for the study, and the research project was positively evaluated by a psychologist (Figure 3) [1, 20].

Obtaining eye tracker record

The Gazepoint Control software was exclusively utilized for the calibration process of the eye-tracking setup. The software operated in conjunction with the video camera embedded in the eye tracker, recording the real-time position of the pupils. This functionality was particularly

Figure 3. Study participant during the research procedure

beneficial when working with very active children, as the software was fast enough to accurately capture the position of their pupils despite movement. The software also indicated precisely how the child's head should be positioned in relation to the device. It marks the position of the pupils with green squares, as shown in Figure 4, and overlays circles around the reflection point on the cornea. This feature is especially useful during calibration, allowing for precise adjustments of head position and distance from the device before starting the experiment. By employing these capabilities, we ensured that accurate eye-tracking data could be obtained even with very energetic children.

To collect data during the research, the Gazepoint GP3 eye tracker was utilized. The Gazepoint GP3 eye tracker is characterized by a precise vision camera, enabling the tracking of subtle eye movements, and easy mounting for attachment to a laptop beneath the screen (Figure 5). The eye tracker's functionality provided insights into aspects such as gaze direction and

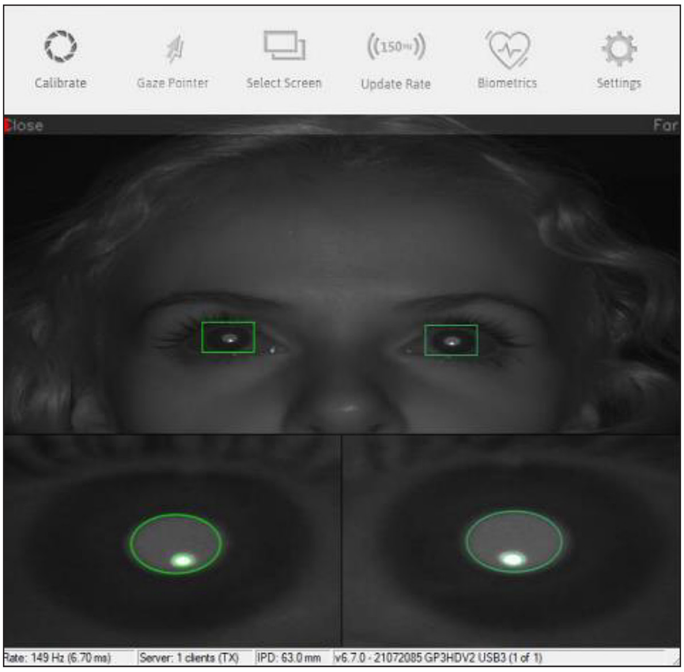

Figure 4. Operation of Gazepoint Control software during study research procedure

Figure 5. Structure of the GP3 eye tracker

the time participants spent on specific areas of the screen. Its application was focused on eye tracking, utilizing a centrally positioned vision camera in the imaging and processing system. The collected data were analyzed using iMotions software, which offers an intuitive interface that does not require specialized training. Its visualization and analysis features enabled the generation of detailed heatmaps and gaze paths, allowing for an accurate representation of the areas of greatest attention focus among participants. Such analytical tools provided a solid foundation for drawing conclusions regarding the perceptual patterns of the children studied and their reactions to specific visual elements.

This methodological approach provided a reliable means of collecting eye-tracking data, which was subsequently analyzed to assess children's focus and reactions to visual stimuli in gameplay.

RESULTS

Data analysis

After completing the research procedure, an analysis of the collected data was performed, which can be divided into the following parameters:

- Temporal signature (ms),
- Fixation index,
- Fixation duration (ms),
- Saccade index,
- Saccade duration (ms),
- Saccade amplitude (deg).

Upon exporting the research results and selecting the relevant parameters, an analysis was conducted, encompassing both graphical and statistical data analysis. Graphical analysis included generating heatmaps and gaze paths. The obtained eye-tracking heatmaps depict the collected and visualized data, identifying the highest visual attention during gameplay. Through the eye-tracking heatmap, one can understand the behavior of the participants during the game, track the gaze path, focus on specific elements, and identify triggering factors responsible for the participants' specific actions. The gaze path represents the trajectory of the child's eye movement during gameplay. Gaze paths reveal how the participants move their gaze between elements or areas during the game. Statistical data analysis primarily focused on comparing parameters, particularly fixation and saccade durations, among the examined children. It was crucial to consider feedback and observations made during the research procedure for each specific child. This approach allowed confirming the consistency of the research results [1].

Maps of eye tracking and gaze paths

The eye tracking heatmap was generated based on the data collected during the monitoring of eye movements. The iMotions software allowed for the export of data gathered during the conducted research. The obtained eye tracking heatmaps present the collected and visualized data, indicating the highest visual attention during gameplay. The collected data represent the number of gazes on individual elements by the participant, as well as the duration of fixations. Eye fixations were visualized in the form of heatmaps, highlighting the elements on which the examined children focused their gaze [1].

A heatmap obtained is presented in Figure 6. It illustrates the aggregated fixations of the examined child. The fixation heatmap, based on fixations, shows the frequency of user interaction with the game throughout the gameplay and which game elements were most frequently viewed. The structure of the heatmap image is divided into a grid, where each square represents the intensity value recorded by the eye tracker, assigning specific colors to these values. The highest value in relation to the rest of the data is indicated by the "hot" color, i.e., red, while the lowest value is represented by the "cold" color, i.e., green. During the "Torches" game, the study participant had to focus on an element, specifically a torch, to make its flame grow larger. The heatmap showed a significant focus near the torch in red, providing precise and accurate eye tracking. Additionally, a gaze path for the same moment of lighting the torch was obtained. The gaze path in Figure 7 illustrates the eye movement trajectory near the torch for the selected gameplay segment [1].

The intensity of focus was measured by analyzing fixation times, which indicate the moments when the child's gaze was concentrated on the torch, as well as the gaze trajectories that illustrate the path of eye movement across the various torches. The heatmap presented in Figure 6, utilizing the Areas of Interest (AOI) technique, allows for the precise identification of the torches that were most intensively observed by the children. The areas of interest were defined in the context of the game elements, enabling us to better understand

Figure 6. Heatmap during the "Torches" gameplay [10]

Figure 7. Gaze path during the "Torches" gameplay [10]

which elements captured the participants' attention the most and how their perception translated into interaction with the game.

A heat map, presented in Figure 8, was obtained based on the intensity of fixations during a child's interaction with the Lemurs game. The heat map is a result of dynamic gameplay, where lemur elements of the game energetically popped out from various pits. The player, namely the child, had the task of quickly capturing them with their gaze, making the entire game full of energy. The structure of the heat map is constructed on a grid, where individual squares represent the intensity of attention captured by the eye tracker. Each square is assigned a specific color, with the highest values marked with an intense red color symbolizing "hot" areas, while the lowest values are marked with "cool" colors, mainly green.

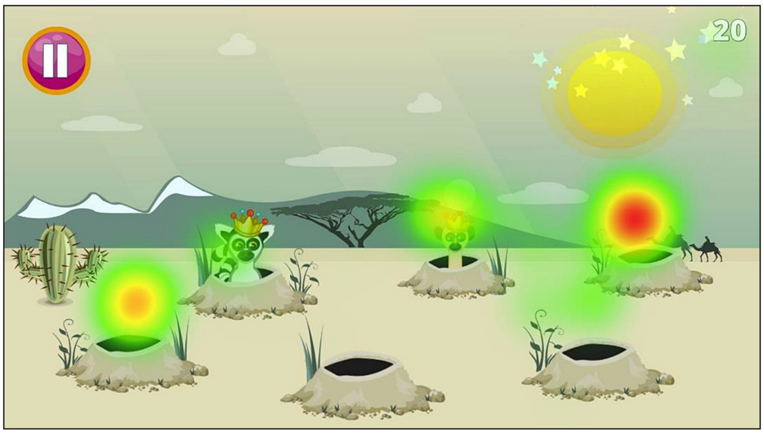

Figure 8. Heat map during the "Lemures" gameplay [10]

Figure 9. Gaze path during the "Lemures" gameplay [10]

During the Lemurs gameplay, the participant had to rapidly track game elements represented by rapidly emerging lemur characters. The heat map revealed that the greatest concentration of gaze occurred in areas where lemur characters appeared, and the participant intensely looked at the popping lemurs to catch them. These areas were marked with an intense red color, confirming the dynamic nature of the game. Additionally, the gaze path presented in Figure 9 during one of the more exciting moments of the game was highlighted, showing how the player's gaze moved in rhythm with rapidly changing challenges. This gaze path provides additional information about the precision and effectiveness of the player's visual reactions during the intense gameplay in the Lemurs game.

Quantitative data analysis

The obtained heat maps and gaze paths provided a accessible and comprehensible visualization of the data from the conducted eye-tracking studies. However, to delve deeper into the acquired data, it was necessary to export them for further analysis and the creation of box plots. Figure 10 presents an example of a box plot and a description of its variables, which will be subjected to analysis for the data obtained from the studies.

For the game "Torches," a chart was developed as shown in Figure 11. The chart depicts the relationship of saccade duration for randomly selected children from a group of individuals. Three randomly chosen children were aged 11, 11, and 10, respectively, labeled as X, Y, and Z. The 11-year-old children were from a healthy group, while the 10-year-old child had Asperger's. In examining the chart, it is evident that child X and child Z exhibited the highest outlier values in saccade duration, suggesting significant differences in cognitive processing between the two groups. This indicates concentration issues compared to child Y, who demonstrates more typical engagement with the game. The eye movements of children X and Z were slower or lasted longer when compared to child Y in the same observational situation during the gameplay of "Torches." The longer saccade duration in children with Asperger's syndrome could imply a distinct approach to visual perception, where processing visual information may be less efficient. This inefficiency might be tied to difficulties in shifting attention or a tendency to become overwhelmed by visual stimuli, affecting their overall concentration

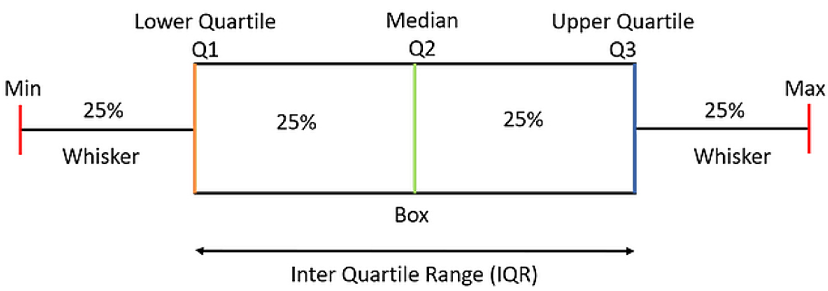

Figure 10. Sample box plot and description of its variables [9]

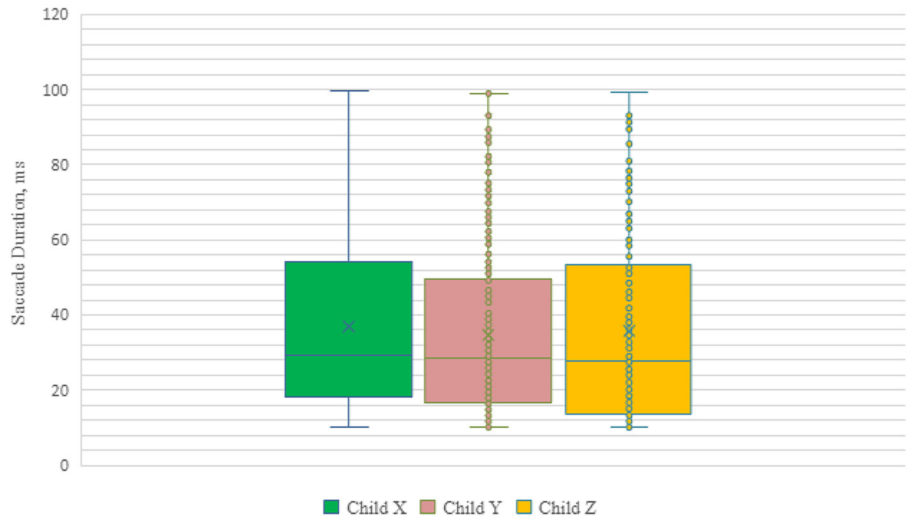

Figure 11. A graph showing the relationship between saccade duration for three children

during the study. Child X showed some initial disorientation related to the functioning of the eye tracker at the beginning of the study, which could have influenced the results. Child Z perceived the game as boring and too simple, contributing to lower engagement in the study and poorer results. These findings suggest that children with Asperger's may have unique responses to stimuli, which not only affect their behavioral outcomes but also imply that their cognitive processing may differ fundamentally from that of typically developing peers. The study results align with additional research methods, namely interviews and observations. Child Y achieved the best results, confirming during the interview that they found the game interesting and easy. This contrast emphasizes that the individual characteristics of children, such as concentration, adaptation to new research situations, or subjective feelings regarding the attractiveness of the game, play a crucial role in their engagement levels. For Child Z with Asperger's, an essential factor may also be the level of interest and the difficulty level of stimuli, highlighting the need for tailored interventions that accommodate varying cognitive processing styles [1].

In Figure 12, three box plots are presented, each having significantly different ranges of fixation duration variables. For the child labeled as X, these were decidedly the lowest values of fixation duration. Following closely, in the second

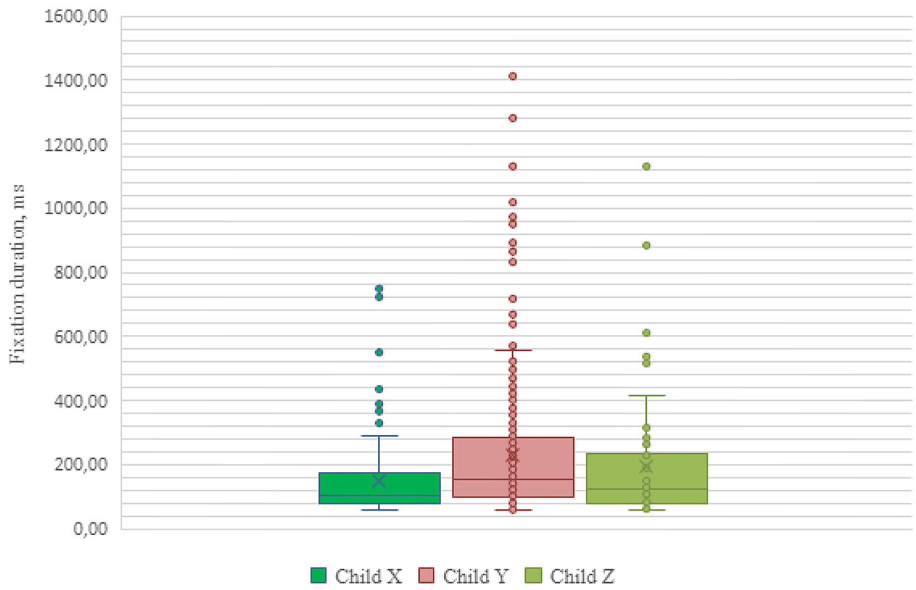

Figure 12. A graph showing the fixation duration relationship for three children

position, was the child labeled as Z. The widest range of variables on the plot belonged to child Y. A low fixation duration indicates issues with the ability to maintain a stable focus on specific elements in the game, as well as weak concentration during gameplay. In the case of the previous plot depicting saccade duration for the child labeled as X, poor results were also evident. This was due to the fact that during the "Torches" game, the participant experienced difficulty understanding the functioning of the eye tracker, leading to a lack of proper focus. Additionally, during moments of gaze distraction, noticeable frequent eye migrations between different objects were observed. Results for the variables of the child labeled as Z were also within a lower range, albeit slightly higher than those for child X. It is worth noting that in the previous plot for saccade duration, child Z also achieved poor results. For the entire trio of children, numerous outliers were present, with the highest number for child Y. Outliers may indicate a child's particular interest in specific elements. Child Y achieved the highest outlier value for the variable, suggesting an intense focus on details and a comprehensive understanding of the presented game. The results suggest that individual differences may stem from factors such as the degree of interest in the game, adaptation to the equipment, and subjective assessment of the task's attractiveness, rather than solely from the presence of developmental disorders [1].

For the game "Lemurs," a chart was created as shown in Figure 13, which includes the same children as in the previous study. Additionally, three similar box plots were obtained for the results of these children. The analysis of the box plots reveals similarities in the values for the lower quartile (Q1), median (Q2), and upper quartile (Q3). The duration of saccades for children with Asperger's was analogous to the saccade durations of healthy children, which aligns with studies indicating that children with ASD may demonstrate a normal level of visual stimulus processing in specific situations. This suggests that children with Asperger's, despite challenges in social skills, do not have significant limitations in concentration and response to visual stimuli, consistent with the information processing theory that emphasizes that children with ASD can process information similarly to their neurotypical peers. The detected extreme values, both high and low, were similar in both groups, confirming the stability of responses. Children with Asperger's may have intensely focused on selected elements of the game, which is in line with the common understanding that children with ASD may have particular interests in specific visual stimuli. The absence of significant deviations in the results suggests that the children were well acquainted with the functioning of the eye tracker after the first game, which is consistent with the theory of experiential learning, where the repetition of actions contributes to improved performance.

Figure 14 shows the results of eye-tracking research conducted during the "Lemurs" game, which involved dynamically "catching" lemur characters that suddenly popped up from the ground. The three children in the study included two neurotypical children (X and Y) and one child with Asperger's syndrome (Z). The game required the children to rapidly shift their gaze to new targets, allowing an assessment of their ability to dynamically respond to sudden visual stimuli. The chart clearly shows a shorter fixation duration for

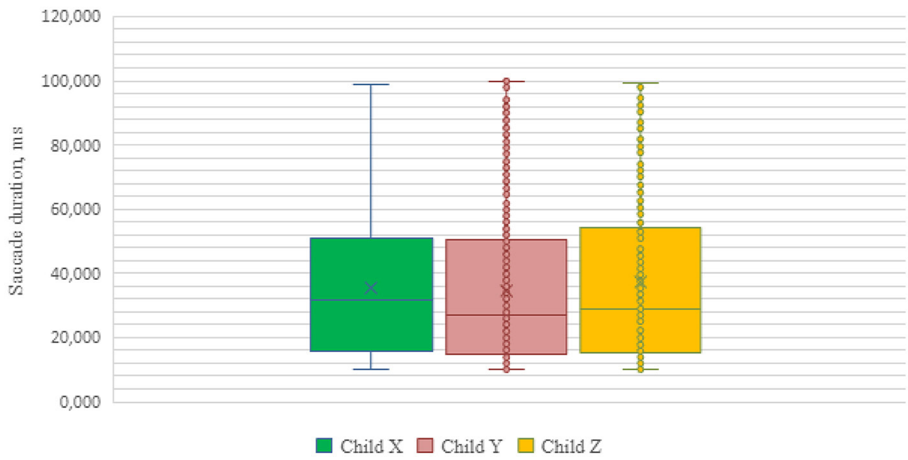

Figure 13. A graph showing the relationship between saccade duration for three children

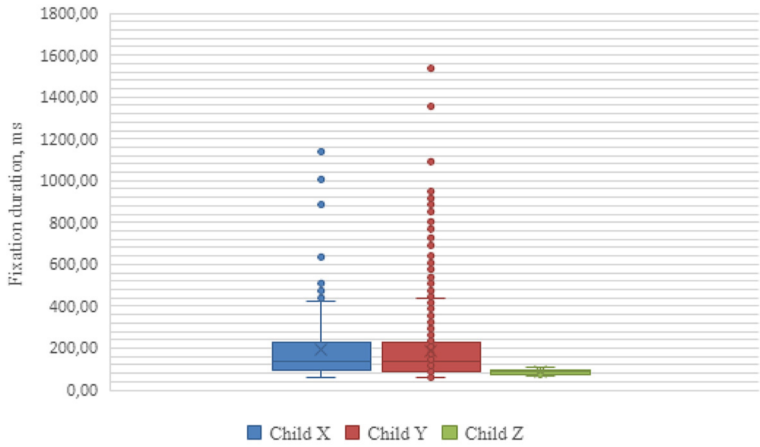

Figure 14. A graph showing the fixation duration relationship for three children

Child Z, suggesting a different approach to visual perception and reaction to stimuli compared to the neurotypical children (X and Y). The intense focus observed in Child Z during the game may have resulted in quicker gaze shifts between the appearing lemurs, without the need for prolonged fixation on any one element. For the neurotypical children, the fixation duration was longer, which may indicate that they required more time to process each stimulus before shifting their gaze to the next target. This difference may imply that the child with Asperger's syndrome had a greater ability to quickly scan the environment, possibly due to a distinctive approach to processing visual stimuli. Such results may indicate a specific perceptual strategy in individuals with Asperger's syndrome, where intense but more dispersed focus allows rapid responses to changing visual elements. In the context of dynamic tasks like "Lemurs," this could lead to more effective detection of sudden stimuli but at the expense of detailed processing of each individual element. These data are valuable for better understanding sensory perception differences and the way individuals with Asperger's interact with dynamic environments that demand rapid shifts in attention.

DISCUSSION

The presented measurement method, combined with eye movement analysis, provides a clear characterization of visual processing functions in different groups of children. A key feature of this paradigm is that performance relies on eye movement reactions to visual stimuli, which are triggered reflexively during gameplay. No specific verbal instructions are given, and there is no need for children to respond verbally. Ultimately, many outcome measures for individual children should be considered on an individual level. Summarizing all outcome measures provides a unique characterization of visual information processing abilities, which can be transformed into a visual profile in children.

Referring to other studies conducted using similar methodologies, it is worth mentioning the research efforts of the team from the Shanghai Children's Medical Center and Shanghai Jiao Tong University School of Medicine. In [23] an innovative approach to assessing intelligence in children with global developmental delay using eye-tracking technology was presented. The results of these studies show that cognitive development in children can be rapidly assessed using eye-tracking technology. Furthermore, it allows for tracking quantitative intelligence outcomes and detecting intellectual impairment [23].

The methods used in both studies employ eye-tracking technology, but the aim and scope of the analyses are different. In our study, we focused on assessing children's visual reactions to visual stimuli during interaction with computer games. In contrast, the study by the research team from Shanghai examined gaze patterns in the context of tasks related to intelligence. Both studies utilize analysis of ocular data, such as saccades and fixations, but in different contexts and with different aims. The results of both studies may have significant implications for clinical practice and intervention design. Despite using the same research method, our study may be useful for user interface designers and digital content creators. Meanwhile, the research by the Shanghai team may be beneficial for clinicians and specialists dealing with cognitive development in children with developmental delays.

The results of the studies mentioned in the publication may indicate changed ways of processing visual information among healthy and sick children, which aligns with our observations. This comparison with other studies confirms the significance of the obtained results and the versatility of using eye-tracking devices in studies on children's visual perception. This would help in understanding the long-term effects of visual stimuli exposure on cognitive development, providing insights that could inform educational and therapeutic strategies [27].

The information about what children pay attention to is not sufficient to draw unequivocal conclusions. Therefore, another research method, namely interviews with the studied children, was also utilized to obtain information about their feelings during the experiment. In all conducted studies, the interviews aligned with the obtained results for each participant. Future studies could also incorporate feedback from parents and educators to gain a more holistic view of children's visual interactions and preferences, enhancing the validity of the findings. For instance, insights from parents about their children's reactions in everyday situations could inform the development of tailored educational interventions, thus bridging the gap between research and real-life applications [29].

The obtained values of gaze or fixation durations refer to measurements and parameters that can determine a child's visual behavior during eye-tracking studies. Comparing specific gazes or fixations with the stimulus of focusing on a particular element shows what captures the most attention of the participant. These insights could inform the design of educational materials and digital content, ensuring they are engaging and appropriately challenging for various age groups and developmental stages. This would promote better learning outcomes by aligning educational content with the visual preferences of children [28].

The conducted data analysis facilitates an understanding of the cognitive process, visual preferences, and the child's interaction with the content in the studied games. This confirms the thesis that using an eye tracker makes it possible to examine visual perception in children.

Child Z, diagnosed with Asperger's syndrome, achieved lower results in both fixation and saccade durations compared to Child Y. This enabled the identification of specific gaze patterns in children with Asperger's compared to the group of healthy children. It is recommended that future research explores the correlation between specific gaze patterns and educational outcomes, particularly for children with developmental disorders. Such research could yield valuable data that help educators tailor their approaches to better support these children's learning experiences.

Additionally, Child Z rated the game as boring and too easy, indicating differences in reactions and feelings compared to healthy children. Understanding these differences can lead to the development of tailored educational interventions that address individual needs and preferences, particularly in therapeutic settings. By considering children's feedback on engagement levels, therapists and educators can refine their approaches to better meet the specific interests of children with developmental disorders.

Children with Asperger's may react differently to social stimuli compared to healthy children. However, in the case of the examined children for the purposes of our work, not all individuals with Asperger's exhibited identical difficulties or specific gaze patterns. This variability highlights the need for personalized approaches in both research and therapy, advocating for individualized treatment plans that consider each child's unique visual processing strengths and challenges. Integrating insights from both eye-tracking data and qualitative feedback can lead to more effective interventions tailored to individual profiles.

Therefore, eye-tracking studies, utilized in the form of computer games, constitute an excellent tool for analyzing visual perception in both healthy children and those affected by Asperger's syndrome. By applying this innovative method, it is possible not only to collect objective data regarding gaze patterns but also to use computer games for therapeutic purposes and monitor the progress of therapy or intervention effectiveness. Integrating eye-tracking technology into existing educational platforms could further enhance the effectiveness of interventions tailored for children with visual processing difficulties, ensuring that educational tools resonate with their specific learning needs.

In the case of healthy children, computer games provide an attractive form, allowing for the natural observation of their visual reactions in a dynamic and engaging environment. The ability to track how children react to various stimuli in the game can provide valuable information about their perception, level of focus, or visual preferences.

In the context of children with Asperger's syndrome, computer games can serve as both a diagnostic and therapeutic tool. To maximize their effectiveness, future research should focus on developing specific game mechanics that cater to the visual preferences and challenges faced by children with developmental disorders, potentially enhancing engagement and therapeutic outcomes. By aligning game design with the cognitive profiles of these children, we can foster both learning and therapeutic engagement.

Through monitoring how children with Asperger's react to a virtual environment, eye-tracking studies enable doctors and therapists to identify specific difficulties related to visual perception. Additionally, computer games can be integrated into the therapeutic process, allowing for the adaptation of visual training to the individual needs of patients.

Research utilizing an eye tracker in the analysis of visual perception in children opens the door to fascinating possibilities for understanding human vision at an earlier stage of development. We encourage collaborations between researchers, educators, and clinicians to create interdisciplinary approaches that can fully leverage eye-tracking data in educational and therapeutic settings. Such partnerships could facilitate the development of comprehensive interventions that are grounded in empirical data and tailored to the needs of children.

However, they are just one of many examples where advanced research technologies allow delving into the intricacies of human visual experience. For instance, studies conducted by a team of researchers from Stanford University using an eye tracker in the analysis of visual perception in children with autism have shown that these children may have altered ways of processing visual information compared to their peers without disorders. Similarly, an eye tracker to analyze visual perception in children with ADHD revealed differences in attentional focus on visual stimuli compared to the control group. These diverse applications of the eye tracker clearly demonstrate its potential as a research tool for better understanding the development of visual perception in children and identifying various related disorders.

In terms of control, eye-tracking studies enable a systematic assessment of therapy effectiveness and provide objective data that aid in making informed clinical decisions. Regular analysis of gaze patterns allows for tracking patient progress, adjusting the therapeutic plan, and monitoring potential changes in visual perception during therapy, making it possible to implement timely interventions that cater to the evolving needs of each child.

In summary, eye-tracking studies used in the form of computer games constitute a versatile tool that not only allows for the analysis of visual perception but also fits into a therapeutic context, offering control possibilities and providing objective data to support the healing process. Going forward, we recommend prioritizing research that directly explores the integration of eye-tracking technology into educational curricula and clinical practices, ensuring that findings translate into meaningful improvements in children's visual and cognitive development. This emphasis on practical applications will enhance the relevance of research outcomes for practitioners working with children in both educational and therapeutic settings [27, 28, 29].

CONCLUSIONS

The analysis of data obtained in connection with the conducted research has allowed for drawing several significant conclusions. The conducted studies revealed the essence of the eye tracker as a device that facilitates a deeper understanding of children's interaction with the digital world. The eye tracker as a research method allowed for a precise understanding of children's perspectives during their interaction with the equipment. To strengthen the applicability of our findings, we recommend conducting longitudinal studies that track visual perception over time, focusing on both healthy children and those with developmental issues.

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