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Application of Eye-tracking in research on the theory of mind in ASD

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Abstract. – **Autism spectrum disorder (ASD) is a broad diagnostic category describing a group of neurodevelopmental disorders which includes the autistic disorder. Failure to develop normal social relationships is a hallmark of autism. An inability to understand and cope with the social environment can occur regardless of IQ. One of the hypotheses of the appearance of ASD symptoms is associated with the theory of mind (TOM). ASD patients do not have the ability to attribute the full range of mental states (goal states and epistemic states) to themselves and to others. Eye-tracking allows for observation of early signs of TOM in ASD individuals, even before they are 1 year old, without the need of developed motor and language skills. This provides a window for looking at the very basics of mindreading – detecting intentionality and eyes in our environment. Studies show that ASD children fail to recognize biological motion, while being highly sensitive to physical contingency within the random movement. Their perception of faces seems disorganized and undirected, while object recognition is intact. Evidence suggests that this orientation of attention following gaze cues is diminished in ASD patients. Available data also show deficits in emotion recognition, that cannot be accounted for by impairments in face processing or visual modality alone. Such observations provide an insight into disturbances of information processing and offer an explanation for poor social functioning of ASD patients. When combined with other methods, Eye-tracking has the potential to reveal differences in processing information on a neural circuitry level. Thus, it may help in understanding the complexity of TOM mechanisms, and their role in social functioning.**

Key Words:
Autistic spectrum disorders, Theory of mind, Eye-tracking, Therapy, Neuropsychology.

Introduction

Autism spectrum disorder (ASD) is a diagnostic category describing a group of neurodevelopmental disorders – autistic disorder, and the less severe: Asperger disorder and pervasive developmental disorder not otherwise specified[1]. Essential features of ASD (the so-called autistic triad[2]) include (1) persistent impairment in social interaction and (2) reciprocal communication (criterion A) and (3) restricted, repetitive patterns of behavior, interests, or activities (Criterion B). Although there is no cure available, a correct management and support can make a difference in a patient's quality of life and ability to function in social situations[3].

Failure to develop normal social relationships is a hallmark of autism. An inability to understand and cope with the social environment can occur regardless of IQ. Intellectual impairment and language disorder, frequently associated with ASD, are not sufficient to explain the social deficits exhibited by ASD individuals[4]. Baron-Cohen[4] hypothesized in 1985 that children with ASD lack theory of mind (TOM) – an ability to impute mental states, such as desires, beliefs, and intentions to others and oneself[5]. This ability helps a person to explain and predict another individual's behaviour[6].

Theory of mind (TOM)[7,8] is an important socio-cognitive skill that involves the ability to think about mental states, both your own and of others. It includes the ability to assign and understand mental states, including emotions, desires, beliefs, and knowledge. TOM refers to the abil-

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ity to understand that other people's thoughts and beliefs may be different from one's own and to the ability to consider the factors that led to these mental states. Developing a strong theory of mind plays an important role in social functioning, as it allows people to understand people's thinking, predict their behavior, thereby engaging in social relationships and resolving interpersonal conflicts.

In order to interact with other people, it is important to be able to understand their mental states and consider how these mental states might affect behavior.

TOM allows people to infer about the intentions of others as well as think about what is going on in someone's head, including their hopes, fears, beliefs, and expectations. Social interaction is a complex process, and misunderstandings can make the participants even more tense. By being able to develop precise ideas about what other people may be thinking, we are more able to respond appropriately.

Shahaeian et al[9] believe that the greatest increase in the ability to assign mental states occurs mainly in preschool, between the ages of 3 and 5. According to these authors, the development of theory of mind is also influenced by a number of factors. For example, Thompson et al[10] suggest that gender and number of siblings in the home may influence how theory of mind will emerge. Theory of mind develops as children gain more experience in social interactions. Pretend-play, stories, and relationships with their parents and peers allow children to develop stronger insight into how other people's thinking may differ from their own. Social experiences also help children learn more about how thinking affects actions.

The development of the theory of mental skills tends to improve gradually and sequentially with age. Children under 3 years of age usually incorrectly answer questions about the theory of mental tasks, while children under the age of 4 usually demonstrate better TOM. For example, most 4-year-olds understand that others may have false beliefs about objects, people or situations. The development of TOM does not stop there. Children between the ages of 6 and 8 are still developing these skills and, in research, were still not fully proficient in all theory of mind tasks[11].

One of the most commonly used methods of assessing the theory of a child's mental abilities is the false belief task[8]. The ability to attribute false belief to others is considered a key element in creating theory of mind. The purpose of such activities is to require children to draw conclusions about what someone has done or what they are thinking when the other person's beliefs about reality conflict with what the children currently know. In other words, children may know something is true; understanding false belief requires them to understand that other people may not be aware of the truth.

As Richardson et al[12] suggested, while theory of mind has historically been assessed using only false belief tasks, current approaches involve measuring on a scale of developmental tasks. For example, the ability to understand what other people want comes before the ability to understand hidden emotions that people may be feeling.

Baron-Cohen[13] suggested that TOM problems are one of the hallmarks of autism. The study looked at how children with autism perform mental theory tasks compared to children with the Down syndrome as well as neurotypical children. These researchers found that while approximately 80% of children with neurotypical or Down syndrome were able to correctly answer theory of mind questions, only about 20% of children diagnosed with autism answered the questions correctly.

According to Baron-Cohen, lack of capability for TOM may offer an explanation for lack of pretend-play in ASD children and difficulties in social interactions. He also postulated that lack of TOM may be a unique characteristic of ASD. One of the first signs of ASD, observable during the first year of life, are differences in the perception of faces and disengagement of visual attention[14]. Klin et al[15] argue that some deficits in adult ASD individuals may result from basic perceptions deficits, observable in early childhood. Those deficits may result in cascading consequences for both social development and lifelong impairments in social interaction, symptomatic for autism spectrum disorders[16]. Eye-tracking – studying of gaze behavior patterns – has been recently employed to carry out research on ASD individuals. Studies typically involve stimuli, such as simplified images, pictures or video clips[17]. Falck-Ytter et al[14] argue that Eye-tracking gives an opportunity to reveal important features of the complex picture of autism. Eye-tracking data can be conceptualized as describing ASD at a unique, intermediate level, with links to underlying neurocognitive processing, as well as to everyday functioning[14].

Modular Theory of Mind

Humans are arguably the only species which possesses a developed TOM – an ability to attribute the full range of mental states (goal states

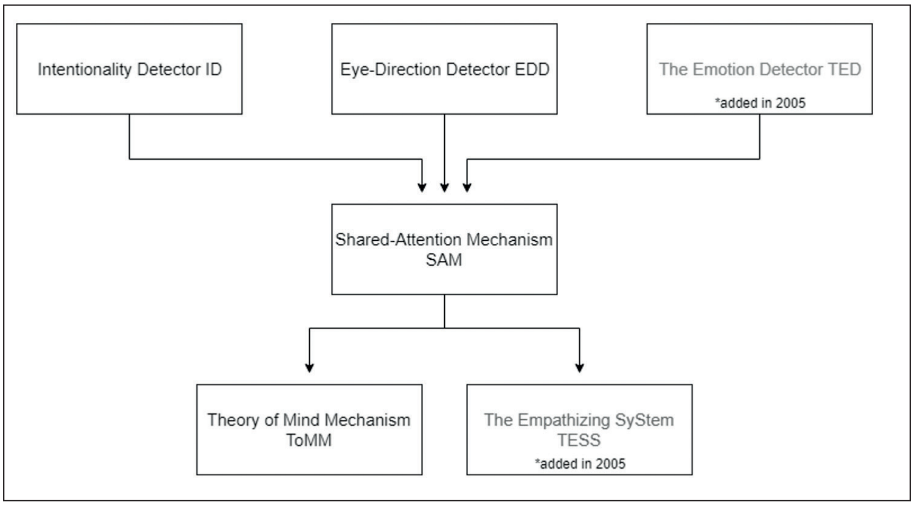

Figure 1. Mindreading System (with 2005 revision).

and epistemic states) to themselves and to others. These attributions help to make sense of other's behavior and predict behaviour[18]. Baron-Cohen argues that the evolutionary development of TOM might not only as important, but maybe even more important for the human species than the development of language and bipedalism. The beginnings of TOM might go back as far as 6-35 million years. Monkeys and apes show the ability to attribute goal states (detect intentionality)[5]. They are aware of gaze direction, which indicates that they are monitoring when they are a target of another's perception[19]. Without TOM, the ability to use language would have been of little value. There is a hypothesis that TOM deficits in ASD can explain pragmatic language and communication impairments[20]. According to Baron-Cohen[18], autism can be considered an illustration of what human life would be like if we lacked TOM. The impact on the ability to socialize, communicate, use imagination, etc. would be devastating.

In the process of language acquisition, correctly mapping references is facilitated by joint attention[21], which is an early form of mind-reading ability[22]. This implies, that typical 12-18-month-old children benefit a great deal by having the capacity for conceptualizing intention and attention of others[18].

Baron-Cohen[22] described 4 mechanisms which underlie the ability to read minds in humans. They can be seen as 4 separate components of human mindreading system (Figure 1).

Intentionality Detector (ID) is a part of innate human equipment for reading the minds of others. The ID is a perceptual tool which interprets the movement of stimuli in primitive, volitional mind states, such as goals and desires. In theory, ID engages every time when movement can be associated with agency (e.g., a moving bowling bowl won't engage ID, but a mouse will). After misidentification, when a person finds out that a given object does not have intentionality, the initial judgment can be revised. Humans show a tendency for identifying movement in terms of agency, even when there is clearly no agent[23]. The ID can use information from any modality. It detects whether self-induced movement can occur taking into account the shape, size, noise, etc. Both the insect and the giraffe are immediately identified as agents with their goals and desires (it wants, it needs).

The Eye-Direction Detector (EDD) is a specialized part of the human visual information processing system that uses only visual modality. Detection of eyes or eye-shaped objects is the main EDD function. When eyes are detected, a person starts monitoring what the eyes are doing and focuses their own gaze at them for a relatively long time. When a human detects eyes gazing at an object, they use their own experience to come to a conclusion that the person in question sees the object. Eye contact also induces immediate changes in cognitive processing and is associated with an activation of the nervous system, especially social networks in the brain[24].

The mechanisms above are dyadic representations – they include only two people. A third one – The Shared Attention Mechanism (SAM) – allows for triadic representations. These involve me, an agent, an object and an element which describes that we are both looking at the same object. The perceived gaze direction of the agent may be such an element (although building triadic representations on the basis of other senses is possible according to Baron-Cohen).

The fourth mechanism is The Theory of Mind Mechanism (ToMM), which is positioned on top and above the three previous mechanisms. It allows for representing complex epistemic states of others (pretending, thinking, knowledge, imagination, deception, etc.) and combining them with data from the 3 previous mechanisms into a coherent conception of how epistemic states and behavior are connected. The effect of ToMM is then a useful theory for explaining the behavior of others.

In 2005[25] Baron-Cohen revised his theory, adding two new components to the mindreading system (see Figure 1). The first new mechanism is The Emotion Detector (TED), placed right next to ID and EDD, which suggests its basic nature. Secondly, The Empathizing System (TESS) was placed next to ToMM. TED is responsible for creating a dyadic representation of affective states (e.g., the mother is happy). Like ID, TED is amodal and can source not only from facial expression but also from hearing the sound of another voice and from touching (relaxed *vs.* tense). According to Baron-Cohen, TED allows for identifying basic emotion[26]. Implementing TED described another source of information for SAM, which was missing before. TESS describes the behavioral explanation and prediction proposed by ToMM in even simpler terms. TESS allows for empathy towards others (not only "I can see your pain," but "I'm empathizing with your pain").

TOM Deficits as a Possible Explanation for Social Deficits in ASD

In 1985, Baron-Cohen[4] published the results of a study involving 20 autistic children aged between 6 and 16 (with normal IQ, x=82), 14 children with Down syndrome aged between 6 and 17 (with lower mean IQ, x=64) and 27 preschool children without clinical diagnoses aged between 3 and 6. In the Sally-Anne task (or false belief task), children are presented with a scene, where one doll (Sally), places a marble in a basket, and then leaves. Without Sally present, another doll (Anne) transfers the marble into another basket. When Sally returns, the experimenter asks: "Where will Sally look for her marble?". If a child points to the first basket, it passes false belief tests. Baron-Cohen argues that passing this test requires the ability to form second-order beliefs, involving the subject reasoning about what one person thinks about another person's thoughts[27]. A typical child is able to pass this test at the mental age of 6 years old[27]. The experiment showed that most high IQ ASD children (16 out of 20) had impaired TOM abilities. ASD participants were indicating the basket where the marble was at the time of question asked by experimenter (ASD children voiced their own belief, not Sally's belief). The Down's Syndrome children and normal preschool children answered by pointing to the marble's original location. Thus, they must have understood that their knowledge cannot be attributed to Sally, who has a false belief about the location of the marble. Baron-Cohen also pointed out, that the skill assessed by this task is a conceptual perspective-taking, rather than perceptual perspective-taking, where a child has to indicate what can be seen from another point of view. Perceptual perspective-taking tasks can be solved using solely visuospatial skills and in no way require imputing beliefs to others. Hobson[28] showed that ASD children succeed in perspective-taking tasks.

A number of subsequent studies employing tasks similar to Baron-Cohen's false belief tasks for TOM assessments[29,30,31] reported intact TOM in some high functioning ASD individuals. In response to those findings, Baron-Cohen argued[27], that "it is unfortunate that many workers in this field have thought of second-order tests as "complex" or high-level tests of the TOM." He claimed that finding an adult who can pass second-order TOM test merely means, that they have intact TOM skill at the level of a 6-year-old, and no conclusion about fully developed TOM can be drawn from such tests. For a more appropriate assessment of TOM in adults, he conducted another experiment using Reading the Mind in the Eyes (or "The Eyes Task" for short). 16 ASD adults with normal intelligence (ASD unconfounded by mental handicap), 50 healthy adults and 10 adults with Tourette Syndrome (TS) participated in the study. Participants had to pass three simpler TOM tests before being recruited, then they were asked to look at photographs of the eye region of faces and make a forced choice between two words describing what the person in the photograph might be thinking or feeling. The had a choice of mental states which were either basic (in the sense of Ekman's basic emotions[26], such as angry, sad, happy, etc.) or more complex (such as reflective, arrogant, scheming, planning, etc.). The experiment provided evidence for subtle theory of mind deficits in individuals with ASD at later points in their development and for higher IQ results than had been previously demonstrated. The study results cannot be simply attributed to developmental neuropsychiatric disability since subjects with TS were not impaired in this test. Baron-Cohen explicitly noted that even this "very advanced test" of theory of mind is still simpler than the real demands of actual social situations. Individuals with a high-functioning autism can often pass formal ToM tests while having real difficulties in everyday social situations. It is possible that they apply some kind of unusual compensation strategies to complete the task[6]. Senju[32] argues that ASD individuals do not have the ability for spontaneous attribution of false belief in everyday situations, which presents an individual with the need for quick, intuitive assessment, rather than complex analysis.

Application of Eye-tracking in ASD Research

Eye-tracking is a technique which allows for the observation of gaze behavior and perception processes. It can be useful for exploring a wide range of scientific and behavior related questions and has long been used to investigate how stimuli are processed[33-37]. It is based on the premise, that when a person fixates on an object, its image falls on the part of the retina (fovea) specialized for detailed visual processing, and therefore eyes need to move, to retrieve details from the visual scene[38]. Simplifying – eye movements can be described as either fixation (stabilized gaze), saccades (rapid jumps between fixations) or smooth pursuit (stabilized gaze on moving stimuli)[14]. Early Eye-tracking studies involved coding gaze behavior from recordings of participants[14], or simply from an observation made by experimenters (such as in case of a neurologist asking "follow my finger with your gaze"). Modern Eye-tracking devices commonly use near-infrared light, which is reflected by the cornea and the pupil, and recorded by cameras mounted below the monitor screen, in front of the observer. From those data, algorithms calculate with high accuracy (<1 visual degree, sampling rate of between 50 and 300 Hz) estimated the position of gaze fixation on the stimuli on the screen[17]. Eye-tracking devices usually specify the size of the virtual "box" (e.g., 20 cm box for Tobii T120 eye tracker) in which a person can move freely, and the device is able to follow the location of the eyes. This technique does not require a head restraint or head-mounted hardware[39]. The method allows for observation of spontaneous gaze behavior without the need for developed motor and language skills[14]. Thus, it is useful in infant and child studies. Recording gaze behavior provides data on where a person is seeking detailed information in the visual scene, and what information they use to understand or solve a given situation[17]. It is important to note, however, that Eye-tracking data does not provide any information on how visual stimuli are processed in the brain. Eye-tracking data are often combined with cognitive tests, and then, they can provide insight into strategies that might have been used by an individual to solve a given problem. There is an agreement, that Eye-tracking captures specific aspects of visual attention[39]. Given that TOM abilities are based on basic perception processes[15,32], Eye-tracking offers a chance for picking up of early ASD signs in spontaneous visual behavior. A study by Merin et al[40] managed to find a subgroup of infants at risk for ASD at 6 months old by observing gaze behavior (length of fixations on the eyes relative to fixations on the mouth). 10 out of 11 identified infants had an older sibling with an ASD diagnosis. The siblings' recurrence of ASD is at least 20 times greater (5-10%) than in the general population[41,42]. Eye-tracking allows for the observation of early signs of TOM in ASD individuals even before they are 1 year old. It provides us with a window for looking at the very basic of mindreading – detecting intentionality and eyes in our environment.

Eye-tracking Studies

Simion et al[43] conducted a study on 43 newborns (postnatal age ranged from 10 to 130 h), showing them point-light animations of either biological motion (points represented joints of moving animal shapes) or nonbiological (random). The results demonstrated that newborns have a visual preference for biological motion, even though they were unfamiliar with it. Therefore, this preference seems to be experience independent. Additionally, the study showed that newborns preferred upright images, compared with inverted (upside-down) images. This preference might reflect the intrinsic constraints of the visual system. A growing body of evidence indicates that humans, among other vertebrates, have neural pathways engaged in preference for motion detection. This bias is critical for a variety of adaptive behaviors, including filial attachment and hunting[44]. Pelphrey et al[45] reported an overlapping of brain regions involved in detection of biological motion and perception of social information sources, such as facial expression and gaze direction. Klin et al[16] conducted experiments similar to Simion et al[43] with 21 ASD toddlers. Control groups comprised 39 typically developing toddlers, and 16 developmentally delayed but non-autistic toddlers. The mean age for the whole group was 2.05. In this study, ASD toddlers failed to recognize biological motion (point light animations prepared using 3D motion capture of actors' movements), while being highly sensitive to physical contingency within a random movement. This observation indicates that Intentionality Detector with its neural underpinning – the very basic mechanism of TOM[18,46] – might be disrupted in ASD.

Pelphrey et al[46] observed gaze behavior of 5 ASD adults with IQ within the normal range and 5 adult male controls as they viewed protographs of human faces. The faces in photographs were showing basic emotion[26]. First, spontaneous gaze behavior was recorded (stimuli were shown for 2 seconds with 2 seconds interval between stimuli), then, participants were instructed to identify emotions in faces (stimuli were shown for 2 seconds with 5 seconds interval between stimuli, and list of basic emotion to choose from). Compared to the control group, ASD individuals spent less time examining core face features (eyes, nose, mouth). Their face perception seemed disorganized and undirected. ASD individuals were often processing one or two relatively unimportant areas (such as an ear, chin, hairline). Scanpaths were not altered by experimental condition (spontaneous perception *vs.* instructed). Dalton et al[47] also reported diminished fixation time on the eyes in ASD individuals. In this study, Eye-tracking was performed in conjunction with fMRI, showing a strong, positive correlation between the time spent fixating the eyes and fusiform gyrus and amygdala activation. In neurotypical individuals, face perception and recognition are based on spatial configuration between the core features of a face[48-50]. ASD children identify significantly fewer pareidolic faces (illusions of faces arising from ambiguous stimuli in the environment) than typically developing peers[51]. They were not different however in the identification of objects. Thus they show a specific inattention to faces. Following a person's gaze helps to reveal their focus of attention, and therefore, perception of gaze is important for imputing mental states (e.g., their interests, desires) to others[52]. Experiments using various cueing paradigms have shown faster reaction times when the gaze of the face is directed towards the target, compared to gaze directed in the opposite direction or directed straight ahead[53,54]. Evidence[55,56] suggests that this orientation of attention is an automatic reflex. Congiu et al[57] compared spontaneous gaze following in ASD children (mean age 5.8 years) to that of typically developing children (mean age 5.7 years). Participants were shown video clips in which an object was visible or was only represented by a gaze directed at a hidden object. According to the study, spontaneous gaze following in ASD children was significantly lower than in the control group. Although they were responsive to gaze as a perceptual cue, they seemed to ignore its representational meaning. Many studies[58-61] found the responsiveness of ASD individuals to gaze cueing to be intact. Impaired joint attention is however one of the core clinical features of ASD. At the same time, a diminished tendency to use gaze to infer desire, intentions, and reference was also demonstrated[62,63]. This discrepancy might be the result of differences between real-life and experimental situations[60]. In natural situations, ASD toddlers do not follow the gaze of others[58]. This might be a reflection of different underlying strategies for gaze processing in ASD individuals. A study by Roubough et al[64] found that ASD individuals preferred following arrow cues, instead of eyes when asked about a cartoon character's mental state. The team interpreted this as lack of response to the social meaning in the eyes. A study by Ashwin et al[65] used a spatial cueing paradigm involving head and body cues on photographs of a person followed by a laterally presented target. They recruited 24 ASD adult males and 23 adult males as a control group. The person in the photographs was either oriented towards, turned left or right, was visible from the waist up and had a neutral facial expression. Cueing stimuli were presented for 50 ms; then, a target appeared 5.6 cm to either the left or right side of the fixation point until a response was executed. Results in the ASD group showed facilitated orienting to targets when both the head and body were rotated towards the target. In contrast, the control group showed facilitated orienting towards the target when presented with a congruently rotated head combined with a front view of a body. Ashwin et al[65] argue that this finding indicates atypical integration of social cues in ASD for orienting attention. This might reflect impaired cognitive and neural mechanisms responsible for the processing of social cues and attention orienting in ASD. The studies described above provide an insight into how EDD mechanism (detecting eyes and gaze direction) and SAM mechanism (joint attention) are failing in ASD individuals contributing to impaired ToMM in ASD.

The ability to recognize emotional states in others from their facial expression is a basic component of social cognition[46,66] and was introduced in 2005[25] as an additional component to the mindreading system. Although there is general agreement that ASD individuals show at least some facial emotion recognition impairment, the available data are highly inconsistent[67]. Pelphrey et al[46] (mentioned above) found that ASD individuals performed worse in recognizing basic emotions[26] than the control group. This effect was driven by deficits in recognition of fear. For 5 other basic emotions, ASD individuals did not differ significantly from the control group, although a consistent trend towards lower levels of emotion recognition was found in ASD individuals. The same study reported disorganized face perception in ASD (described above). Law Smith et al[68] reported impaired disgust, anger, and surprise recognition when presented with dynamic stimuli at varying intensity of expression. Disgust recognition appeared to be most impaired (at 100% and lower levels of expression intensity), with surprise and anger intact at 100% but impaired at lower levels. This finding suggests that a subtlety of facial expression might make it difficult to read for ASD individuals[66]. Neumann et al[69] argue that ASD individuals tend to rely more on the mouth area than the eyes when given a task requiring them to identify facial emotion expressions. In their study, the ASD group fixated the location of the mouth more than matched controls, even when the mouth was not shown (removed from the picture), or the face was inverted. Philip et al[70] showed that ASD individuals are impaired when it comes to the recognition of facial emotions (mostly anger, sadness and fear). They also showed that emotion recognition deficits cannot be accounted for by impairments in face processing or visual modality alone, as they found significant deficits in emotion recognition from body movement and vocal stimuli. All this data indicates that the newest components of the mindreading system – TED and TESS[25], might also be impaired in ASD individuals.

Conclusions

The application of Eye-tracking provides a potential for direct, objective, and quantitative observation of behaviour[17]. Such observation yields information on where a participant looks for detailed information and when they looked there. This allows for inferring a strategy for completing a task when Eye-tracking data are combined with other methods (such as cognitive tests, social tasks). Combining Eye-tracking with neuroimaging[47] is a possible future direction, which allows for a search for a neural base of processing visual scenes. Being non-invasive and requiring no more than the ability to move eyes, Eye-tracking makes it possible to research newborns as young as 10 hours postnatal age[43]. Such research provide valuable data, not confounded by experience, culture, and development. Early ASD identification makes early intervention possible and offers a chance for minimizing social deficits during a lifespan. Eye-tracking studies reveal different social information processing strategies employed by ASD individuals and their limitations in everyday social situations[6]. All the above issues make Eye-tracking a valid tool for ASD research. Eye-tracking provides valuable information on differences in perception processes which constitute the basis for TOM development[18]. When combined with other methods Eye-tracking has the potential to reveal differences in processing information on a neural circuitry level. Thus, it may help understand the complexity of TOM mechanisms, and their role in social functioning. It is possible that better understanding of intact and impaired processing of socially relevant information in ASD individuals will help design better interventions.

Although the data available today is promising, the clinical value of Eye-tracking remains to be established[14]. Heterogeneity of results of Eye-tracking studies on ASD individuals might be a result of different types of stimuli used – from schematic pictures to more ecologically relevant. Differences and deficits seem to be best detected when dynamic stimuli presenting human characters are used[71].

Conflicts of Interest
All authors declare there are no possible conflict of interest regarding the topic of the submitted paper.

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