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Measuring Cognitive Empathy and Emotional Recognition in Children with Autism Spectrum Disorders Using Eye-Tracking Technology

Margarita Stankova*[a], Ivan Ivanov[b], Daniela Tuparova[a], Polina Mihova[a], Georgy Tuparov[a]

[a]*New Bulgarian University, Montevideo 21 str, Sofia, 1618, Bulgaria*
[b]*College of Veterinary Medicine & Biomedical Sciences, Texas A&M University, United States*

Abstract

This study attempts to identify differences in the performance of tasks related to cognitive empathy in children with autism spectrum disorders (ASD) and typically developing children, using Tobii Pro Fusion eye-tracking technology. The tasks are divided into two groups: recognizing emotions displayed by facial expressions and in contextualized social scenarios. Differences in attention to the AOIs were measured in two groups: children with ASD (n = 15) and typically developing children (n = 27).
The results show that in both groups, for tasks involving facial emotion recognition and those involving emotion recognition in a scene, greater attention was directed toward the stimulus displaying the specified emotion. However, regarding this target stimulus, typically developing children showed significantly higher levels of attention compared to children with ASD.
We hypothesize that these results can be explained by three possible pathways of neurodevelopmental functioning: difficulties in language comprehension, basic social difficulties, or specific impairments in understanding others and difficulties in understanding others' experiences, and cognitive and communicative problems that involve less practical experience in social situations without underlying basic social dysfunctions.

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Keywords: Autism spectrum disorder (ASD); cognitive empathy; emotion recognition; eye-tracking; Theory of mind; assistive technologies.

* Corresponding author. Tel.: +359888996114;
E-mail address: mstankova@nbu.bg

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1. Introduction

In recent years, there has been a growing trend toward researching the mechanisms underlying the recognition and regulation of emotions. Technologies are also being applied to assess the capacity to recognize and name one's own and others' emotions, as well as to process and respond to the emotional states of others. There are various definitions and classifications of emotions in research data and practice, although there is no firm consensus regarding their conceptualization [1]. Ekman's model posits that emotions are distinct experiences and that each one can be universally recognized. Ekman classifies six basic emotions in his research: anger, disgust, fear, happiness, sadness, and surprise [2]. Another classification by Plutchik identifies eight basic emotions: joy, sadness, anger, fear, trust, disgust, surprise, and anticipation [3].

Empathy is the ability to experience and understand what others are feeling, without confusing one's own feelings with theirs. Understanding what someone else is feeling plays a fundamental role in interpersonal interactions. Empathic experiences often involve understanding emotions, sharing emotions, perspective-taking, and regulating emotions [4]. The phenomenon of empathy is highly flexible, and it involves the ability to share the affective experiences of others. It is influenced by a number of factors, such as contextual appraisal, the interpersonal relationship between the empathizer and the other, and the perspective adopted during observation of the other [5]. Empathy has become an important construct in research on interpersonal communication. It is a powerful communicative skill that is also frequently used in clinical practice as a tool to improve relationships with others [6]. Perhaps due to its prevalence in everyday language, the scientific significance of empathy is often taken for granted. Empathy, however, is a complex idea, and its conceptual boundaries are difficult to define [7]. Regardless of the specific terminology used, there is broad agreement on two points: (1) that the field of empathy encompasses both cognitive and affective dimensions, and (2) that the affective dimensions encompass various important emotional responses to an object associated with distress [8].

Children with autism spectrum disorder (ASD) differ significantly from typically developing children in terms of both cognitive and affective empathy [9]. Children with autism score lower than typically developing children on measures of cognitive empathy and affective empathy [10]. Individuals with Asperger's and high-functioning autism have difficulties with empathy and score lower on empathy questionnaires, with women scoring higher than men [11].

A leading theory regarding the manifestations of autism suggests that people with autism have difficulties with "Theory of Mind," meaning that they find it hard to infer the mental states of others. Difficulties in understanding others' minds are not the only cognitive characteristic of autism spectrum disorders, but they appear to be a fundamental and likely universal problem [12]. People with autism typically perform worse on "false-belief" tasks, which measure "Theory of Mind" by assessing a person's ability to distinguish between events in reality and how events might be (incorrectly) represented in another person's mind [13].

Another model that attempts to explain the differences among individuals with autism spectrum disorders is the social motivation hypothesis. Conditions associated with autism spectrum disorders can be interpreted as an extreme case of reduced social motivation, which provides a powerful model for understanding people's inherent drive to seek acceptance and avoid rejection [14].

The aim of this study is to examine whether there are significant differences in performance of tasks related to cognitive empathy between children with autism spectrum disorders and typically developing children. The tasks have been divided into two main groups: tasks related to empathic understanding and recognition of emotions expressed on faces, and tasks related to empathic understanding and recognition of emotions presented in a story. Performance was measured using eye-tracking technology.

2. Methodology

2.1. Participants

The study includes 15 children with ASD. The diagnosis was made using the criteria of the ICD-11 and DSM-5 classifications. All participants in the group of children with ASD also have medical records with a prior diagnosis made at a medical facility by a specialist psychiatrist. Additionally, two instruments were used as entry criteria for inclusion in the group of children with ASD: the Childhood Autism Spectrum Test (CAST) questionnaire [15, 16],

with the Bulgarian version of the instrument used in the present study [17] and the CARS2 questionnaire with its two Bulgarian-language versions: CARS2–ST for specialists and CARS2-QPC for parents, Giunti Psychometrics [18]. The children and their parents were recruited from two specialized centers for children with developmental disorders. The study also included 27 typically developing children, matched in age to the children with ASD, who were recruited from two mainstream kindergartens.

2.2. Methods

Eye-tracking methods were used to examine how children with ASD and typically developing children perform tasks involving cognitive empathy and recognize emotions expressed in faces and story pictures. The eye-tracking device measures the position and movements of the participant's eyes [19]; and uses parameters such as fixation, point of gaze, and pupil size to track what the subject's eyes are focusing on. The technology can be successfully used to analyze visual attention to emotional information [20, 21].

Eye-tracking is a method for studying the mechanisms underlying emotion recognition. Raw data on fixation duration and eye movement allows us to determine which parts capture the subject's attention and to observe their subconscious behavior. These can be important cues for context-aware environments that contain additional information about emotion recognition and the user's emotional states [22], such as visual fixation, can be used to study preferences for specific faces with specific emotional expressions [20]. Eye-tracking methods may also be used effectively to assess the effect of interventions in individuals with autism [23].

2.3. Equipment and software used

The following technical resources were used in the study: Tobii Pro Fusion 120 Hz Hardware Package; Tobii Pro LAB Screen Based One Edition – Perpetual; Dell Vostro 3520 laptop; BenQ GW2480T monitor; Logitech Pro C920 webcam; Logitech Silent Wireless Combo MK295 Graphite. Tobii Pro Fusion is a high-precision eye-tracking system that enables objective measurement of visual attention in children exposed to a series of visual stimuli.

By recording gaze coordinates in time and space, the system enables the extraction of quantitative metrics related to both the initial fixation and fixation duration on specific elements of the stimuli.

The analysis is structured around predefined Areas of Interest (AOIs), ranging from 4 to 25 per task, which include: socially significant stimuli (e.g., faces, gaze, interactions); non-social objects.

2.4. Technical parameters of the system

The technology used is based on infrared eye tracking, integrating a camera, a projector, and image processing algorithms.

Key parameters:

- sampling frequency: 120 Hz
- eye-to-monitor distance: approximately 50 cm
- screen diagonal size: 26 inches

A major limitation of the eye-tracker application is that it measures only focal vision and therefore cannot account for attention directed toward the periphery of the visual field. This distinction appears to be important in autism spectrum disorders (ASD) [24].

2.5. Preparation of the stimuli

In the present study, tasks with a pre-designed scenario were used. The first group of tasks included stimuli with images of human faces. To test the children's cognitive empathy skills, the tasks were designed so that participating children could put themselves in the shoes of the characters in the pictures.

The first set of tasks included the instruction: "Listen to what the child says and point to the correct picture.". The task was narrated by a voiceover, and the response was in a child's voice using the first-person singular, e.g., "I am

sad." The stimuli included faces expressing 4 different emotions. The results analyze the fixation time on the correct emotion, as well as the fixation time on the other three pictures that do not express the correct emotion. All children in the study received the stimuli in the same sequence and had the same exposure time to the visual stimuli.

In the second set of tasks, the instructions were similar, but the response included context, and the pictures depicted a scene, e.g., "I am happy because it is my birthday.". In this case, the expectation was that not only the child's response, but also the story in the picture, would provide additional cues for identifying the correct emotion, thereby aiding emotion recognition through an understanding of the social context. A more detailed description of the scenarios in the full version of the study can be found in Tuparova et al. [25]. This study presents the results of 3 tasks involving the identification of the correct face in response to a question about an experienced others' emotions and 3 tasks involving the identification of a story picture related to the recognition of a others' emotions in a story, presenting a study of cognitive empathy in children from both groups, Table 1.

Table 1. Tasks with their respective target emotion, type of stimulus, and expected correct response

Task	Target Emotion	Type of Stimulus	Expected Correct Response
Task 1	Sadness	Illustrated facial expressions	Correct identification of sadness
Task 2	Anger	Illustrated facial expressions	Correct identification of anger
Task 3	Happiness	Illustrated facial expressions	Correct identification of happiness
Task 4	Happiness	Contextualized social scenario illustration	Correct identification of happiness
Task 5	Sadness	Contextualized social scenario illustration	Correct identification of sadness
Task 6	Anger	Contextualized social scenario illustration	Correct identification of anger

2.6. Parameters used

The Area of Interest (AOI) helps collect targeted information on how long it took the user to look at that specific area. According to Holmqvist et al. [26], the area of interest is a region within the visual stimulus that the researcher intends to examine for the relevant eye-tracking data. In the literature, AOI is not the only term referring to such an area [26]. A common application is the use of AOIs to assess the effectiveness of different regions of an image or video clip. Typically, an AOI is defined on a spatial plane using a geometric shape (e.g., a rectangle) that encompasses all the necessary information. Furthermore, AOIs can be grouped into higher-level AOIs, forming a hierarchy of AOIs. In the present study, AOIs are defined by the contours of the eye area, mouth, and hair for the facial emotion recognition tasks (Fig.1a) or by the contours of relevant social scenario stimuli for the contextualized emotion recognition tasks (Fig. 1b).

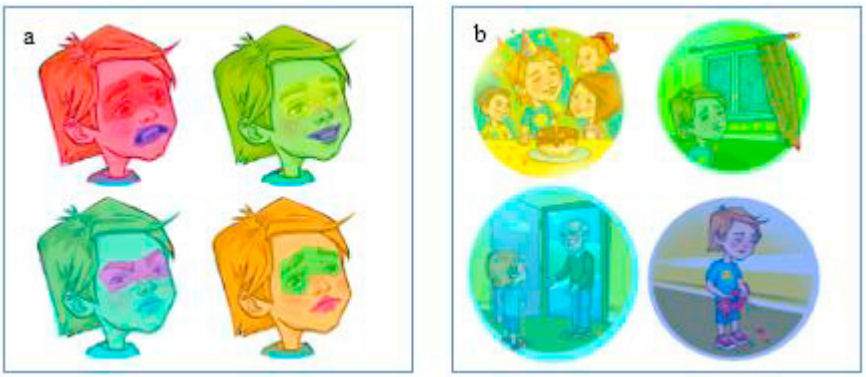


Fig.1. (a) AOIs for tasks 1-3; (b) AOIs for Tasks 4-6

With a static stimulus, the displayed information maintains a fixed position on the screen. As a result, the AOIs that encapsulate this information correspond to static coordinates. This consistency ensures that the correspondence between gaze points and AOI coordinates is always the same [27].

Fixation duration provides an estimate of the direction of the user's gaze. In most cases, estimating the direction of gaze means identifying the object on which the gaze is fixed.

2.7. Data Processing and Statistics

We chose to evaluate the differences in attention to the AOIs for each of the tasks in our study in a two-step process: (1) Binarizing the percentage of fixation time spent on each of the four faces or scenes related to the corresponding task, where "1" represents the "Attention" category and "0" represents the "No Attention" category; (2) Running a Fisher exact test on the 2x2 contingency table to determine how many children with Autism (ASD) and Typical Development (TD) fall into each of these two attention categories. Binarization was performed for each individual participant based on the median m of the four values representing the percentage of fixation time spent by that participant on each of the four images for the respective task. Whenever a child had a percentage of fixation time greater than m, the child was assigned to the "1" category; otherwise, the child was assigned to the "0" category for the respective AOI. Note that this approach allows a child to belong to the "1" category for more than one image among the four available ones that represent the corresponding task. If the p-value computed by the Fisher exact test was less than 0.05, we interpreted the distribution of ASD and TD children into the two categories "0" and "1" as an extreme case and associated it with a significant difference in the attention the children from those two groups paid to the respective image in that task. We also discuss the individual distributions of ASD and TD children in the two attention categories for the AOIs in each task.

2.8. Results

Table 2 shows the results obtained from the analysis of the fixation parameter in tasks 1 through 3 related to emotion recognition in faces. Table 3 contains analogous results for tasks 4 through 6 related to emotion recognition in scenes and Fig 2 and Fig 3 show some examples of attention heat maps.

Table 2. Contingency tables for tasks 1 to 3 and p-values of the Fisher exact test used to detect extreme distribution of the participating ASD and TD children into two attention categories.

	Emotion	Group	Attention	No_Attention	Fisher exact test p-value
Task 1	Angry	ASD	8	7	p > 0.05
		TD	10	17	
	Scared	ASD	8	7	p > 0.05
		TD	11	16	
	Happy	ASD	4	11	p > 0.05
		TD	7	20	
	Sad*	**ASD**	**5**	**10**	**p < 0.001**
	Target emotion in the task	**TD**	**26**	**1**	
Task 2	**Angry***	**ASD**	**9**	**6**	**p < 0.001**
	Target emotion in the task	**TD**	**27**	**0**	
	Scared	ASD	11	4	p > 0.05
		TD	10	17	
	Happy	ASD	2	13	p > 0.05
		TD	3	24	
	Sad	ASD	6	9	p > 0.05
		TD	11	16	
Task 3	Angry	ASD	6	9	p > 0.05
		TD	6	21	
	Scared	ASD	6	9	p > 0.05
		TD	11	16	
	Happy*	**ASD**	**10**	**5**	**p < 0.05**
	Target emotion in the task	**TD**	**26**	**1**	
	Sad	ASD	4	11	p > 0.05
		TD	11	16	

Table 3. Contingency tables for tasks 4 to 6 and p-values of the Fisher exact test used to detect extreme distribution of the participating ASD and TD children into two attention categories.

	Emotion	Group	Attention	No_Attention	Fisher exact test p-value
Task 4	Angry	ASD	4	11	
		TD	4	23	p > 0.05
	Happy*	**ASD**	**12**	**3**	
	Target emotion in the task	**TD**	**27**	**0**	**p < 0.05**
	Sad	ASD	6	9	
		TD	12	15	p > 0.05
	Surprised	ASD	5	10	
		TD	7	20	p > 0.05
Task 5	Angry	ASD	7	8	
		TD	9	18	p > 0.05
	Happy	ASD	5	10	
		TD	12	15	p > 0.05
	Sad*	**ASD**	**9**	**6**	
	Target emotion in the task	**TD**	**27**	**0**	**p < 0.001**
	Surprised	ASD	4	11	
		TD	4	23	p > 0.05
Task 6	**Angry***	**ASD**	**11**	**4**	
	Target emotion in the task	**TD**	**27**	**0**	**p < 0.05**
	Happy	ASD	4	11	
		TD	5	22	p > 0.05
	Sad	ASD	3	12	
		TD	8	19	p > 0.05
	Surprised	ASD	5	10	
		TD	11	16	p > 0.05

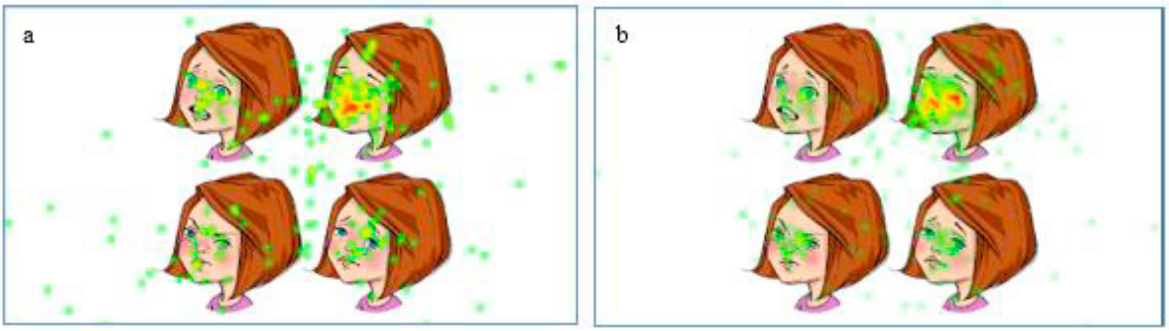


Fig. 2. (a) Attention heat map of ASD group for happy emotion (Task 3); (b) Attention heat map of TD group for happy emotion (Task 3)

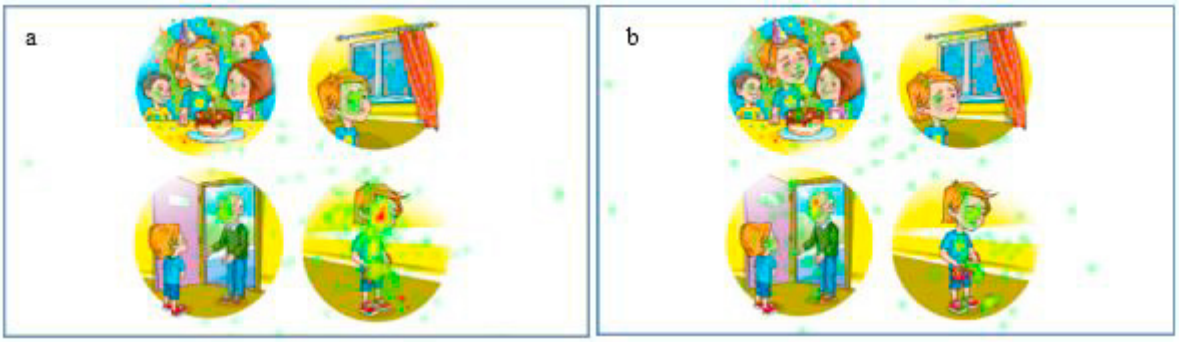


Fig. 3. (a) Attention heat map of ASD group for angry emotion in situations (Task 6); (b) Attention heat map of TD group for angry emotion in situation (Task 6)

3. Discussion

In both stimulus groups (face recognition and emotion recognition in a story picture), more attention is observed toward the stimulus displaying the target emotion. Regarding these target stimuli, typically developing children showed significantly higher levels of attention compared to children with ASD.

The reduced attention in children with autism toward the target picture may be due to several reasons:

1. Difficulties in linguistic decoding. The emotion-naming task involving facial recognition is very brief and consists of only three semantically distinct words, one of which is the emotion label, but the instruction contains a more complex sentence. In the second group of tasks, a complex two-part sentence is used to name the emotion, with the second part presenting the plot/situation as the cause of the emotion in question. This could pose a challenge for children with autism who have difficulties with linguistic decoding, although the plot would aid in recognition. Norbury et al., 2009, observed that verbally capable adults with autism spectrum disorder (ASD) show a strong correlation between fixations on facial features and social or communicative abilities, suggesting that their visual scanning strategies are linked to their language skills [28]. Other authors also report that verbal abilities, assessed using an eye tracker, show particularities in children with ASD [29].

2. Fundamental social difficulties or specific impairments in understanding others, and consequently in putting oneself in their shoes and understanding their experiences. Children with autism spectrum disorders (ASD) experience greater difficulties in selecting socially significant facial expressions, and these differences can be effectively identified using computer vision methods [30]. Behavioral studies of facial emotion recognition in autism spectrum disorders (ASD) yield mixed results [31], with some studies showing differences in individuals with autism in the recognition of happiness and fear [32]. According to functional magnetic resonance imaging (fMRI) results, activity in the amygdala and other brain regions associated with emotional recognition is reduced in children with ASD, which explains the characteristics at the biological level [33]. Tsang, 2018 notes that in the HFA group, atypical emotional processing is observed in identifying facial emotions during an eye-tracking study. According to this author, children recognize overt emotions such as happiness and sadness more easily, but have greater difficulty with disgust and anger, which require more cognitive strategies during emotional perception [34]. Other authors also note that children with ASD have greater difficulty recognizing emotions, particularly anger [35] and sadness [36]. A meta-analysis shows that fear recognition is worse than happiness recognition [32], while other authors note that the autism spectrum group shows deficits in Empathic Accuracy for anger [37]. Difficulties in recognizing negative emotions are also reported in studies of adults with autism [38]. Another study, however, shows that children with ASD display a lack of interest in sad faces and often avert their gaze from such facial stimuli [39].

3. Cognitive and communication difficulties, without underlying social dysfunctions. In this section, we hypothesize that the combination of difficulties in language comprehension and communication difficulties, which are due solely to limited experience in communicative situations and situations shared with others, could account for significant individual differences in the understanding of emotions as well as in social behavior among children with ASD. Consequently, various studies will yield diverse results regarding performance on tasks involving cognitive empathy and the recognition of emotions in faces and scenes.

4. Conclusion

Understanding and recognizing others' experiences and emotions are functions that people need for social interaction, social inclusion, and communication with others. In our efforts to understand the challenges faced by children with autism spectrum disorders, we seek to define the cognitive elements involved in emotion recognition, the development of social skills, and communication skills. In addition to assessing these functions, a challenge for developmental psychopathology lies in the methods through which children with autism can be helped to learn more about how to recognize their own and others' emotions, better regulate their own reactions, and better cope with the reactions of others in a social setting. Recognizing the emotions and experiences of others and developing empathy skills will likely provide children with autism spectrum disorders with significant advantages in social functioning; as they grow closer to their peers and adults in their living environment, they will also gain more social experience and social knowledge.

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