Robotics and Diagnosis of Autism Spectrum Disorder

Konstantinos Karakiozis[1]
Evangelos C. Papakitsos[2]
Michail Papoutsidakis[2]

[1]The Second Center for Educational and Counseling Support of Piraeus, Piraeus, Greece
[2]University of West Attica, Athens, Greece

Abstract. Autism Spectrum Disorder (ASD) is an umbrella term that describes a neurodevelopmental disorder that affects children's ability to communicate with those around them and to develop mutual relationships with them. There is a reduced social interaction and communication observed, as well as limited, repetitive and stereotyped behavior. The gradual increase over time of the prevalence of children evaluated with ASD suggests the growing need to have a valid diagnosis in time, in order to develop effective interventions. In the present work, the use of Robotics for the diagnosis of Autism Spectrum Disorder is investigated. Technological developments in the last decade have led to significant results in recording and decoding children's behavior based on ASD criteria. The use of robots to record and decode eye contact, speech and behavior, and/or gestures of children with ASD can lead to more objective observations, improved objectivity and reliability of the diagnostic process, cost reduction and more early diagnoses. On the other hand, so far, the diagnosis by robots cannot work autonomously, so in many cases the presence of a robot operator is considered necessary.

Key words: autism spectrum disorder, neurodevelopmental disorder, diagnosis technology, special education, educational robotics.

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that affects people from birth and its symptoms appear in the early stages of development. It is a complex developmental disorder with high levels of heterogeneity within the clinical population, in terms of symptom presentation and severity (Grzadzinski et al., 2013: 1-6). People with ASD show persistent deficits in social communication, social interaction, and repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2013). The term "autism" was first used by the Swiss psychiatrist Eugen Bleuler in 1911, etymologically derived from the Greek word "self", and was intended to characterize specific symptoms of psychopathology in people with schizophrenia, who tended to be confined and cut off from contact with reality (Stotz-Ingenlath, 2000: 153-159). In the sense it has today, it is first mentioned in 1943 by Leo Kanner and aims to interpret the introversion of the child (himself) and the inability to communicate with the environment. In general, in the early 1940s, Leo Kanner and Hans Asperger, through different research conducted separately in different regions (USA, Germany), recorded cases of children with social skills deficits, peculiar verbal development and stereotyping behavior (Lyons and Fitzgerald, 2007: 2022; Merrick et al., 2004). Hans Asperger published his research on children with similar characteristics in a newspaper, the year after Kanner's publication, however, it was not until 1981 that Wing (1991: 93-121) published a paper comparing Kanner's syndrome with Asperger's syndrome, and Asperger's disorder gained special recognition. Over the next 30 years, various diagnostic tools were proposed to categorize some or all of the features described by Kanner (Wilmshurst, 2014).

The relevant term (ASD) is an umbrella term (Volkmar and Klin, 2005: 5-41), which describes in DSM-V a number of related disorders (American Psychiatric Association, 2013), such as: Autistic disorder (Autism), Asperger's disorder, Childhood Disintegrative disorder, Rett's disorder, and Pervasive Developmental disorder not otherwise specified. Actually, ASD diagnosis should be given in individuals with DSM-IV diagnosis of autistic disorder, Asperger's disorder, or Pervasive Developmental disorder not otherwise specified. Children diagnosed with autism are categorized in a wide range (Ismail et al., 2019: 389-410). In the DSM-V (American Psychiatric Association, 2013), the autistic spectrum is divided into 3 categories of severity, based on the level of functionality in two domains (social communication and repetitive behavior):

- Level 1 – "Requiring support",
- Level 2 – "Requiring substantial support" and
- Level 3 – "Requiring very substantial support".

According to a recent research (Mazurek et al., 2019: 468-476), it was observed that:

- 25% of children were rated as requiring support (Level 1) in both social communication and repetitive behavior domains,
- 27% were rated as requiring substantial support (Level 2) in both domains, and
- 15% were rated as requiring very substantial support (Level 3) in both domains.

Asperger's Syndrome, named after Hans Asperger, was commonly used to describe either the less severe type of autism or variations in autism criteria, based on different language ability (Wilmshurst, 2014). In the DSM-5 standard (American Psychiatric Association, 2013), the term Asperger Syndrome has been abolished and now such children belong to Level 1 (Requiring support) in ASD.

Characteristics of ASD

A key feature of autism and ASD in general are the difficulties faced by some children in the field of social interaction and especially in eye contact, imitation and social behavior (Amran et al., 2018: 1779). Children with ASD have difficulty maintaining eye contact, usually looking elsewhere when talking to others (Dautenhahn, 2000). They also have difficulty in imitating (Amran et al., 2018: 1779; Mundy and Crowson, 1997: 653-676), which suggests limited cognitive and social skills in interacting with other people (Ingersoll, 2008: 107-119), as well as limited social behavior, communication and interaction with others (Mundy and Crowson, 1997: 653-676).

The most recent (5th) edition of the DSM-5 (Diagnostic and Statistical Manual of Mental Disorders) of the American Psychiatric Association (2013, 50) includes diagnostic criteria, divided into 2 groups:

– (I) "Persistent deficits in social communication and social interaction across multiple contexts", including deficits in: social-emotional reciprocity, non-verbal communication behaviors used for social interaction, in developing, maintaining, and understanding relationships.

– (II) "Restricted, repetitive patterns of behavior, interests, or activities", including: Stereotyped or repetitive motor movements, use of objects, or speech, insistence on sameness, inflexible adherence to routines, or ritualized patterns of verbal or nonverbal behavior, highly restricted, fixated interests that are abnormal in intensity or focus, hyper- or hypo-reactivity to sensory input or unusual interest in sensory aspects of the environment.

The above symptoms should have been manifested in the early developmental period of children and interfere with their daily functioning. Also, DSM-5 criteria for ASD introduce a series of specifiers, such as intellectual impairment, language impairment, a known medical or genetic condition or environmental factor, another neurodevelopmental, mental, or behavioral disorder and catatonia.

Prevalence

The prevalence (frequency of occurrence and spread over a period of time) of Autism Spectrum Disorders has steadily increased in recent years. For many years, autism was considered a rare disorder with an incidence of between 5 per 10,000 people in the 1960s and/or 6.5 per 10,000 children (CDC, 2020; Moldin and Rubenstein, 2006). In the following years the ratio is estimated at:

– 1 per 150 children in 2000,
– 1 in 110 children in 2006,
– 1 in 68 children in 2012 and
– 1 in 54 children in 2016, the year with the most recent data available from the US Centers for Disease Control and Prevention (CDC, 2020).

These data suggest that autism is more common than serious childhood diseases, such as diabetes or even childhood cancer (Heward and Wood, 2006: 23-29). Autism is more common in boys than girls in a ratio of about 4/1 and is independent of the socio-economic status, race and nationality of children. In 2018, it was estimated by the US Centers for Disease Control and Prevention that 1 in 42 boys are affected, as opposed to 1 in 189 girls (Richardson et al., 2017: 30-39). On the contrary, in 2008 there was an estimation of 1 in 54 boys compared to 1 in 252 girls (Baio, 2012). In the past, prevalence rates varied between the United States and ranged from 5.7 to 21.9 per 100 children in 2012, compared to the latest figures of 18-19.1 per 100 children (CDC, 2020). Differences in prevalence figures are largely due to (Volkmar and McPartland, 2014: 5-41):

– the evolution and broadening of diagnostic criteria,
– public awareness,
– greater recognition of ASD.

According to a recent survey in the United States, the mental capacity of children with ASD is classified as follows:

– 31% of children in the range of mental disability (IQ < 70),
– 25% marginal (IQ = 71-85),
– 44 % on average and above average (i.e., IQ > 85).

Data vary by gender, race and ethnicity (Baio et al., 2018: 1-12).

Diagnosis of ASD and the need for early diagnosis

The diagnosis of autism is based on behavioral observations by experienced clinicians, based on specific behavioral indicators of autism (Petric et al., 2018: 18500). Some of the characteristics of ASD are observed even from the age of 12 months (Zwaigenbaum et al., 2005: 143-152), although a reliable diagnosis can be made in children of 18 (Eggebrecht et al., 2017: 1709-1720) or 24 months old (Steiner et. al., 2012: 1183). Particularly in the US, although developmental concerns are recorded for 85% of children with ASD by the age of 36 months, only 42% have had a comprehensive assessment by this age, suggesting the need for early diagnosis (Baio et al., 2018: 1-12).

In addition, the mean age of the early known ASD diagnosis was 52 months and did not differ significantly by gender, race or nationality (Baio et al., 2018: 1-12). The diagnosis of ASD is mainly based on behavioral observations that in turn are based on:

- Criteria from the Diagnostic and Statistical Manual of the American Psychiatric Association (DSM-5) (American Psychiatric Association, 2013).
- Examination of children, using the Autism Diagnostic Observation Schedule, and the revised ADOS-2 (Lord et al., 2000: 205-223; Hus and Lord, 2014: 1996).
- Scale Rating Autism Rating (CARS-2) (Schopler et al., 2010).
- Interview with therapists, using the Autism Diagnostic Interview-Revised (ADI-R) framework (Rutter et al., 2003: 30).
- The Modified Checklist for Autism in Toddlers (M-CHAT) (Robins et al., 1999).
- Autism Spectrum Rating Scales (ASRS) (Goldstein and Naglieri, 2009).

Despite the efforts made so far to improve and standardize the diagnostic procedure, the variable nature of ASD and the onset of symptoms in early childhood (Zwaigenbaum et al., 2015: 10-40), based on the developmental changes that take place, have the effect of difficulties, observed in the recognition and diagnosis of ASD (Huerta and Lord, 2012: 103; Posar et al., 2015: 146).

The diagnosis of ASD is a very difficult task, insofar as behaviors are subjective and differentiate between individuals with similar characteristics (Ismail et. al., 2019: 389-410; Posar et al., 2015: 146). It is based on the interpretation of current and previous behavioral observations of an individual and his/her developmental characteristics, by psychiatrists and in addition by specialists such as psychologists and speech therapists (Yates and Le Couteur, 2016: 513-518). Studies show that the agreement between clinical observations for autism and the DSM-5 criteria is satisfactory, although not always if we refer to an earlier version of the DSM (Klin et al., 2000: 163-167). Also, they have highlighted the need for further improvements (Posar et al., 2015: 146). Respectively, the two tools (Autism Diagnostic Observation Schedule [ADOS-2] and Autism Diagnostic Interview-Revised [ADI-R]) are based on the DSM-5 criteria and have been satisfactorily tested for validity and reliability (Zander et al., 2016: 769-780; 2017: 219-227). In each case, of course, a more detailed assessment is required (McPartland et al., 2012: 368-383). According to the ADOS protocol, the following are specifically tested (Lord et al., 2000: 205-223):

- the child's ability to respond when called by his/her name,
- the existence of common attention,
- the request for play and the target of functional imitation.

The diagnosis of ASD in early developmental stages can lead to early intervention and higher functionality of the child later, significantly increasing the long-term benefits of clinical treatment (Landa, 2018: 25-39; Rotholz et al., 2017: 20161061). In particular, researches asking parents about the ASD diagnosis process for their child have found that although parents firstly seek a diagnosis when the child is 3.9 years old (on average), the final diagnosis is not received until the age of 7.5 years (Bartlett et al., 2020: 81). Consequently, one way in which the diagnostic process could be improved would be to reduce the time required from when parents initially seek diagnosis until receiving the final diagnosis (Crane et al., 2016: 153-162).

Diagnosis using robots

There is a large number of studies in the international literature that focus on the treatment of autism spectrum disorder using robots (Billard, 2003: 259-269; Bonarini et al., 2016: 823-830; Cabibihan et al., 2013: 593-618; Dautenhahn et al., 2002; Diehl et al., 2012: 249-262; Huijnen et al., 2017: 278; Shamsuddin et al., 2012a: 1533; 2012b: 1448; Simut et al., 2016: 113-126; Wainer et al., 2014: 45-65; Wood et al., 2017: 53-63). Robotic interventions in people with autism aim at the following behaviors (Cabibihan et al., 2013: 593-618): imitation, shared attention, sequence rotation, recognition of emotions and expressions, initiation of interaction, and ternary interaction. Issues that are specifically studied: eye monitoring, speech detection, speech analysis, posture monitoring, gesture monitoring, facial expressions, object detection, sound detection, specific events (Bartlett, et al., 2020: 81).

Many research efforts have been also made in the field of robotic ASD diagnosis (Arent et al., 2019: 652-656; Bartlett et al., 2020: 81; Neto et al., 2019; Petric and Kovacic, 2020: 371-388; Petric et al., 2018: 18500; Ramirez-Duque et al., 2019: 267-281; Scasselati, 2007). The introduction of robotics in the field of ASD diagnosis is not intended to replace the evaluations performed by specialist physicians, but to facilitate access to evaluations that will be done in a timely manner, at a lower cost and more efficiently, based on more objective decision-making or measurement procedures (Bartlett et al., 2020: 81). Possible uses of robots for the diagnosis of ASD are (Scasselati, 2007; Tapus et al., 2007: 35-42).

–The existence of robots can contribute to the design of social reactions, so that the participants' responses and behaviors can be used in diagnosis. In particular, the presence, absence or quality of each answer is checked. This approach is similar to the social reactions used in the Autism Diagnostic Observation Scale (ADOS). It has also the added advantage that there is the same reaction to all interventions, thus increasing the reliability of the intervention, e.g., a robot may be programmed to assume the role of a bubble weapon, producing bubbles in order to elicit an interaction between the child and the examiner (Feil-Seifer and Mataric, 2009).

–The robot can provide quantitative measurements of behaviors that are diagnostic features of this disorder. Through observation, robots can record behaviors, either directly or indirectly, to decode social behaviors (for example, tone of voice or eye contact) through qualitative measurements.

An important element for the diagnosis of autism is the categorization based on criteria, according to the literature, into: mild and severe autism, high and low-functioning autism or based on the criteria of DSM-5 at severity levels 1, 2 or 3. This distinction can contribute to the choice of the type of human-robot interaction to be used, because different categories of children on the autism spectrum require different types of interaction. Namely, children with severe autism have difficulty to engage in a simple interaction designed for children with mild autism and can react very aggressively to the robot (Ismail et. al., 2019: 389-410). In case that robots are used for the ADOS-based evaluation process, the following are tested (Petric and Kovacic, 2020: 371-388):

–the child's ability to respond when called by his/her name and visual contact is detected by the robot,

–the child's ability for shared attention when shifting his/her attention from one robot to another and there is a positive response through contact with other robots,

–the game request: indicates the simultaneous communication of multiple channels, e.g., vocal stimulation of the child and visual contact in coordination with handshakes and body gestures, in order to assess the child's ability to communicate in many ways simultaneously,

–the assessment of the child's ability to imitate simple actions, a process that may consist of imitations of secondary tasks with two objects: e.g., a toy frog and a cup.

In this research there are positive results for the diagnosis through robots, to the extent that the results of the evaluations from the model MOMDP (Mixed Observability Markov Decision Processes) were compared, through an experimental session, with typically developing children and children with ASD (Petric and Kovacic, 2020: 371-388). Research efforts to diagnose ASD focus primarily on eye contact, vision, and analysis of the behavior and gestures of children with ASD.

Eye contact

Research into the diagnosis of autism at an early age, through the observation of infants' eyes, has been going on for 13 years and is based on the fact that children usually develop typical ways of focusing on the movements of others during their development, before they even learn to speak, especially on the face and eyes of their caregiver (Scassellati, 2007). The behavior of children with ASD is not a consequence of biological movement; on the contrary, children with ASD are oriented towards unpredictable non-social behaviors (Klin et al., 2009: 257-261). With the use of technology, differences in eye contact can be observed during eye monitoring (Magrelli et al., 2013: 840; Swanson and Siller, 2013: 1087), often difficult for researchers to detect when comparing results with the common attention of typically developing children and children with ASD. Eye monitoring in populations with ASD is used primarily to detect atypical behaviors, rather than to interpret internalized conditions, and to identify relevant diagnostic behavioral evidence (Bartlett et al., 2020: 81).

Speaking

There are two main types of speech in the context of ASD diagnostic criteria: speech presence/absence detection and speech content processing (consisting of reference speech detection, keyword recognition and comprehension) (Magrelli et al., 2013: 840; Bartlett et al., 2020: 81). The best possible recording of speech usually requires the use of multiple microphones (Athanasopoulos et al., 2015: 129-153; Magrelli et al., 2013: 840). In any case, children with ASD participate in fewer conversations and produce fewer voices than normal children (Warren et al., 2010: 555-569). A child's level of vocal development can explain differences in language use and predict the use of spoken language for children with ASD (Plumb and Wetherby, 2013: 721-734), even under different conditions (Yoder et al., 2013: 103-107). It should of course be checked whether the existence of different language environments by the adults a child grows up with (e.g., different number of words produced by adults) can affect a child's language development and, therefore, cause confusion in estimates about speech in children with ASD (Bartlett et al., 2020: 81). Although the diagnosis of autism through voice analysis is still in its infancy (Schmitt et al., 2016: 1-5), automated speech recording can help in this direction, as clinicians do not need to listen to and record manually a child's speech, since they can evaluate his/her speech during physical interactions in his/her daily life (Bartlett et al., 2020: 81).

Behavior and gestures

For a child with ASD, social behavior is very difficult and unpredictable and therefore may seem threatening (Arent et al., 2019: 652-656). Monitoring a child's behavior in real time during a clinical evaluation can provide very important data (Bartlett et al., 2020: 81). For example (Petric et al., 2018: 18500), the effectiveness of an autonomous robot protocol for performing diagnostic activities with children has been successfully tested. These activities included the robot:

–detecting if the child was playing with a toy before attracting the child's attention (calling it by name),

–directing a child's attention to an object (common attention), and

–checking if the child would mimic actions using functional objects (functional imitation).

A framework has also been designed that combines an image recording system with automated parsing of non-verbal cues and scalable architecture to automatically record common-sense events and eye-contact patterns (Ramirez-Duque et al., 2019: 267-281). Tracking objects, based on visual data in each case, is widespread, by using algorithms (Jia et al., 2014: 675-678). Behavior monitoring may include face detection, recognition and monitoring of head posture, gaze, and assessment of visual focus. The only problem recorded is the inability to capture an image when the child is covering the recording camera, otherwise, therapist or robot interventions can be overcome by using multiple cameras (Ramirez-Duque et al., 2019: 267-281).

Results and Discussions

Brief results from the use of Robotics in the diagnosis of autism include:

–Robotics can contribute to the diagnosis of ASD, by operating consistently and reliably in the quantification of behavior if it goes beyond the currently observed ways of observation and offers clear advantages to clinicians in evaluating the symptoms of ASD (Bartlett et al., 2020: 81; Nazneen et al., 2015: 68; Petric and Kovacic, 2020: 371-388; Ramirez-Duque et al., 2019: 267-281).

–The need to develop technological applications in order to improve the diagnostic process for children with developmental disabilities, such as ASD, is highlighted. In particular, the need to record behavior through the creation of algorithms that will help to decode internalized situations and the development of a protocol for the use of robots in the diagnosis of ASD, with adaptations to different behaviors of children (Bartlett et al., 2020: 81; Petric and Kovacic, 2020: 371-388; Ramirez-Duque et al., 2019: 267-281). For example, it is important to quantify behaviors such as: patterns of verbal expression, physical and emotional involvement, preferences for objects or events (Ramirez-Duque et al., 2019: 267).

–Coding the prior knowledge and experience of specialized evaluators could help to contribute to the development of automated methods, a process that requires, among other things, the application of cognitive models to characterize human behavior (Bartlett et al., 2020: 81).

–Robotics can help to reduce the evaluation time and improve process efficiency, so that diagnoses become more reliable (with the application of standard technologies) and affordable (Bartlett et al., 2020: 81; Petric and Kovacic, 2020: 371-388; Ramirez-Duque et al., 2019: 267-281).

–The limitations that exist refer to the possibilities provided by sensor technologies, e.g., when there is coverage of some sensors, but mainly when interpretation of the recorded behavior is required (Bartlett et al., 2020: 81; Ramirez-Duque et al., 2019: 267-281). The accuracy of detecting social behavior cannot be very high when the robot is fully autonomous, instead it needs an operator to make the necessary corrections (Petric and Kovacic, 2020: 371-388).

–Some issues arise regarding the automation of the diagnosis of ASD, as well as the role of social robotics in the diagnosis of ASD, to the extent that it seeks to characterize human behavior from observable aspects (Bartlett et al., 2020: 81; Petric and Kovacic, 2020: 371-388; Ramirez-Duque et al., 2019: 267-281).

–The urgent need to analyze the child's behavior in physical conditions (Neto et al., 2019), with free play (Petric and Kovacic, 2020) and/or with the presence of a caregiver (Ramirez-Duque et. al., 2019: 267-281) is highlighted, possibly with more sessions, helping to improve the validity of the evaluation process (Neto et al., 2019; Petric and Kovacic, 2020: 371-388; Ramirez-Duque et. al., 2019: 267-281).

–An important issue is the accessibility of professionals in terms of the availability of new technology, its ease of operation and its cost (Bartlett et al., 2020: 81).

In any case, the use of robots in the diagnosis of ASD helps to improve the traditional tools used in diagnosis (Ramirez-Duque et al., 2019: 267-281). On the other hand, the need to interpret diagnostic results is recognized, even when clear criteria are provided by the therapist and there is substantial technological progress (Bartlett, et al., 2020: 81). The possibility of robots performing diagnostic functions autonomously in the near future is unlikely. A more likely scenario is for robots to be part of the autism diagnosis process, to be present in an area with multiple sensors, and to help monitor the child and observe his or her behavior (Petric and Kovacic, 2020: 371-388).

Conclusion

In the present work, an attempt is made to record the latest research data, regarding the use of robotics for the diagnosis of ASD. ASD characteristics include deficits in social interaction, social communication, and repetitive patterns of behavior, interests, or activities. The increasing prevalence of ASD in recent decades, as well as the need to implement a comprehensive intervention program, intensifies the need for early diagnosis. Robotics can work effectively in the diagnosis of ASD, to the extent that it contributes to the quantification of human behavior, in the formulation of standards, based on the recognized diagnostic criteria of ASD, in reducing diagnostic costs but also in increasing the validity and reliability of the diagnostic process. On the other hand, the limitations of the application of technology must be taken into account. The diagnosis of ASD by autonomous robots may not be considered an immediately feasible practice, but the possibilities offered by the new technology are very important in standardizing the diagnostic process and improving the whole approach.

References

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (DSM-5). American Psychiatric Pub. Available at: https://cdn.website-editor.net/30f11123991548a0af708722d458e476/files/uploaded/DSM%2520V.pdf

Amran, N.A.B., Gunasekaran, S.S., Mahmoud, M.A. (2018). Investigating the factors that influence the efficiency of using robots as social skills therapy for children with autism spectrum disorder (ASD). Journal of Fundamental and Applied Sciences, 10(6S), 1779-1792. http://dx.doi.org/10.4314/jfas.v10i6s.142

Arent, K., Kruk-Lasocka, J., Niemiec, T., Szczepanowski, R. (2019). Social robot in diagnosis of autism among preschool children. 2019 24th International Conference on Methods and Models in Automation and Robotics (MMAR), Międzyzdroje, Poland, pp. 652-656. http://dx.doi.org/10.1109/MMAR.2019.8864666

Athanasopoulos, G., Verhelst, W., Sahli, H. (2015). Robust speaker localization for real-world robots. Computer Speech & Language, 34(1), 129-153. https://doi.org/10.1016/j.csl.2015.03.009

Baio, J. (2012). Prevalence of Autism Spectrum Disorders: Autism and Developmental Disabilities Monitoring Network, 14 Sites, United States, 2008. Morbidity and Mortality Weekly Report. Surveillance Summaries, Volume 61(3). Centers for Disease Control and Prevention. Available at: https://www.cdc.gov/mmwr/preview/mmwrhtml/ss6103a1.htm

Baio, J., Wiggins, L., Christensen, D.L., Maenner, M.J., Daniels, J., Warren, Z., Durkin, M.S. (2018). Prevalence of autism spectrum disorder among children aged 8 years—autism and developmental disabilities monitoring network, 11 sites, United States, 2014. MMWR Surveillance Summaries, 67(6), 1-12. http://dx.doi.org/10.15585/mmwr.ss6904a1

Bartlett, M.E., Costescu, C., Baxter, P., Thill, S. (2020). Requirements for Robotic Interpretation of Social Signals “in the Wild”: Insights from Diagnostic Criteria of Autism Spectrum Disorder. Information, 11(2), 81. https://doi.org/10.3390/info11020081

Billard, A. (2003). Robota: Clever toy and educational tool. Robotics and Autonomous Systems, 42(3-4), 259-269. https://doi.org/10.1016/S0921-8890(02)00380-9

Bonarini, A., Garzotto, F., Gelsomini, M., Romero, M., Clasadonte, F., Yilmaz, A.N.Ç. (2016). A huggable, mobile robot for developmental disorder interventions in a multi-modal interaction space. 2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), New York, NY, 2016, pp. 823-830. https://doi.org/10.1109/ROMAN.2016.7745214

Cabibihan, J.J., Javed, H., Ang, M., Aljunied, S.M. (2013). Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. International Journal of Social Robotics, 5(4), 593-618. https://doi.org/10.1007/s12369-013-0202-2

CDC (2020). Autism Spectrum Disorder (ASD). US Centers for Disease Control and Prevention. Available at: https://www.cdc.gov/ncbddd/autism/index.html

Crane, L., Chester, J.W., Goddard, L., Henry, L.A., Hill, E. (2016). Experiences of autism diagnosis: A survey of over 1000 parents in the United Kingdom. Autism, 20(2), 153-162. https://doi.org/10.1177/1362361315573636

Dautenhahn, K. (2000). Design issues on interactive environments for children with autism. In Proceedings of ICDVRAT 2000, the 3rd Int. Conf. on Disability, Virtual Reality and Associated Technologies. University of Reading. Available at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.91.8945&rep=rep1&type=pdf

Dautenhahn K., Werry I., Rae J., Dickerson P., Stribling P., Ogden B. (2002) Robotic Playmates. In: Dautenhahn K., Bond A., Cañamero L., Edmonds B. (eds) Socially Intelligent Agents. Multiagent Systems, Artificial Societies, and Simulated Organizations, Vol 3. Boston, MA: Springer. https://doi.org/10.1007/0-306-47373-9_14

Diehl, J.J., Schmitt, L.M., Villano, M., Crowell, C.R. (2012). The clinical use of robots for individuals with autism spectrum disorders: A critical review. Research in autism spectrum disorders, 6(1), 249-262. https://doi.org/10.1016/j.rasd.2011.05.006

Eggebrecht, A.T., Elison, J.T., Feczko, E., Todorov, A., Wolff, J.J., Kandala, S., Zwaigenbaum, L. (2017). Joint attention and brain functional connectivity in infants and toddlers. Cerebral Cortex, 27(3), 1709-1720. https://doi.org/10.1093/cercor/bhw403

Feil-Seifer, D., Matarić, M.J. (2009). Towards the integration of socially assistive robots into the lives of children with ASD. In International Conference on Human-Robot Interaction Workshop on Societal Impact: How Socially Accepted Robots Can be Integrated in our Society (Vol. 21). Available at: https://rrl.cse.unr.edu/media/documents/2016/Feil-Seifer-2009-610.pdf

Goldstein, S., Naglieri, J.A. (2009). Autism spectrum rating scales (ASRS). Multi-Health System. In: Volkmar F. (eds) Encyclopedia of Autism Spectrum Disorders. New York, NY: Springer. https://doi.org/10.1007/978-1-4614-6435-8_102344-1

Grzadzinski, R., Huerta, M., Lord, C. (2013). DSM-5 and autism spectrum disorders (ASDs): an opportunity for identifying ASD subtypes. Molecular Autism, 4(1), 1-6. https://doi.org/10.1186/2040-2392-4-12

Heward, W.L., Wood, C.L. (2006). Exceptional children: An introduction to special education. New York: Pearson Education/Merrill/Prentice Hall.

Huerta, M., Lord, C. (2012). Diagnostic evaluation of autism spectrum disorders. Pediatric Clinics of North America, 59(1), 103. https://dx.doi.org/10.1016%2Fj.pcl.2011.10.018

Huijnen, C.A.G.J., Lexis, M.A.S., de Witte, L.P. (2017). Robots as new tools in therapy and education for children with autism. International Journal of Neurorehabilitation, 4, 278. https://doi.org/10.4172/2376-0281.1000278

Hus, V., Lord, C. (2014). The autism diagnostic observation schedule, module 4: revised algorithm and standardized severity scores. Journal of Autism and Developmental Disorders, 44(8), 1996-2012. https://dx.doi.org/10.1007%2Fs10803-014-2080-3

Ingersoll, B. (2008). The social role of imitation in autism: Implications for the treatment of imitation deficits. Infants & Young Children, 21(2), 107-119. https://doi.org/10.1097/01.IYC.0000314482.24087.14

Ismail, L.I., Verhoeven, T., Dambre, J., Wyffels, F. (2019). Leveraging robotics research for children with autism: a review. International Journal of Social Robotics, 11(3), 389-410. https://doi.org/10.1007/s12369-018-0508-1

Jia, Y., Shelhamer, E., Donahue, J., Karayev, S., Long, J., Girshick, R., Darrell, T. (2014). Caffe: Convolutional architecture for fast feature embedding. In Proceedings of the 22nd ACM international conference on Multimedia (pp. 675-678). Orlando Florida USA. https://doi.org/10.1145/2647868.2654889

Klin, A., Lang, J., Cicchetti, D.V., Volkmar, F.R. (2000). Brief report: Interrater reliability of clinical diagnosis and DSM-IV criteria for autistic disorder: Results of the DSM-IV autism field trial. Journal of Autism and Developmental Disorders, 30(2), 163-167. https://doi.org/10.1023/A:1005415823867

Klin, A., Lin, D. J., Gorrindo, P., Ramsay, G., Jones, W. (2009). Two-year-olds with autism orient to non-social contingencies rather than biological motion. Nature, 459(7244), 257-261. https://dx.doi.org/10.1038%2Fnature07868

Landa, R.J. (2018). Efficacy of early interventions for infants and young children with, and at risk for, autism spectrum disorders. International Review of Psychiatry, 30(1), 25-39. https://dx.doi.org/10.1080%2F09540261.2018.1432574

Lyons, V., Fitzgerald, M. (2007). Asperger (1906-1980) and Kanner (1894-1981), the two pioneers of autism. Journal of Autism and Developmental Disorders, 37(10), 2022-2023. https://doi.org/10.1007/s10803-007-0383-3

Lord, C., Risi, S., Lambrecht, L., Cook, E.H., Leventhal, B.L., DiLavore, P.C., ... Rutter, M. (2000). The Autism Diagnostic Observation Schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism. Journal of Autism and Developmental Disorders, 30(3), 205-223. https://doi.org/10.1023/A:1005592401947

Magrelli, S., Jermann, P., Basilio, N., Ansermet, F., Hentsch, F., Nadel, J., Billard, A. (2013). Social orienting of children with autism to facial expressions and speech: a study with a wearable eye-tracker in naturalistic settings. Frontiers in Psychology, 4, 840. https://dx.doi.org/10.3389%2Ffpsyg.2013.00840

Mazurek, M.O., Lu, F., Macklin, E.A., Handen, B.L. (2019). Factors associated with DSM-5 severity level ratings for autism spectrum disorder. Autism, 23(2), 468-476. https://doi.org/10.1177/1362361318755318

McPartland, J.C., Reichow, B., Volkmar, F.R. (2012). Sensitivity and specificity of proposed DSM-5 diagnostic criteria for autism spectrum disorder. Journal of the American Academy of Child & Adolescent Psychiatry, 51(4), 368-383. https://dx.doi.org/10.1016%2Fj.jaac.2012.01.007

Moldin, S.O., Rubenstein, J.L. (2006). Understanding autism: from basic neuroscience to treatment. Boca Raton: CRC Press.

Mundy, P., Crowson, M. (1997). Joint attention and early social communication: Implications for research on intervention with autism. Journal of Autism and Developmental Disorders, 27(6), 653-676. https://doi.org/10.1023/A:1025802832021

Nazneen, N., Rozga, A., Smith, C. J., Oberleitner, R., Abowd, G. D., & Arriaga, R. I. (2015). A novel system for supporting autism diagnosis using home videos: iterative development and evaluation of system design. JMIR mHealth and uHealth, 3(2), 68. https://doi.org/10.2196/mhealth.4393

Neto, A.F., de Oliveira Caldeira, E.M., Ferreira, A., Andrade, A., Lima, E., Bastos Filho, T.F. (2019). From Robot-Assisted Intervention to New Generation of Autism Screening: an Engineering Implementation Beyond the Technical Approach. Vitória: Universidade Federal do Espírito Santo. Available at: http://repositorio.ufes.br/handle/10/11376

Petric, F., Miklić, D., Kovačić, Z. (2018). POMDP-based coding of child–robot interaction within a robot-assisted ASD diagnostic protocol. International Journal of Humanoid Robotics, 15(02), 18500-18511. https://doi.org/10.1142/S0219843618500111

Petric, F., Kovacic, Z. (2020). Design and validation of MOMDP models for child–robot interaction within tasks of robot-assisted ASD diagnostic protocol. International Journal of Social Robotics, 12(2), 371-388. https://doi.org/10.1007/s12369-019-00577-0

Plumb, A.M., Wetherby, A.M. (2013). Vocalization development in toddlers with autism spectrum disorder. Journal of Speech, Language, and Hearing Research, 56(2), 721-734. https://doi.org/10.1044/1092-4388(2012/11-0104)

Posar, A., Resca, F., Visconti, P. (2015). Autism according to diagnostic and statistical manual of mental disorders 5th Ed.: The need for further improvements. Journal of pediatric neurosciences, 10(2), 146. https://dx.doi.org/10.4103%2F1817-1745.159195

Ramirez-Duque, A.A., Frizera-Neto, A., Bastos, T.F. (2019). Robot-Assisted Autism Spectrum Disorder Diagnostic Based on Artificial Reasoning. Journal of Intelligent & Robotic Systems, 96(2), 267-281. https://doi.org/10.1007/s10846-018-00975-y

Richardson, K., Coeckelbergh, M., Wakunuma, K., Billing, E., Ziemke, T., Gomez, P., ... Belpaeme, T. (2018). Robot Enhanced Therapy for Children with Autism (DREAM):

A Social Model of Autism. IEEE Technology and Society Magazine, 37(1), 30-39. https://doi.org/10.1109/MTS.2018.2795096

Robins, D.L., Fein, D., Barton, M.L. (1999). Modified checklist for autism in toddlers (M-CHAT) Follow-Up Interview. Self-published. Available at: https://mchatscreen.com/wp-content/uploads/2015/09/M-CHAT-R_F_Rev_Aug2018.pdf

Rotholz, D.A., Kinsman, A.M., Lacy, K.K., Charles, J. (2017). Improving early identification and intervention for children at risk for autism spectrum disorder. Pediatrics, 139(2), 20161061. https://doi.org/10.1542/peds.2016-1061

Rutter, M., Le Couteur, A., Lord, C. (2003). Autism diagnostic interview-revised. Los Angeles, CA: Western Psychological Services, 29(2003), 30.

Scassellati B. (2007) How Social Robots Will Help Us to Diagnose, Treat, and Understand Autism. In: Thrun S., Brooks R., Durrant-Whyte H. (eds) Robotics Research. Springer Tracts in Advanced Robotics, Vol. 28. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-48113-3_47

Schmitt, M., Marchi, E., Ringeval, F., Schuller, B. (2016, October). Towards cross-lingual automatic diagnosis of autism spectrum condition in children's voices. Speech Communication; 12. ITG Symposium, Paderborn, Germany, 2016, pp. 1-5. Available at: https://www.researchgate.net/publication/309370034_Towards_Cross-lingual_Automatic_Diagnosis_of_Autism_Spectrum_Condition_in_Children's_Voices

Schopler, E., Van Bourgondien, M.E., Wellman, G.J., Love, S.R. (2010). CARS-2: Childhood Autism Rating Scale (2nd edn.). Los Angeles, CA: Western Psychological Services. Available at: https://www.carautismroadmap.org/childhood-autism-rating-scale/

Simut, R.E., Vanderfaeillie, J., Peca, A., Van de Perre, G., Vanderborght, B. (2016). Children with autism spectrum disorders make a fruit salad with Probo, the social robot: an interaction study. Journal of Autism and Developmental Disorders, 46(1), 113-126. https://doi.org/10.1007/s10803-015-2556-9

Shamsuddin, S., Yussof, H., Ismail, L.I., Mohamed, S., Hanapiah, F.A., Zahari, N.I. (2012a). Humanoid robot NAO interacting with autistic children of moderately impaired intelligence to augment communication skills. Procedia Engineering, 41, 1533-1538. https://doi.org/10.1016/j.proeng.2012.07.346

Shamsuddin, S., Yussof, H., Ismail, L.I., Mohamed, S., Hanapiah, F.A., Zahari, N.I. (2012b). Initial response in HRI-a case study on evaluation of child with autism spectrum disorders interacting with a humanoid robot Nao. Procedia Engineering, 41, 1448-1455. https://doi.org/10.1016/j.proeng.2012.07.334

Steiner, A.M., Goldsmith, T.R., Snow, A.V., Chawarska, K. (2012). Practitioner's guide to assessment of autism spectrum disorders in infants and toddlers. Journal of Autism and Developmental Disorders, 42(6), 1183-1196. https://doi.org/10.1007/s10803-011-1376-9

Stotz-Ingenlath, G. (2000). Epistemological aspects of Eugen Bleuler's conception of schizophrenia in 1911. Medicine, Health Care and Philosophy, 3(2), 153-159. https://doi.org/10.1023/A:1009919309015

Swanson, M.R., Siller, M. (2013). Patterns of gaze behavior during an eye-tracking measure of joint attention in typically developing children and children with autism spectrum disorder. Research in Autism Spectrum Disorders, 7(9), 1087-1096. https://doi.org/10.1016/j.rasd.2013.05.007

Tapus, A., Mataric, M.J., Scassellati, B. (2007). Socially assistive robotics [grand challenges of robotics]. IEEE Robotics & Automation Magazine, 14(1), 35-42. Available at: https://scazlab.yale.edu/sites/default/files/files/Tapus-RAM2007.pdf

Volkmar, F.R., Klin, A. (2005). Issues in the classification of autism and related conditions. In: F.R. Volkmar, R. Paul, A. Klin, D. Cohen. (Eds.), Handbook of autism and pervasive developmental disorders: Diagnosis, development, neurobiology, and behavior (p. 5-41). Hoboken: John Wiley & Sons Inc.

Volkmar, F.R., McPartland, J. C. (2014). From Kanner to DSM-5: autism as an evolving diagnostic concept. Annual Review of Clinical Psychology, 10, 193-212. https://doi.org/10.1146/annurev-clinpsy-032813-153710

Wainer, J., Dautenhahn, K., Robins, B., Amirabdollahian, F. (2014). A pilot study with a novel setup for collaborative play of the humanoid robot KASPAR with children with autism. International Journal of Social Robotics, 6(1), 45-65. https://doi.org/10.1007/s12369-013-0195-x

Warren, S.F., Gilkerson, J., Richards, J.A., Oller, D.K., Xu, D., Yapanel, U., Gray, S. (2010). What automated vocal analysis reveals about the vocal production and language learning environment of young children with autism. Journal of Autism and Developmental Disorders, 40(5), 555-569. https://doi.org/10.1007/s10803-009-0902-5

Wing, L. (1991). The relationship between Asperger's syndrome and Kanner's autism. In: U. Frith (Ed.), Autism and Asperger syndrome (p. 93-121). Cambridge University Press. https://doi.org/10.1017/CBO9780511526770.003

Wilmshurst, L. (2014). Essentials of child and adolescent psychopathology. Hoboken: John Wiley & Sons.

Wood, L.J., Zaraki, A., Walters, M.L., Novanda, O., Robins, B., Dautenhahn, K. (2017, November). The Iterative Development of the Humanoid Robot Kaspar: An Assistive Robot for Children with Autism. In International Conference on Social Robotics (pp. 53-63). Springer, Cham. https://doi.org/10.1007/978-3-319-70022-9_6

Yates, K., Le Couteur, A. (2016). Diagnosing autism/autism spectrum disorders. Paediatrics and Child Health, 26(12), 513-518. https://doi.org/10.1016/j.paed.2016.08.004

Yoder, P.J., Oller, D.K., Richards, J.A., Gray, S., Gilkerson, J. (2013). Stability and validity of an automated measure of vocal development from day-long samples in children with and without autism spectrum disorder. Autism Research, 6(2), 103-107. https://dx.doi.org/10.1002%2Faur.1271

Zander, E., Willfors, C., Berggren, S., Choque-Olsson, N., Coco, C., Elmund, A., ..., Linder, J. (2016). The objectivity of the Autism Diagnostic Observation Schedule (ADOS) in naturalistic clinical settings. European Child & Adolescent Psychiatry, 25(7), 769-780. https://doi.org/10.1007/s00787-015-0793-2

Zander, E., Willfors, C., Berggren, S., Coco, C., Holm, A., Jifält, I., ..., Bölte, S. (2017). The interrater reliability of the autism diagnostic interview-revised (ADI-R) in clinical settings. Psychopathology, 50(3), 219-227. https://doi.org/10.1159/000474949

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. International Journal of Developmental Neuroscience, 23(2-3), 143-152. https://doi.org/10.1016/j.ijdevneu.2004.05.001

Zwaigenbaum, L., Bauman, M. L., Stone, W. L., Yirmiya, N., Estes, A., Hansen, R.L., Kasari, C. (2015). Early identification of autism spectrum disorder:

recommendations for practice and research. Pediatrics, 136(Supplement 1), 10-40. https://doi.org/10.1542/peds.2014-3667c