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Original Article

An Examination of Eye Tracking in Videos and 3D Animations in Children with ASD and TD Children

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Abstract

Visual attention impairments of children with autism spectrum disorder (ASD) have been investigated in many studies over the past two decades. The purpose of this study was to examine the visual attention of children with ASD and typically developing (TD) children in different social interaction contexts. Videos and 3D animations with three different levels of social interaction content (low, medium, and high) were created for the current study. The participants included 21 children with ASD ($\bar{X}$ = 7.6, SD = 1.7) and 22 TD children ($\bar{X}$ = 8.5, SD = 1.0), all aged between 5 and 12 years. The participants observed the video and 3D animation presentations on a computer screen as a passive viewing task. While the children watched the social interaction scenarios, eye-tracking data was collected to analyze their total fixation duration. The findings indicated that both children with ASD and TD children exhibited the longest total fixation duration on the Eyes and Mouth regions, particularly during the Chocolate Bread scenario, which featured low-level social interaction. When we examined visual attention during the presentation of videos and 3D animations, we found that both groups of children displayed significantly more fixation duration on the face region, especially the Eyes region during the 3D animation presentation compared to the video presentation. The research findings were discussed, and recommendations for future studies were provided.

Keywords

Autism spectrum disorder
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Introduction

With the development of eye-tracking technologies in the last two decades, understanding how individuals with autism spectrum disorder (ASD) perceive and gather information from human faces has become one of the important research areas for autism researchers (e.g., Behrmann, Thomas, & Humphreys, 2006; Chawarska, Klin, Paul, & Volkmar, 2007; Falck-Ytter, Bölte, & Gredebäck, 2013; Hamner & Vivanti, 2019; Nagai et al., 2013). The reasons for this interest are the difficulties that individuals with ASD experience during social interactions and their diminished social interest in people. Infact, numerous studies have shown that individuals with ASD have difficulty understanding human facial expressions and anticipating intentions through eye contact, which may hinder their ability to regulate their reactions (Davidovitch, Stein, Koren, & Friedman, 2018; Mastergeorge, Kahathuduwa, & Blume, 2021; Pierce et al., 2016).

Examining the underlying reasons for social communication difficulties in children with ASD and understanding the nature of their social difficulties are critical areas of focus in the current study. Threfore, understanding the visual attention patterns displayed by children with ASD when observing social cues across diverse social contexts has gained significant attention. Studies using eye-tracking techniques have offered insights into distinct visual attention patterns specific to children with ASD, children at risk of developing ASD, children with developmental delays, and typically developing (TD) children (Jones & Klin, 2013; Mastergeorge et al., 2021; Pierce et al., 2016; Shic, Wang, Macari, & Chawarska, 2020). Eye-tracking is a data collection technique used to examine various eye movements, such as fixations and saccades, while an individual engages in an activity or observes a visual stimulus. This visual attention data offers valuable insights into cognitive and psychological processes, including perception, attention, and interest (Brockmole & Henderson, 2005; Forde, Rusted, Mennie, Land, & Humphreys, 2010; Hayhoe & Ballard, 2005).

Eye tracking measures eye movements and the distribution of gaze patterns in response to processing visual information (Mastergeorge et al., 2021). Face processing involves directing visual attention to human face and observing eye movements displayed on a human face (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000; Farroni, Csibra, Simion, & Johnson, 2002). This skill begins to develop from birth (Bedford et al., 2012). By the end of the first year, infants can shift their gaze to objects that an adult looks at or points towards, establishing joint attention with the adult (Mundy, Sigman, Ungerer, & Sherman, 1986; Tomasello & Farrar, 1986). The development of joint attention skills in infants continues through early childhood with children starting to intentionally track human faces (Rump, Giovannelli, Minshew, & Strauss, 2009; Scherf, Behrmann, Minshew, & Luna, 2008). However, early challenges in directing attention to and processing human faces are linked to adverse effects on social cognition and language development (Kuhl, Williams, Lacerda, Stevens, & Lindblum, 1992; Leppanen & Nelson, 2009; Pascalis et al., 2005; Thiessen, Hill, & Saffran, 2007). For example, if a child struggles to follow a person's gaze during dyadic social interactions in their early years, it can impede their processing of nonverbal social cues, which in turn may lead to challenges in responding to joint attention (Falck-Ytter, Fernell, Lundholm-Hedvall, Von Hofsten, & Gillberg, 2012).

Since the turn of the century, eye-tracking technology has significantly advanced our understanding of the social difficulties faced by children with ASD. This technology has been employed in research as an indicator of social attention and perception, yielding valuable insights (Noris, Nadel, Barker, Hadjikhani, & Billard, 2012; Özer & Özdemir, 2015). Current studies argue that visual attention is an important biomarker in children with ASD and demonstrate that toddlers with ASD can be distinguished with an 87% accuracy rate using machine learning methodologies (Özdemir, Akın-Bülbül, Kök, & Özdemir, 2022). While some researchers use eye-tracking techniques for ASD risk assessment, many others examine the nature of visual social attention in individuals with ASD. Researchers use eye-tracking technique to classify children with ASD's face recognition skills and examine their facial processing development (Klin et al., 1999; Scherf et al., 2008), eye movements (e.g., Chawarska, Klin, & Volkmar, 2003; López, Donnelly, Hadwin, & Leekam, 2004) and reaction time in visual attentional processing (eg., van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2002). Many researchers reported how children and adults with ASD process object and face recognition (Dawson et al., 2002) while watching human actions by directing visual attention to the model (Akın-Bülbül & Özdemir, 2021) and whether their visual attention differs from that of TD individuals while watching biological human movements (Kaliukhovich et al., 2021). In particular, research findings suggest that individuals with ASD, both children and adults, show a reduced preference for observing biological movements compared to TD individuals indicating less attention to these movements (Kaliukhovich et al., 2021). When observing people's actions, young children with ASD are often found focusing on unrelated external areas instead of the motor action areas (Akın-Bülbül & Özdemir, 2021). Furthermore, Dawson, Meltzoff, Osterling, Rinaldi, and Brown (1998) found that individuals with ASD experience a delay in directing their visual attention to social stimuli compared to non-social stimuli. And, when they do eventually focus on social stimuli, their initial fixation time is typically delayed.

Examining face processing and face recognition in relation to visual attention in children with ASD has gained momentum, as evidenced by different studies (e.g., Bradshaw, Shic, & Chawarska, 2011; Chawarska & Shic, 2009; Chawarska, Volkmar, & Klin, 2010; Hobson, Ouston, & Lee, 1988; Langdell, 1978). Many studies indicate that, in facial processing, children with ASD often pay less attention to human faces. When viewing static images or videos, they direct their gaze to face comprehension for shorter durations compared to TD children (e.g., Chawarska et al., 2010; Dawson et al., 2002; Kaliukhovich et al., 2021; Kang, Han, Song, Niu, & Li, 2020; Scherf et al., 2008). Furthermore, it's been reported that children with ASD have significant difficulties in identifying facial expressions reflecting different emotions and in processing unfamiliar human faces (e.g., Golan & Baron-Cohen, 2006; Hobson et al., 1988; Jiang et al., 2019; Langdell, 1978; Nag et al., 2020). In contrast, research with both children and adults with ASD has shown that while their visual attention when examining objects is similar to that of TD participants, they exhibit weaker visual perception when interpreting human faces (Scherf et al., 2008). Scherf et al. attributed this limitation to the fact that human faces have more homogeneous features than objects, emphasized that individuals with ASD have a general visual perceptual limitation, and this limitation is specific to children and adults with ASD who have a low level of social interaction experience, such as looking at human faces.

Recent literature has shown that compared to children with TD, children with ASD show more fixations on areas such as the chin and neck when viewing images of human faces or a social image, rather than focusing on areas such as the eyes, nose, and mouth, which are considered social areas in face processing (Chawarska, Klin, Paul, Macari, & Volkmar, 2009; Klin, Jones, Schultz, Volkmar, & Cohen, 2002a; Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011). More specifically, when researchers use eye tracking to study the visual attention patterns of individuals with ASD, they find that these individuals exhibit more saccadic eye movements during face-to-face interactions (Zhao, Tang et al., 2021) and have shorter fixation durations in social areas (Nackaerts et al., 2012; Wass et al., 2015).

In summary, many studies have consistently demonstrated that children with ASD exhibit significant limitations in directing and sustaining visual attention to human faces (Klin et al., 1999; Marsh Scheele, Postin, Onken, & Hurlemann, 2021). These limitations extend to the depth of face processing, perceptual distinctions (e.g., face vs. faceless), and semantic features (e.g., mother vs. non-mother) (Bradshaw et al., 2011; Golan & Baron-Cohen, 2006; Shanok, Jones, & Lucas, 2019). Some researchers highlight potential oculomotor impairments affecting visual attention (Zhao, Xing et al., 2021). In contrast, others suggest broader attentional challenges, as evidenced by the eye movement patterns between social and non-social stimuli (Chita-Tegmark, 2016; Frazier et al., 2017). In addition to these researchers who discuss a general attentional problem based on the idea that human attention should be more selectively focused on social stimuli (Chita-Tegmark, 2016; Frazier et al., 2017), many others also show that TD individuals focus more on social areas and less on non-social areas (Zhao, Tang et al., 2021; Zhao, Zhu et al., 2021).

Moreover, recent research findings indicate that children with ASD show diminished visual attention to social stimuli, and these attentional limitations are unique to individuals with ASD (Nackaerts et al., 2012; Wass et al., 2015; Zhao, Xing et al., 2021). For instance, Golan and Baron-Cohen (2006) found in their study that individuals with ASD had significant difficulties recognizing emotions conveyed through social contexts, body language, facial expressions, voices, and eyes when compared to a control group. Similarly, Bradshaw et al. (2011) compared children with ASD and TD children in recognizing social stimuli, such as human faces and non-social stimuli, like basic objects. Their findings revealed that children with ASD children with ASD exhibited better performance in recognizing non-social stimuli than their TD peers, but showed limitations in recognizing social stimuli such as human faces compared to their TD peers.

Results from a limited number of eye-tracking studies indicate that as children with ASD grow older, their visual attention on human faces decreases. Specifically, a study by Chawarska and Shic (2009) examined visual attention in 26- and 46-month-old children with ASD and TD children of similar ages. Researchers found no difference in visual attention between TD children and children with ASD to the eyes and nose regions in static images, with the exception that children with ASD looked at the mouth region less than TD peers. Furthermore, children with ASD spend more time looking at the outer face areas, like the hair, cheeks, and forehead. Interestingly, these group differences were not significant among 2-year-old children but became apparent among 4-year-olds. The study also highlighted that as children with ASD aged, their attention to the social parts of the face decreased. In a similar study, Shic, Chawarska, Bradshaw, and Scassellati (2008) observed that 26-48-month-old children with ASD and their TD peers exhibited different eye movement patterns when observing human faces in static images. While the attention of TD children to the face area increased with age, marked by shifting gaze between eyes and mouth, their ASD peers increasingly shifted their attention from these social areas to other, non-social areas.

One of the leading theories to explain the nature and underlying causes of the differences seen in the eye tracking of children with ASD is Social Motivation Theory. This theory posits that the restricted visual attention to social stimuli in children with ASD stems from low social motivation (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Dawson et al., 2002; Grelotti, Gauthier, & Schultz, 2002; Harrison & Slane, 2020; Klin et al., 2002a; Schultz, 2005). Although there are various research findings supporting that limitations in social motivation have negative effects on face processing, experimental limitations in existing studies make it challenging to determine if differences in face processing can be directly attributed to diminished social motivation.

Many researchers have developed computer-mediated social skills interventions using 2D (2D) and 3D (3D) animations based on the observations that children with ASD show low social motivation associated with social experiences in real life, but remain highly motivated in front of the screen (Kana, Keller, Minshew, & Just, 2007; Liu, Wu, Zhao, & Luo, 2017). Animations are created by designing many still images of an object and passing these images in rapid mode, making them appear to be moving (Elliot ve Miller, 1999; Stephenson, 1973). Animated films add to the narrative by visually representing abstract concepts from an educational standpoint (Baglama, Yücesoy, & Yıkmış, 2018; Dalacosta, Kamariotaki-Paparrigopoulou, Palyvos, & Spyrellis, 2009). Visual, auditory, and interactive animations can make educational content more appealing, thus enhancing learning motivation (Rieber & Kini, 1991). Since the 2000s, the impact of animation's enhanced visual features on the visual attention and learning processes of children with ASD has been studied, with much of the literature reporting positive outcomes (Liu et al., 2017; Kana et al., 2007). Virtual reality and animations have been used in studies to support improvements in social skills, social cognition, and social adaptation (Cheng & Ye, 2010; Cheng, Huang, & Yang, 2015; Kandalaft, Didehbani, Krawczyk, Allen, & Chapman, 2013), enhance communication (McGonigle-Chalmers, Alderson-Day, Fleming, & Monsen, 2013), develop problem-solving skills (Bernard-Opitz, Sriram, & Nakhoda-Sapuan, 2001), and help identify emotions from facial expressions (Golan et al., 2010; Miranda et al., 2012). Due to their effective visual stimulus quality, 2D and 3D animation applications have shown promising results in supporting the social communication skills of children with ASD. However, it's worth noting that some parents have reported that their children, in the early years of ASD, watched 2D cartoons extensively. They observed an increase in their child's interest in real-world social interactions after reducing cartoon exposure (Özdemir, 2020). Additionally, there are anecdotal clinical reports suggesting that children with a history of heavy cartoon viewing show decreased interest in real-world social interactions, but this interest improves once cartoon watching is limited.

Despite the numerous studies on supporting learning through technology use in children with ASD, there are few studies comparing visual attention during video model presentation and 3D animated character presentation (Töret, Özdemir, Gürel-Selimoğlu, & Suna, 2018). It's well-documented that children with ASD, even from the early years, show clear differences in social attention compared to their TD peers. Specifically, they often display diminished visual attention to social stimuli such as human faces (Akın-Bülbül & Özdemir, 2021; 2022; Guillon et al., 2016; Klin et al., 2002a; Moore et al., 2018; Özdemir, Gürel-Selimoglu, Töret, & Suna, 2017). In fact, a defining characteristic that distinguishes children with ASD from their TD peers is this diminished visual attention to social stimuli (Frazier et al., 2017). Negative consequences of limited social visual attention have been reported in the areas of early social-cognitive development and language development (Bradshaw et al., 2019; Kuhl et al., 1992; Leppanen & Nelson, 2009; Pascalis et al., 2005; Thiessen et al., 2007; Zhou, Zhan ve Ma, 2019). Therefore, experimental studies aimed at better understanding the atypical visual attention of children with ASD deepen the debate on how to transform children with ASD's interest in computer technologies into an effective intervention context.

In this study, we examined the visual attention of both children with ASD and TD children, aged between 5-12 years, directed towards three distinct social interaction contexts. These contexts were presented in two different computer formats: video presentation of human models and 3D animations of human models. The three social interaction contexts created for this study represented different levels of social interaction. The three social interaction scenarios created for this study represented different levels of social interaction. In the first context, viewers were prompted to respond to a joint attention bid. In the second, the model narrated a story to the viewer, maintaining eye contact. In the third, the model demonstrated how to make chocolate bread without maintaining eye contact. Although the visual attention of children with ASD in social contexts has been studied in various studies, experimental studies that manipulate the level of social interaction are extremely limited. In a study conducted by Chawarska, Macari, and Shic (2012), similar to this study, visual attention features of children with ASD in early childhood were examined by presenting them with video material of three different social contexts and toys moving in the fourth context. Unlike Chawarska et al.'s (2012) research, our study introduced social interaction contexts in both video and 3D animation formats. Here, we created experimental contexts depicting a highly social, moderately social, and low level of social interaction, grounded in literature, to analyze the visual attention patterns of children with ASD in their early middle childhood. Experimental research is essential for understanding the effects of various social contexts and material types (video and 3D animation) on the visual attention of children with ASD. Therefore, this study sought to examine the visual attention of children with ASD and TD children by having them view three distinct social interaction scenarios through two presentation mediums: video models and 3D animations. In this research line, our study aimed to address two research questions:

1. Does the visual attention of children with ASD and TD children differ within groups when viewing scenarios with three distinct levels of social interaction?
2. Does the visual attention of children with ASD and TD children differ within groups between video and 3D animation presentations of social interaction scenarios?

Method

Study Design

The causal comparison design was used in this study. The causal comparison design attempts to determine the causes of a situation as well as the variables influencing the causes (Büyüköztürk, Kılıç-Çakmak, Akgün, Karadeniz, & Demirel, 2008). The design's possible variables that affect the outcome are manipulated, and their effects on the dependent variable are investigated. In this study, the visual attention features directed to social areas by children with ASD and TD children were used in three different social context scenarios (high-medium-low) in which the social interaction levels were manipulated, as well as using two different material types (video-3D animation).

Participants

The participants in this study, which was conducted as part of a research project supported by the Scientific and Technological Research Council of Turkey (Grant Code: 112K276), included 21 children with ASD and 22 TD children. The study was approved by the Scientific Research Ethics Committee of Gazi University (Approval Code: 086), which ensures that ethical considerations are taken into account in research involving human subjects based on the Helsinki Declaration. Study participants were recruited from among volunteer families who responded to study announcements from the Learning Development Education Research Centre of Gazi University. Parental consent and voluntary participation of the children were also important considerations in the recruitment process. Official diagnoses of participating children with ASD were completed by child psychiatrists using the DSM-IV (American Psychiatric Association [APA], 2000) diagnostic criteria. Educational diagnosis and assessment of the children were carried out by the Ministry of National Education, Guidance, and Research Centres. Participants in this study were recruited based on the study inclusion criteria. The study inclusion criteria for children with ASD included being between 5 and 12 years of age, having a clinical diagnosis of ASD or a high probability of having ASD based on the results of the Gilliam Autistic Disorder Rating Scale-2-Turkish Version (GARS-2-TV), having no additional neurological and/or sensory disorders such as vision and hearing impairments or epilepsy, and being willing to participate in the research with parental consent.

The study criteria for TD children included having no history of developmental problems, attending to age and grade-level education, and willingness to participate in the study with parental consent. The children with ASD who met the prerequisites for participation in the study were 2 girls and 19 boys, with a chronological age range of 5-12 years ($\bar{X}$ = 7.6, *sd* = 1.7). The study included 11 female and 11 male participants with TD, with chronological ages ranging from 5 to 12 years ($\bar{X}$ = 8.5, *sd* = 1.0).

Interviews were conducted with the primary caregivers of the participating children and the teachers of the children in private special education institutions among the families who applied for participation in the study. The teachers of the children with ASD completed the GARS-2-TV (Diken, Ardıç, Diken, & Gilliam, 2012), and the ASD symptom severity levels of the candidate children were reported. The children's subscale standard score averages ($\bar{X}$ = 8.7), range values (Xmin - Xmax = 7-11), autistic disorder index averages ($\bar{X}$ = 93,8), and range values (Xmin - Xmax = 85-110) were measured using the GARS-2-TV scale. The GARS-2-TV results indicated that children's autistic disorder index scores were highly likely to indicate ASD, and 22 children were included in the study, excluding two candidate children.

Data Collection Tools and Data Collection Process

Instruments Used to Identify Participant Characteristics

Gilliam Autistic Disorder Rating Scale- 2-Turkish Version (GARS-2-TV): GARS-2-TV was used to determine the ASD severity levels of the participants. The GARS-2-TV scale was developed by James Gilliam in 1995 for the purpose of screening and diagnosing individuals aged 3 to 23 with ASD. GARS-2-TV is a four-point Likert-type scale with three subscales of 14 items each: (1) stereotypical behaviors, (2) communication, and (3) social interaction, for a total of 42 items (Diken et al., 2012). Diken et al. (2012) conducted a Turkish validity and reliability study of GARS-2-TV. Study results indicated that the GARS-2-TV is a valid and reliable measurement tool for assessing the severity of symptoms in Turkish children with autism. The results of this study demonstrate the usefulness of the GARS-2-TV as a tool for evaluating and monitoring the symptoms of children with autism, which can be a valuable resource for both researchers and practitioners working with children with ASD in Turkey. The internal consistency reliability of the items in the GARS-2-TV was examined using Cronbach's alpha coefficient. Diken et al. (2012) reported internal consistency coefficients as .79 for stereotypical behaviors, .77 for communication, .85 for social interaction, and .88 for the total scale. The test-retest reliability coefficients of the scale were reported as .98 for stereotypical behaviors, .99 for communication, and .99 for social interaction.

Experimental Stimuli

Social Interaction Video and 3D Animations: In the current study initially experimental stimuli were designed to display three different social interaction contexts as video materials. Second, three social interaction videos were recreated as 3D animations. Real-life social interaction scenarios reflected three different social contexts with varying levels of social interaction. The three different levels of social scenarios included: "High: Which Bag," "Medium: Henna Lamp, and "Low: Chocolate Bread," each representing a different level of social interaction. Which Bag context was developed as having the highest level of social interaction. In this scenario, a female model interacted with the viewer by constantly maintaining eye contact and establishing joint attention. She asked the viewer which of the two bags positioned to the left and right sides of the table contained a toy, and displayed gestures that showed that she was expecting the viewer to respond. Finally, the model removed the toy from its bag and showed it to the viewer. In the second level of social interaction, Medium: Henna Lamp, the same model maintained eye contact with the viewer and told a story called Henna Lamp using a verbal narrative technique. Henna Lamp included a simple story of an event that the main characters, a lamb and a child, experienced. Finally, in the context of Low social interaction: Chocolate Bread, the same model explained and showed the viewers how to spread chocolate on a slice of bread. Specifically, she showed and explained the task to the viewer without using any eye contact. The model in this context looked directly at the task materials while she was explaining the task.

To ensure the research's internal validity, a female model enacted three different social scenarios with a plain dress and an open face (See Figure 1). The character in 3D animation videos is designed using rounded lines. In character design, characters with rounded forms represent completion, integrity, delicacy, joy, comfort, protectiveness, and childishness (Tillman, 2012). Another factor to consider when designing the character is the head-to-body ratio. The ideal human head-to-body ratio is known to be seven and a half to eight head lengths. According to Özden and Ülgen (2015), the ratio between the body and the head in animated films can be designed with different proportions to reflect the psychological characteristics of the film character and increase its visual appeal. In animated films, the character's head can be designed to be larger than a real human head in order to increase attractiveness and draw the audience's attention to the face (Diva & Anggraeni, 2018). As a result, the 3D animated character in this study was designed as a girl with a rounded head larger than a real human head (See Figure 1).

Figure 1. The Models Used in Which Bag, Henna Lamb, and Chocolate Bread Videos

Tobii Studio 3.2: Eye tracking data from study participants were collected using Tobii Studio 3.2, an eye movement analysis program. Eye movements in Tobii Studio 3.2 software are determined using pupil/corneal reflection techniques. The software converts the receiver's and the monitor's reflective infrared cameras' eye movement data into visual and quantitative data, such as a heat map, and displays it to the user. The software offers the opportunity to record the image of the computer screen, the participant's eye movements, and the screenshot during the application. This recorded data can then be used to analyze the participant's visual attention and eye movements, giving researchers valuable insights into their behavior and preferences.

Experimental Process

The research applications were carried out at the Human-Computer Interaction Application Laboratory at Middle East Technical University. The Human-Computer Interaction Laboratory, which is separated by a glass window, consists of two sections. The research implementations were carried out in the section that contains the computer-mounted eye-tracking device. In the experimental room, where the walls were covered with black to prevent reflection, there was a computer and an eye-tracking device used during the collection of eye-tracking data. This side of the laboratory contained no other distractions for children. A second computer, separated by double-sided glass, was placed in the other side of the laboratory, allowing the researchers to control the experimental process. The application was carried out on a desktop computer with a 17-inch screen and a Tobii eye-tracking device with a resolution of 60 Hz.

The researchers implemented the application process by taking the children with ASD and TD children one at a time to the section where the eye-tracking device is located. The children were seated in front of the computer, with the eye tracking device positioned so that they could look at the computer at a 25 angle from a distance of 60 cm on average. Initially, a five-point calibration phase was completed with children. At this stage, children were asked to follow 5 dots appearing in different parts of the computer screen with their eyes. After the 5-point calibration process was completed, a "Welcome cartoon" was shown to draw the children's attention to the screen. Following the cartoon, the participants watched three videos and three 3D animations in a counterbalanced order. A total of six social context materials were balanced among participants in two different application presentations and an equal number of participants watched as video materials were prioritized and 3D animations were prioritized. The videos representing each social context lasted about 40 seconds. Since three social context scenarios were presented as video and animation material, it took approximately 4 minutes to watch a total of 6 applications.

Data Analysis

Data from the Tobii Studio 3.2 ClearView software program was used to analyze the visual attention parameters of the participating children. The visual attention of children with ASD and TD children was examined in the study, with total fixation duration as the dependent variable. Total fixation duration corresponds to expressing the participants' total fixation duration in milliseconds. During the analysis process, the visual attention distributed to the model's region, which displays the social context on the screen, was examined by determining four different Area of Interests (AoIs). The AoIs created were: Eyes, Mouth, Lower Body, and Upper Body. Figure 2 depicts the AoIs analyzed in the study (See Figure 2). The regions were drawn to avoid overlapping between the regions. Consistent with previous research, data from the participants with a data rate of 50% or higher were included in the analysis (Frank, Vul, & Johnson, 2009; Thorup, Nyström, Gredebäck, Bölte, & Falck-Ytter, 2018). All of the participants in the study had eye-tracking data levels that were higher than this rate. Therefore, there was no data loss in the current study.

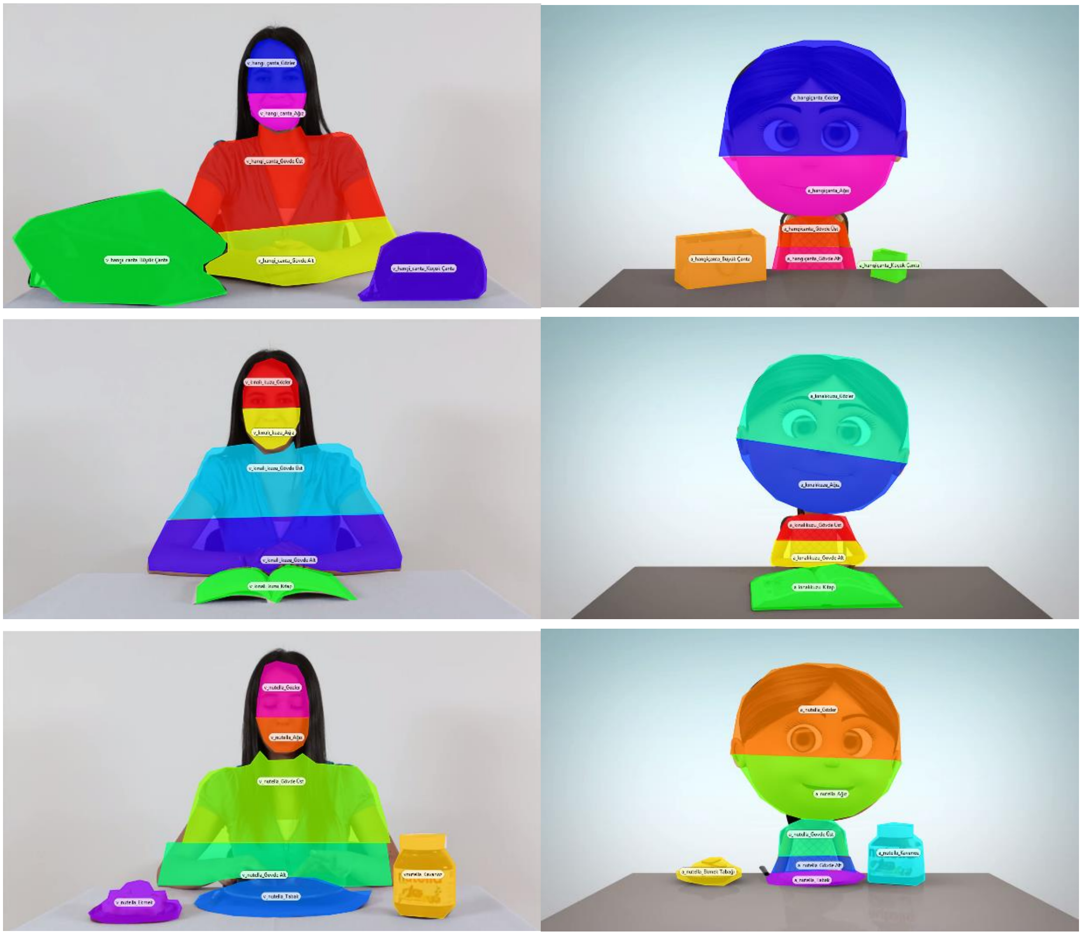


Figure 2. AOIs in the Videos of 1-Which Bag, 2-Henna Lamb, and 3-Chocolate Bread

The first question in the study was, "Does the visual attention of children with ASD and TD differentiate within groups while watching three different social interaction level scenarios? Study analyses were carried out for the first research question. These analyzes included eye-tracking data gathered from the video materials. Consistently, the effects of the social contexts shown to the participants on the total fixation duration were examined within groups both in children with ASD and TD children. The analyses were carried out using a repeated measures analysis of variance (Repeated Measures ANOVA), which allows the significance of within-group differences to be tested. The repeated measures analysis of variance is a statistical method used to test the significance of the difference between the means obtained in measurements taken under different conditions in the same group of participants (Tabacknick & Fidell, 2013). The effect sizes were calculated in the analysis of variance along with the differences between the means. Considering the effect sizes, comparisons were calculated regarding the effect of the social interaction conditions on the children's fixation time on different AoIs.

The analyzes for the second question of the study were carried out to determine whether the visual attention of children with ASD and TD children differed within the groups based on the type of materials presented (video and 3D animation). Therefore, the effects of the presentation of each social context as animation or video on children's total fixation duration on different AoIs were determined. Using the effect sizes, the effects of animation and video materials on total fixation durations were examined.

The limited number of participants in the study caused abnormal distributions in total fixation durations in developmental groups (ASD and TD) and AoIs. However, the Factorial ANOVA designs used in the study are highly powerful to deviations from the normal distribution (Schmider, Ziegler, Danay, Beyer and Bühner, 2010) and are often used in experimental studies. The calculated effect sizes were analyzed in terms of small (η2 = 0.01), medium (η2 = 0.06), and large (η2 = 0.14) effects reported by Cohen (1988).

Results

Findings on the Effects of Different Social Contexts on the Total Fixation Duration of Children with ASD and TD Children

In line with the first research question of the study, the variations of the total fixation duration on different AoIs of the children based on the social interaction levels were examined. For this purpose, repeated measures analysis of variance was used separately for the ASD and TD groups of children. The results of repeated measures analysis of variance for TD children are shown in Table 1.

Table 1. Analysis of Variance Results Regarding the Change in Total Fixation Duration of TD Children According to Different Social Contexts

Sosyal Context	**Mouth**		**Lower Body**		**Upper Body**		**Eyes**	
	$\bar{X}$	*SD*	$\bar{X}$	*SD*	$\bar{X}$	$\bar{X}$	*SD*	$\bar{X}$
Which Bag (1)	46,89	20,29	19,60	7,64	54,71	17,66	4,88	7,99
Henna Lamp (2)	26,06	11,16	34,89	12,35	4,37	5,34	5,56	9,90
Chocolate Bread (3)	55,47	23,14	20,04	8,00	57,67	19,25	7,98	10,11
	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2
	0,196*	0,804	0,119*	0,881	0,073*	0,927	0,429*	0,571
Differences	1-2, 1-3, 2-3		1-2, 2-3		1-2, 1-3, 2-3		1-3	

*p<0,05

As shown in Table 1, there were significant differences in the mean duration of total fixation duration of TD children in all AoIs in three social contexts. The Eyes region is the AoI where the difference between the total fixation duration of TD children was the lowest, and the significant difference was found only between the Which Bag and the Chocolate Bread social contexts (Λ=0.429, p<0.05, η^2=0.571). In the Eyes AoI, findings showed that the social context in which the total fixation duration of the TD children was the longest was the Chocolate Bread and the social context in which it was the shortest was the Which Bag. There were also significant differences in the Mouth (Λ =0.196, p0.05, η^2=0.804) and the Upper Body (Λ =0.073, p0.05, η^2=0.927) AoIs between the three social contexts. In both AoIs, the social context with the highest mean total fixation duration for TD children was the Chocolate Bread and the lowest social context was the Henna Lamb. The social context with the greatest total fixation duration for TD children in the Lower Body AoI was the Henna Lamp (Λ=0,119, p<0,05, η^2=0,881). The results of repeated measures analysis of variance for children with ASD are shown in Table 2.

Table 2. Analysis of Variance Results Regarding the Change in Total Fixation Duration of Children with ASD According to Different Social Contexts

Social Contexts	Mouth		Lower Body		Upper Body		Eyes	
	$\overline{X}$	*SD*	$\overline{X}$	*SD*	$\overline{X}$	$\overline{X}$	*SD*	$\overline{X}$
Which Bag (1)	20,80	15,24	21,79	5,62	35,72	10,93	5,03	5,52
Henna Lamp (2)	10,83	7,10	38,28	11,49	4,86	4,42	5,93	7,32
Chocolate Bread (3)	22,01	16,54	21,24	6,76	39,09	11,86	6,78	6,49
	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2
	0,480*	0,520	0,154*	0,846	0,097*	0,903	0,354*	0,646
Differences	1-2, 2-3		1-2, 2-3		1-2, 1-3, 2-3		1-3	

*p < 0,05

Table 2 shows that there were significant differences in the mean total fixation duration of children with ASD across all AoIs and social contexts. In regard to the Eyes AoI, findings showed that the only difference was found between the means of the Chocolate Bread and the Which Bag social contexts, and this difference was in favor of the Chocolate Bread social context (Λ = 0,354, p < 0,05, η^2 = 0,646). There were significant differences in the Upper Body region between the means of the three social contexts (Λ = 0,097, p < 0,05, η^2 = 0,903). In this region, it was seen that the context in which children with ASD had the highest total fixation duration was the Chocolate Bread, the Which Bag followed this context, and the Henna Lamp had a much lower mean than these two contexts.

In the Mouth AoI, findings showed that the means were at the same level in the Chocolate Bread and the Which Bag contexts and the means obtained in both contexts were significantly higher than the mean in the context of the Henna Lamb (Λ = 0,480, p < 0,05, η^2 = 0,520). In the Lower Body AoI, unlike the other AoIs, the highest mean was calculated in the context of Henna Lamb, and this mean was found to be significantly higher than the average in the other two contexts (Λ = 0,154, p < 0,05, η^2 = 0,846). When the findings obtained from TD children and children with ASD were analyzed together, findings showed that there was a general similarity in terms of the change in the total fixation duration of the two groups of children in different social contexts. In both groups of children, results showed that the social context in which children had the highest mean of total fixation duration in the Eyes, the Mouth, and the Upper Body AoIs was the Chocolate Bread context. Similarly, in the Lower Body AoI, the highest total fixation duration was found in the Henna Lamb social context in both groups. Therefore, although the mean and standard deviation scores found in both groups of children differ, the patterns of the variations were similar based on the social contexts.

Findings on the Effects of Material Type on the Total Fixation Duration of Children with ASD and TD Children

In line with the second purpose of the study, the changes in children's total fixation duration in different AoIs according to different materials (3D animation and video) were analyzed using repeated measures analysis of variance. In the analysis, three social contexts were analyzed separately for TD children and children with ASD. Table 3 shows the results of the analysis of variance regarding the effect of material type on the total fixation duration of TD children in different social contexts.

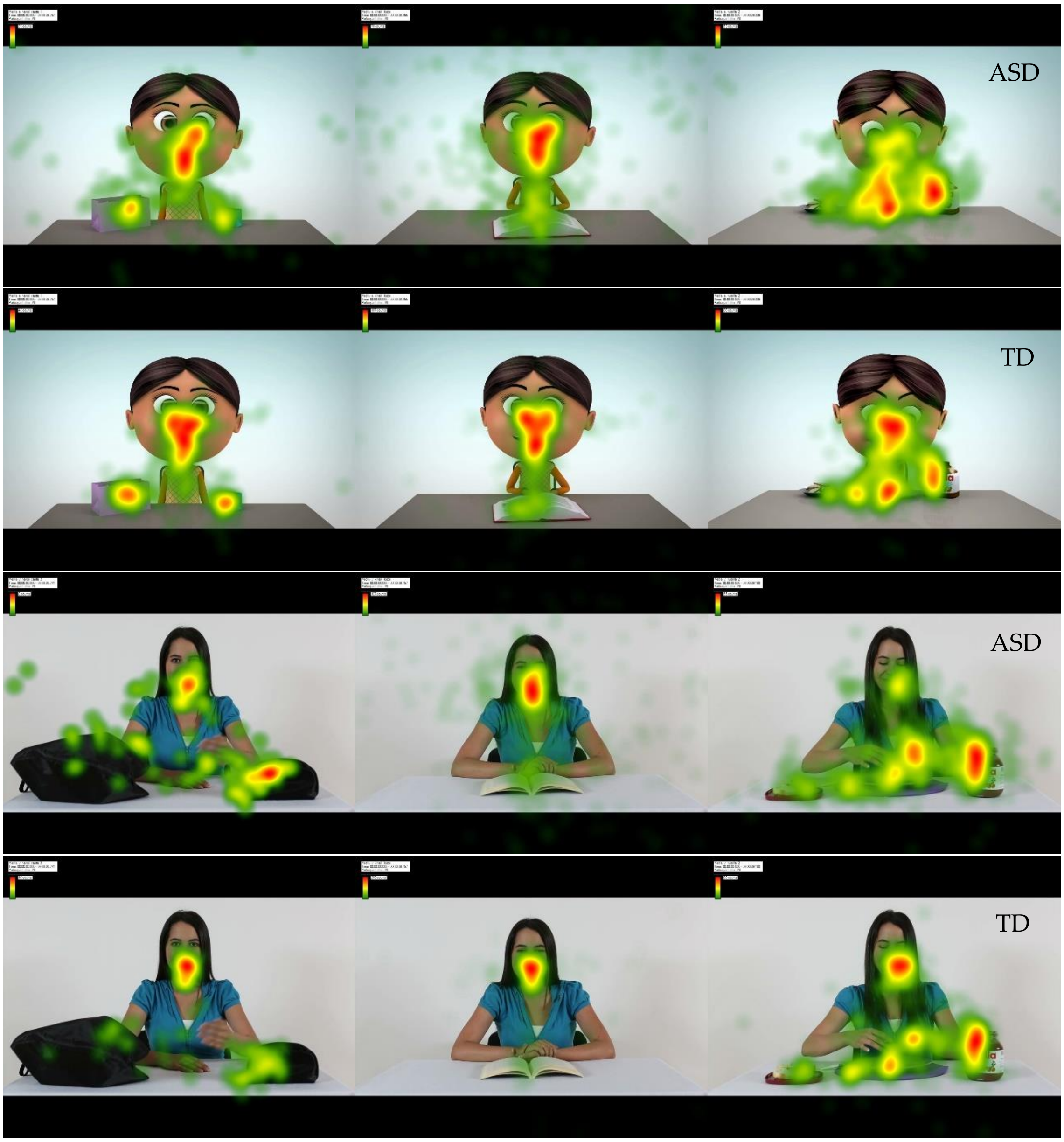
Table 3. Analysis of Variance Results on the Effect of Material Type on the Total Fixation Duration of TD Children in Different Social Contexts

Which Bag Context								
	Mouth		**Lower Body**		**Upper Body**		**Eyes**	
Material Type	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**
Animation (1)	49,74	18,58	15,41	6,86	10,23	5,27	94,40	32,35
Video (2)	46,89	20,29	19,60	7,64	54,71	17,66	4,88	7,99
	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2
	0,988	-	0,457*	0,543	0,120*	0,880	0,125*	0,875
Henna Lamp Context								
	Mouth		**Lower Body**		**Upper Body**		**Eyes**	
Material Type	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**
Animation (1)	58,55	19,95	11,59	4,73	8,61	5,14	74,87	24,77
Video (2)	26,06	11,16	34,89	12,35	4,37	5,34	4,51	9,04
	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2
	0,204*	0,796	0,154*	0,846	0,508*	0,492	0,132*	0,868
Chocolate Bread Context								
	Mouth		**Lower Body**		**Upper Body**		**Eyes**	
Material Type	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**
Animation (1)	43,19	16,96	5,42	3,06	10,56	6,17	93,03	32,69
Video (2)	55,47	23,14	20,04	8,00	57,67	19,25	7,40	9,91
	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2
	0,798*	0,202	0,208*	0,792	0,108*	0,892	0,145*	0,855

*p < 0,05

The results in Table 3 showed that the presentation type of the content (3D animation or video) creates a significant difference in the total fixation duration of TD children in almost all AoIs in three social contexts. The only exception was the Mouth AoI in the Which Bag social context where the material type did not create a significant difference ($\Lambda = 0.988$, $p > 0.05$).

In the social contexts of Which Bag and Chocolate Bread, the biggest differences between material types were found in the Upper Body and the Eyes AoIs, and the Eyes AoI showed a significant advantage in 3D animation. In the Henna Lamp social context, 3D animation also showed a higher mean in the Eyes AoI compared to video material, but the second largest difference was seen in the Lower Body AoI. Therefore, 3D animation in all social contexts significantly increased the total fixation duration in the Eyes AoI. The only AoI where different results were obtained in all social contexts was the Mouth AoI. The Which Bag did not show a significant difference between material types, but the Henna Lamp had higher means for 3D animation and the Chocolate Bread for video. Heat maps depicting total fixation duration examples of the participants in the video and 3D animation presentations can be seen in Figure 3. The heat maps visually represent the visual attention displayed by the participants in total fixation duration. Red areas reflect intense visual attention, while areas that vary from yellow to green show diminished visual attention.



Note 1: The heat map examples in the 1st and 3rd positions belong to children with Autism Spectrum Disorder (ASD), while the heat map examples in the 2nd and 4th positions belong to Typically Developing (TD) children.

Figure 3. Heat Map Examples for Which Bag, Henna Lamb, and Chocolate Bread Videos

The results showed that in the contexts of the Which Bag and the Chocolate Bread, the means of video in the Lower Body and Upper Body AoIs were significantly higher than 3D animation. Therefore, in these contexts, it can be stated that TD children's total fixation duration on the Upper Body was higher in the video presentation. On the other hand, the Henna Lamp context was different from the other two contexts in that its focus on the Upper Body was higher in the 3D animation. Therefore, similar to the results of the first study question, it can be stated that the results obtained in the contexts of Which Bag and Chocolate Bread had similar patterns. Table 4 shows the results of variance analysis on the effect of material type on the total fixation duration of children with ASD in different contexts.

Table 4. Results of Variance Analysis for Changes in Total Fixation Duration of Children with ASD by Material Type in Different Social Contexts

Which Bag Context								
	Mouth		**Lower Body**		**Upper Body**		**Eyes**	
Material Type	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**
Animation (1)	31,06	11,37	10,21	4,74	10,97	5,02	53,91	32,50
Video (2)	19,79	15,51	21,79	5,62	35,72	10,93	4,39	5,34
	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2
	0,648*	0,352	0,215*	0,785	0,090*	0,910	0,229*	0,771
Henna Lamp Context								
	Mouth		**Lower Body**		**Upper Body**		**Eyes**	
Material Type	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**
Animation (1)	32,78	13,07	13,41	4,67	7,72	2,87	48,54	27,87
Video (2)	10,46	7,11	38,28	11,49	4,86	4,42	4,80	6,91
	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2
	0,184*	0,816	0,155*	0,845	0,791*	0,209	0,230*	0,770
Chocolate Bread Context								
	Mouth		**Lower Body**		**Upper Body**		**Eyes**	
Material Type	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**	**$\bar{X}$**	**SD**
Animation (1)	24,56	9,9	6,76	2,92	9,03	3,46	52,50	31,57
Video (2)	19,94	16,99	21,24	6,76	39,09	11,86	4,96	6,12
	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2	Wilks' Lambda	η^2
	0,906	-	0,184*	0,816	0,094*	0,906	0,238*	0,762

*p < 0,05

Table 4 shows that the form in which the content is presented (animation or video) makes a significant difference in the total fixation duration of children with ASD in nearly all AoIs in all three contexts, with the exception of the Mouth AoI in the context of Chocolate Bread, where the type of material makes no difference ($\Lambda = 0.906$, $p > 0.05$).

The Which Bag and Chocolate Bread contexts shared similarities in that the greatest differences between material types were observed in the Lower Body and Upper Body AoIs. In all three contexts, the total fixation duration on the Eyes AoI in 3D animation presentation was significantly longer than in the video presentation. Another finding across all three contexts was that children with ASD had significantly longer total fixation durations on the Lower Body AoI in video than in the 3D animation. The results obtained in the Mouth AoI, on the other hand, differ slightly. The total fixation duration means of the animation type in the Which Bag and the Henna Lamp contexts were significantly higher than in the video, while the difference between the means in the Chocolate Bread context was found to be insignificant.

The animation presentation of all contexts significantly increased the total fixation duration on children's Eyes AoI. The Mouth region, on the other hand, was the only AoI that yields different results in all contexts. There was no significant difference between material types in the Which Bag context, whereas in the Henna Lamp context, the 3D animation type had higher means, and in the Chocolate Bread context, the video type had higher means. Finally, the mean total fixation duration on the Upper Body AoI in the Which Bag and Chocolate Bread contexts showed that the video had higher means, whereas the 3D animation had higher means in the Henna Lamp context, as shown in Table 4.

When the findings of TD children and children with ASD were compared, study findings showed a general similarity. The total fixation duration on the Lower Body and the Eyes AoIs in both groups were determined to be significantly higher in the 3D animation type. Furthermore, the patterns in the Which Bag and the Chocolate Bread contexts were similar in both groups. As a result, while the distributions obtained in the two groups differed, the changes observed from one social context to another were generally similar.

Discussion and Conclusion

The current study analyzed the visual attention of children with ASD and TD children across three distinct social context scenarios reflecting varying levels of social interaction (high, medium, and low). We further compared children's visual attention in two different presentation formats: video and 3D animation. Visual attention was measured in specific AOIs including Eyes, Mouth, Upper Body, and Lower Body. In the current study, the "Which Bag" scenario represented high-level social interaction. In this scenario, the model asked viewers to identify which of the two bags, positioned on the right and left sides of the table, contained a toy. The "Henna Lamp" scenario provided medium-level social interaction. In this scenario, the model narrated a story directly to the camera, maintaining eye contact with the viewer and using expressive gestures. In the "Chocolate Bread" scenario, reflecting low-level social interaction, the model demonstrated how to spread chocolate on a slice of bread without establishing eye contact with the viewer.

The results revealed that children with ASD directed significantly more visual attention to the Eyes AoI during the Chocolate Bread context, where there was minimal eye contact with the viewer, compared to the Which Bag scenario, characterized by high-level social interaction. Furthermore, children with ASD were observed to focus more on the Mouth AoI—another key social area—both in the Chocolate Bread and Which Bag contexts. In particular, in the Chocolate Bread context, children with ASD most often directed their visual attention to the Upper Body AoI, which is often the primary area to which they direct their attention when avoiding human faces.

The results of the study showed that both children with ASD and TD children significantly directed more attention to the Eyes and Mouth AoIs during the Chocolate Bread scenario. Moreover, TD children looked more at the Upper Body and the Mouth AoIs in the Which Bag context, which was a high-level social interaction scenario where children were expected to focus predominantly on the Eyes and Mouth AoIs. In the Henna Lamp context, the total fixation duration was highest on the Lower Body AoI for both groups of children. The decrease in visual attention was observed in the Henna Lamp context, even though the model used different gestures and facial expressions. Overall, the mean total fixation duration across the four AoIs in the three different levels of social contexts demonstrated a significant decrease in the Henna Lamp context, which represents a moderate level of social interaction.

When examining the eye-tracking patterns of both children with ASD and TD children in terms of the total fixation time across three distinct levels of social context, the findings revealed similar visual attention patterns, though with quantitative differences between the groups. Specifically, when examining the mean visual attention directed to the Mouth AoI, the results indicated that children with ASD spent approximately half of the time focusing on the Mouth AoI compared to their TD peers. These findings are consistent with Chawarska and Shic (2009)'s study, which found no significant difference in visual attention towards the Eyes and Nose AOIs between TD children and children with ASD. However, a significant difference was observed in children with ASD focusing less on the Mouth AoI than TD children. The current research results showed that when compared to TD children, children with ASD tend to "look less at the face" and support the research findings reported in the literature (Bradshaw et al., 2011; Chawarska & Shic, 2009; Harrison & Slane, 2020; Shanok et al., 2019; Swettenham et al., 1998). For example, Klin, Jones, Schultz, Volkmar, and Cohen's (2002b) study reported that individuals with ASD spent more time observing objects in social contexts, and when directing their visual attention to a person's face in the social scene, they displayed gaze avoidance by directing their attention more to the Mouth AoI. Similarly, Swettenham et al. (1998) found that children with ASD paid less attention to human faces in free-play environments than their peers, and when they did, their fixation duration was notably shorter.

Overall, the study found that children with ASD often direct their visual attention more towards the Upper and Lower Body AoIs. This pattern of attention might be interpreted as an effort to avoid the more socially intense regions, the Eyes and Mouth AoIs, across varying social contexts. Such visual attention pattern could stem from a tendency to initially shift attention away from the most socially salient areas of the face, especially the eyes and mouth.

This study examined the visual attention patterns of children with ASD and TD children, when exposed to video and 3D animation materials across various social context. Current study findings showed that children with ASD demonstrated greater visual attention to the Mouth and Eyes AoIs, which are considered as social areas, in 3D animations than in video materials. The same pattern was observed in TD children, who also demonstrated increased visual attention to social areas in 3D animations. When comparing video and 3D animation materials, there wasn't a significant difference in visual attention directed at the Mouth AoI in TD children. However, a significant increase in visual attention to the Mouth AoI was evident in children with ASD when viewing 3D animations. In general, both groups of children showed greater visual attention to the non-social AoIs in video materials compared to 3D animations. This may be due to the design of the characters in the animations, which had rounded lines and larger heads compared to real human heads in order to increase their visual appeal and attract participants' attention. This design may result in the body occupying a smaller area in the visual scene and the head occupying a larger area, leading to a decrease in visual attention to the body and an increase to the face. Overall, the results of the study showed an increase in visual attention to the social areas in the Eyes and Mouth AoIs in children with ASD when viewing 3D animated materials.

The findings from this study are important in understanding the mechanisms underlying the diminished social attention observed in children with ASD. Many researchers offer different perspectives on why children with ASD pay less attention to human faces. For example, Trepagnier, Sebrechts, and Peterson (2002) and Pelphrey et al. (2002) discussed that individuals with ASD experience neuroprocessing difficulties when viewing human faces and do not find human faces as socially stimulating as TD individuals. Furthermore, some researchers suggest that early deviations in visual attention to faces can compound over time, resulting in more pronounced impairments in face processing as children with ASD grow older. These early limitations may further hinder the ability to accurately interpret complex facial expressions, identify emotions, or infer other people's intentions in later years (Noris et al., 2012). Moreover, some researchers argue that the homogeneity of the perceptual features of the face may lead to a visual perceptual problem in individuals with ASD (Kaliukhovich et al., 2021). Other researchers point to potential oculomotor issues, like eye movement problems (Zhao, Xing et al., 2021), as factors that might negatively impact visual attention. Selective attention problems have also been noted as possible contributors (Chita-Tegmark, 2016; Frazier et al., 2017). Finally, current study findings support the Social Motivation Theory. We observed that the increase in the attractiveness of social areas in 3D animations may have caused a motivation-based increase in children's visual attention.

Overall, it is important to note that the eye-tracking paradigm used in this study was a passive viewing task, which means that participants simply watched 3D animations and video materials without actively engaging with them. Consequently, this study didn't examine the hypothesis that increased visual attention to the Eyes and Face AoIs in 3D animations might enhance the processing of social information. Furthermore, longitudinal studies suggest that heightened social attention to the human face is positively correlated with subsequent language and communication skills (Campbell, Shic, Macari, & Chawarska, 2014) and later social abilities (Chawarska & Shic, 2009). The question of whether passive visual attention to social regions in 3D animations impacts real-life social learning in children with ASD deserves further investigation. This curiosity stems from anecdotal reports by parents who note that their ASD children show increased interest in real-world social interactions as their screen time, particularly cartoon viewing, diminishes. Given the limitations of this study, such as the use of a passive viewing task and the small sample size, future research should consider task-based approaches with larger participant groups. Such a direction would provide a deeper understanding of the correlation between visual attention and social understanding in children with ASD..

Ethical Approval /Parental Consent

This study was approved by the Ethics Committee of Gazi University (Approval Code: 086). Informed parental consent was obtained from all participants.

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