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ORIGINAL RESEARCH

Robot and virtual reality-based intervention in autism: a comprehensive review

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Abstract Autism Spectrum Disorder is a neurological and developmental disorder. Children diagnosed with this disorder have persistent deficits in their social-emotional reciprocity skills, nonverbal communication, and developing, maintaining, and understanding relationships. Besides, autistic children usually have motor deficits that influence their imitation and gesture production ability. The present study aims to review and analyze the current research findings in using robot-based and virtual reality-based intervention to support the therapy of improving the social, communication, emotional, and academic deficits of children with autism. Experimental data from the surveyed works are analyzed regarding the target behaviors and how each technology, robot, or virtual reality, was used during therapy sessions to improve the targeted behaviors. Furthermore, this study explores the different therapeutic roles that robots and virtual reality were observed to play. Finally, this study shares perspectives on the affordances and challenges of applying these technologies.

Keywords Autism Spectrum Disorder · Robot · Virtual reality · Autism · Augmented reality

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1 Introduction

Autism Spectrum Disorder (ASD) is a neurological and developmental disorder. Children diagnosed with ASD have persistent deficits in developing, maintaining, and understanding relationships. Autistic children also have deficits in social-emotional reciprocity and nonverbal communication skills. Besides, they usually have motor deficits that influence their imitation and gesture production ability. There are two categories of motor deficits: the basic motor deficit and the praxis performance, including children with difficulty in social, communication, and behavioral skills. Although all autistic children share common characteristics, the precise degree to which each child is affected significantly differs [1].

Different therapeutical methods exist to communicate with autistic children and improve their skills. However, choosing a suitable method imposes a great challenge since autism needs a comprehensive intervention to aid diverse autistic children most appropriately. Besides, teaching autistic children is usually associated with high therapy costs [2]. Recently, the usage of new technologies, such as the robot, virtual reality (VR), and augmented reality (AR), in autism therapy has been considered, motivated by the fact that children with ASD prefer to engage socially with objects [3]. Moreover, the preference for interaction with these technologies is due to their predictable, enjoyable, interactive, and straightforward environment [4]. Further, during the learning process, no need for children to consider socio-emotional expectations, which should decrease their social anxiety. Finally, the current advancement in these technologies offers eye contact, non-verbal communication skills, and self-initiated interactions, to list a few.

Table 1 Experimental data summary

Targeted behavior	Participants	Method	Challenges	Robot
Eye contact Imitation Repetition words	7–12 years old Mild autism	Three game modules executed by NAO that cover drawing a number, math game, and emotional gesture Each module starts with NAO introductory rapport	A teacher/guardian must be present Room setup such as lighting	NAO [24]
Talking Literary reading	No ASD sample is chosen	Multimodal picture book recommendation framework Textual info extraction, an image info extraction, and a multimodality info integration module	Finding research on topic obtainment Providing parents with training courses	NAO [26]
Gestural recognition and production	Twelve children aged 6–12 years Low-functioning autism	Use NAO robot as a teaching agent for gestures NAO engaged in daily life conversations and demonstration	Determining suitable learning environments	NAO [27]
Attention Visual stimulation	Seven children aged 5–14 years Moderate to severe autism	Tangram puzzle game Graded cueing feedback NAO asked for help during his turn to stimulate the child's cooperation	Participants interested in the robot decreased with time due to habituation to it	NAO [22]
Attention Gazing	Three children aged 6–12 years Language disabilities and poor communicative skills	A network of sensors to capture the children gazing Dog and cat different pictures placed at two opposite sides of the room	Availability of complete data about children Limited degrees of freedom	NAO [21]
Interaction Early detection of ASD	1–14 years	An observation-based autism screening system Six questions were adapted to the robotic context The robot collected response directly from toddlers	Data extrapolation	NAO [28]
Interaction Emotion	One typically developed child	Partially observable Markov decision process to model the diagnostic protocol	Manual setup per each child Open-space environment	NAO [30]
Eye contact	Three children aged 6–13 years High functioning ASD	An AI system based on robot-assisted treatment of autism Detects the child's non-verbal signals Exercises focus on: eye contact, joint attention, body imitation, facial imitation, facial expression imitation	The therapist has to assign each exercise to a child according to the functioning levels	NAO [31]
Interaction	Five children aged 5–8 years moderate to severe autism	Face recognition Eye gaze detection	The two degrees of freedom PABI has	PABI [33]
Interaction	No ASD sample is chosen	Applied Behavioral Analysis therapy Aid diagnosing autistic children	PABI has only 8 degrees of freedom	PABI [20]
Interaction	Eighteen children aged 4–6 years Moderate ASD	Complex and semi-unstructured interaction in ASD therapy Fully autonomous robot	Maintain a fully autonomous robot	ASTRO [1]
Tactile interaction	Eight boys aged 6–9 years	Teaching how to identify human body parts Teaching triadic relationships	KASPAR is a semi-autonomous robot	Kaspar [36]
Imitation Attention Turn-taking	Seventy-three professionals and adults with ASD	Evaluate robot, end-user, environment, and practical implementation requirements	Manual analysis of collected data The sample is limited to one country	Kaspar [37]

Table 1 continued

Targeted behavior	Participants	Method	Challenges	Robot
Facial expression recognition Emotions	Forty-five children High functioning ASD	Game-based scenario Storytelling to improve emotions	High manufacturing costs	ZECA [38]
Cognitive flexibility Interaction	Forty-one autistic children aged 4–13 years Forty typically developed children aged 4–7 years	Each participant goes through robot interaction and human interaction Probabilistic reversal learning task	The robot may distract the ASD children Repeated measures that may interfere with results	Keepon [10]
Social and self-regulation skills	Nineteen children with ASD	Student and Milo engage through social narratives Milo delivers lessons	Some children have a newfound ability to communicate	Milo [42]
Interaction Communication and social skills	Three children with ASD	Specially designed educational scenarios Enhance short-term and long-term memory	The therapist manually evaluate the observation sheets	Pepper [84]
Attention Facial expression skill	Fifteen parents of children with low-level autism aged 6–15 years Six autistic children aged 7–12 years	Train autistic children on recognizing facial expressions Parents answer survey questions	Limited robot's skills	ifbot [45]
Interaction	Eleven autistic children aged 5–8 years	Individual interactive session Children engage in self-directed exploratory play The experimenter asked a series of pre-established questions	Simple mechanical toy dog	AIBO [46]
Attention Imitation	Four autistic children aged 4–5 years Low functioning autism	Imitation of body movements Evaluation sheet that lists child's expressions/reactions observed	Observing imitation for low functioning autistic children	Tito [47]
Social interaction	Sixty autistic children aged 5–16 years	Free play and structured games Single autistic subjects The robot starts with a free play period and then switch to a structured game session	The robot requires three interventions from developers	TeoG [85]
Emotional and social skills	Four children with ASD	Educational games and activities Identify interactive behaviors Measure amount of social engagement	Integrating quantitative data with qualitative data	Aisoy [48]
Communication skills Interaction	Twenty children with ASD	Introduce each child to the robot, talk freely, and play Conversation and playtime	The robot has limited skills and degrees of freedom	Zoomorphic [86]

Robots' use as therapeutic tools for individuals with ASD can be considered according to three angles: academic, industry, and legal development [5].

- Academic development: In 1995, artificial, social intelligence, and autonomous robots were proposed. Social intelligence robots can complete different tasks without any help. Further, different hypothetical scenarios were suggested for robot-human and robot-robot communication and cooperation. At that time, robots were controlled in a well-structured environment. However, few robots showed a degree of intelligence concerning robustness, autonomy, flexibility, and adaptability [5].
- Industry development: the literature indicates a growing industry and a significant demand for educational robot technology [6]. Robokind, Aldebaran, and Origami Robotics are among the leading companies in manufacturing robots for autistic people. The first company, Robotkind, provides the market with

advanced social robots such as the Milo robot [7]. The Aldebaran company develops educational and therapeutical tools for autistic children with the NAO robot as the main product. The Origami company manufactures the Romibo robot, which offers expressive eyes and can track eye contact.
- Legal development: in 1975, the Individuals with Disabilities Education Act (IDEA) was proposed as a federal statute to formulate special-need education and determine the feasibility of educational robotic systems for public schools of the United States [8]. The IDEA was revised in 2004. According to the Assistive Technology clause, long experience and research can improve special-education children's learning experience by utilizing assistive technology devices and assistive technology services.

A strange phenomenon is worth discussing regarding the use of robots as therapeutic and educational tools for autism. The best practices of using the robot in the autism field are mainly determined by industry professionals who mostly lack academic training or clinical experience. External input should improve any system. However, we end up having autistic therapists and educational practitioners reacting to assistive technology instead of proactively aiding its development [5]. The correct order of influence on the autism field should be clinical therapists, followed by educational practitioners, and followed by the industry's direction.

In this paper, we review and analyze the current autism works, mainly based on robots, and to a lesser extent, virtual reality and augmented reality in supporting the therapy of improving the social, communication, emotional, and academic deficits of children with autism. Furthermore, experimental data from the surveyed works are analyzed regarding the targeted behaviors and how each technology was used during therapy sessions to improve the targeted behaviors. Moreover, this study explores the different therapeutic roles that robots and virtual reality were observed to play. Finally, this study shares perspectives on the affordances and challenges of applying these technologies.

2 Search and selection method

An online search had been conducted using systematic literature search procedures. The review focused on the online scientific databases relevant to the addressed subject, such as PubMed for medical science, Embase for biomedical literature, PsycINFO for behavioral science and mental health, Scopus, and Web of Science. In addition, we searched interdisciplinary databases that include international conference proceedings and journal papers related to science, information technologies, and health science. The selection of the articles was focused on the following:

- The academic peer-reviewed papers were published in English journals and conference proceedings from 2002 to 2021.
- The search query considered the following terms: autism, autistic children, virtual reality, augmented reality, robot, robot-based intervention, social behavior, or virtual education.
- The selection was limited to the articles associated with studies focusing on using robots and virtual reality for autistic children. Studies that focus on other technologies and in different languages had been excluded.
- Each author had to review papers and focus during the reading process on the title, abstract, methodology, and conclusion sections.
- The inclusion criteria of the selected articles considered: (1) the robot-based intervention or virtual reality-based intervention as well as human-based intervention and robot-based intervention (2) Targeted participants are children diagnosed with autism or typically developed children.
- The exclusion criteria considered papers covering other technologies not related to robots or virtual reality.

3 Robot-based intervention

The choice of the robot to be used in autism therapy is a crucial factor. Indeed, several considerations must be considered, such as the robot's interaction quality and structure. The interaction quality explores the level of social interaction between children and robot. For example, some robots offer a straightforward form of social interaction, while others provide different forms of advanced social interaction. On the other hand, the interaction structure explores the type of activities offered during the interaction. For example, some robots offer unstructured activities, such as free play, while other robots offer highly structured activities.

Robot autonomy is another critical point to consider when developing therapies for autism. Some robots are fully autonomous, while other robots are remotely controlled during the interaction. Remotely controlled robots adopt the Wizard-of-Oz (WoZ) method, where a human operator remotely controls a robot [9]. Many researchers adopted this approach since human perception is used to overcome autonomous robots' perceptual challenges. Further, a remotely controlled robot offers productive interactions and divers' social behaviors. It is worth mentioning that remotely controlled robots provide broad features and interactions that vary from simple ones where the robot can emotionally respond to a child through engagement like the Keepon robot [10] and Pleo robot [11]; to other complex interactions like playing turn-taking games or imitation such as the Kaspar robot [12]. Throughout scenarios, a therapist meditates a child during interaction with a robot. The WoZ setup may require more than one therapist, apart from the robot's technical staff. Further, human operators' responsibilities increase, which demands them to process many inputs and handle complex actions since the interactions with children become more complicated. Therefore, more human operators are needed to provide a rich and multimodal interaction for an autistic child [1].

Nevertheless, the long-term dependence of the WoZ method on human operators makes it a costly solution for autism therapy [13]. In a previous work involving autonomous robots, two additional clusters, mainly differ in the child-robot interaction, were identified. The first cluster covered autonomous robots that included works that introduced robots like Bubbleblower [14] and Roball [15], to list a few. These robotic systems allow only the simplest form of interaction and exhibit no social interaction. Experimental results indicate that children interacted with robots during their free play, in an unstructured interaction, where these robots behave just little more than sophisticated toys [14, 15]. The other cluster is marked as autonomous social robots. It includes works that use robots like NAO [13, 16], Infanoid [17], and iRobiQ/CARO [18], to list a few. It is worth mentioning that robots that are dependable enough to interact with humans while operating autonomously over an extended period were rarely reported in the literature.

Several guidelines were suggested for the ASD domain as a roadmap to robot-mediated intervention and evidence-based practice in autism [19]. The guidelines describe intervention objectives, participants, dependent and independent variables, research design, and training procedure. In addition to the listed considerations, researchers identified that selecting a robot for the autism field could be driven by [20–22]:

- Shape: robots can take different forms such as android, human-like, and animal-shaped, to list a few. This may distress the children during the therapy sessions.
- Embodiment: social robots' physical presence allows them to do physical explorations and interactions with their environment, using gestures and touch to communicate with children.
- Complexity: using robots can dramatically decrease the complexity of interactions between children and people. The robots can be programmed to focus on a few skills and only one interaction aspect.

In this section, an exhaustive list of the most relevant research that adopted social robots in autism studies is presented based on the type of used robot.

3.1 NAO robot

The NAO robot introduces an ideal platform to improve different skills among autistic children. The NAO is designed to look approachable and to express emotions like a toddler. NAO has various features such as autonomous, 19 languages, fully programmable, grasping small objects, understanding spoken words and confine sounds, walking, wandering, and distinguishing people. The NAO is equipped with different hardware such as cameras, microphones, motors, legs, head, hands, and arms. All the conversations between NAO and children are recorded for future analysis. NAO is the most used robot-based intervention for research, education, and healthcare [2]. The NAO achieved a higher gazing time with kids than a human therapist [23]. Besides, children who interacted with NAO achieved higher scores on communication behavior tests. Many researchers used NAO to improve the communication and social skills of autistic children [24]. For example, picture books can improve reading, understanding, expressing, role reversing, and emotional skills [25]. Each picture book contains image information and textual information.

The NAO robot was used to develop a multimodal picture book recommendation framework based on the conversation content [26]. The proposed framework consisted of textual information extraction, image information extraction, and a multimodality information integration module. However, the proposed framework needs improvement with more competent association functions. Besides, therapists and parents should be involved in the experiments.

A study compared the learning outcomes of NAO robot-based intervention against human-based intervention in teaching autistic children the use of intransitive gestures [27]. The study used production assessments that evaluated children's attention, fine motor skills, and visual perception. Two NAO robots were programmed to offer fourteen different intransitive gestures and utilized to perform role-play. Results indicated that autistic children from both groups successfully recognized the various gestures and produced them accurately. However, more research is required to determine suitable learning environments and investigating nonverbal communication skills.

The tangram puzzle game was proposed to assist children [22]. The tangram puzzle was made up of seven geometrical pieces of different shapes used by children during therapy sessions. In addition, the graded cueing feedback was implemented, where children facing difficulties during the game were given gradual cues or prompts. Occasionally, the NAO robot asked for help during his turn to stimulate the child's cooperation. All participants showed considerable interest in the robot during the first sessions. However, this interest decreased over time due to habituation.

In [21], the dynamics of joint attention for children with ASD were investigated. A network of sensors was used to capture the children gazing, displacement, and kinematic energy. The NAO robot and the sensors were placed on a table to keep them at the same level as the child's head. Two different pictures, dog and cat, were placed at two opposite sides of the room. The robot tried to draw the children's attention to any of the photos in the room by increasing the amount of information and using different modalities such as gazing and head movement. Results showed that the participants with ASD spend less time focusing on the target picture than the tardive dyskinesia (TD) participants in terms of gazing. Also, in terms of displacement, the ASD participants had a higher amplitude on the ground.

In [28], The NAO robot was used to develop an observation-based autism screening system. Six questions from the Quantitative Checklist for Autism in Toddlers were adapted to the robotic context. The robot collected responses to the six questions directly from toddlers rather than from their parents. Another work was conducted to study the possibility of utilizing NAO and Pepper robots as a robot-assisted diagnostic protocol [29]. The partially observable Markov decision process was used to model the diagnostic protocol tasks to automate robot actions. Results showed definite signs of the robot's interaction and observation of children's behavior. Another study was done on a typically developed child, instead of an autistic child, since he can express emotions and handle stress [30].

The NAO robot was used to detect the eye contact behavior of three children diagnosed with high functioning ASD [31]. Each session lasted for 20 min, where the eye contact exercise was performed 15 times. The eye-detection algorithm was based on the Viola–Jones detector. Results indicate that children need help to complete all levels. In [32], four single-subject experiments were conducted to compare the social engagement level of autistic children with NAO robot versus humans. All sessions, used motor imitation exercise and joint attention, indicated that children showed interest in NAO, especially at the beginning. This interest diminished with time, especially with the severe autism case. The study concluded that NAO is considered a better facilitator for moderate autism level children.

3.2 PABI robot

The PABI is a cartoonish robot specifically designed to provide applied behavioral analysis (ABA) therapy to children with autism using the discrete trial training method [20]. Due to its penguin-like shape, it is called Penguin for Autism Behavioral Intervention (PABI). PABI provides all ABA therapy levels, considering the children's psychological underpinnings. The PABI robot's eyes include stereo cameras for tracking the child's movements and modeling eye contact through monitoring children's attention to the therapy sessions and chart their progress.

In [33], a PABI-based intervention was developed. The proposed system consisted of two phases: face recognition and eye-gaze detection. The histogram of oriented gradients extracted features invariant to lighting, object occlusion, and orientation changes for the face detection phase. Then, a linear classifier was used to classify positive and negative feature samples. Finally, a multi-scale sliding window search was used to detect skewed images. In [20], PABI-based intervention achieved better interaction results than human-based intervention.

3.3 Astro robot

Unlike teleoperated robots, the Astro robot system works in a fully autonomous way. Manufacturers state that Astro offers enhanced social interaction capabilities than autonomous social robots. For example, the developed system promotes and explains different therapeutical activities, provides feedback on various tasks, asks for assistance, and offers a rich set of activities wherein the child can move freely around the therapy room [1]. It is worth mentioning that allowing the child to move freely around a room presents significant challenges in terms of perception. This is due to the need to monitor the whole room space and autonomously differentiate the child from all other objects. The child performs different activities during a therapy session, such as finding hidden balls, solving a geometric puzzle, playing a turn-taking game, and assisting the robot in moving from one place to another. The robot encourages a child to perform certain activities, explains how to perform activities, and rewards through positive reinforcements.

To develop an autonomous robot platform capable of interacting with a human, the robot must act in situations where neither the human nor the robot can fully complete the task without the other's assistance. The Astro robot can perform activities such as saying hello, giving an introduction, tracking the child's collection of colored balls hidden in the room, improving a child's empathy and social reciprocity by asking for a child's help in removing some obstacles from the robot's path, and improving social-communicative behavior skill by encouraging children to make requests.

3.4 Kaspar robot

The Kaspar robot has different features such as singing, playing games and tambourine, combing its hair, and imitating eating [34]. In addition, the Kaspar robot is equipped with touch sensors to differentiate between soft and harsh touch and consequently respond [35]. Kaspar is a semi-autonomous humanoid robot that acts as a social companion to improve the communication difficulties of autistic children. The Kaspar robot allows three distinct operation modes. An example of the autonomous control mode is when a child activates the robot's sensors, such as arm and feet sensors. In the controlled operating mode, a therapist, or professional controls the robot via a remote-control device. Finally, the semi-autonomous mode includes a combination of the two modes.

The Kaspar robot was used to teach children how to identify body parts and appropriate physical interaction [36]. In [37], 73 autistic adults participated in different focus groups to draw out requirements for robot-assisted intervention. Moreover, 22 participants, children's parents, professionals, and autistic adults, attended sessions to generate ideas for interventions. It is recommended to add to Kaspar the ability to fetch, grasp, manipulate, and hold objects [37].

3.5 ZECA robot

The Zeno Engaging Children with Autism (ZECA) robot is a humanoid robot that can walk and has a human-inspired character face and gestural body that enables the robot to do facial expressions [38]. In [38], a game-based scenario was used, where 45 children diagnosed with high functioning ASD had been divided equally and randomly into three groups. The first group was exposed to robot-intervention settings. The second group was exposed to human-intervention settings only. The third group was considered a control group; they only have to do pre-test and post-test sessions. The research consisted of four phases: familiarization phase, pre-test phase, practice phase, and post-test phase. Results showed that the robot could partially contribute to development of facial expression recognition skills.

3.6 Keepon robot

The Keepon robot was used to study the interpersonal coordination and social development skills of autistic children [39]. In [10], the Keepon robot was used to examine how 41 autistic children and 40 typically developed children perform cognitive flexibility tasks. During an interaction with the robot, autistic children showed more task engagement and enjoyment than human interaction. Further, there was no significant difference in the robot-based intervention and human-based intervention's cognitive flexibility performance. Finally, during the learning stage, children's performance was improved during robot sessions.

3.7 Milo robot

The Milo robot is developed to aid autistic children in improving their communication skills [40]. Milo has advanced social features, uses facial and vocal expressions to interact with children, and can listen or tell a story. The Milo robot can be used to improve feelings and sentiments. It also provides calming aptitude and two-sided discussion [41]. The study in [42] showed that the Milo robot had improved self-regulation, social, and academic skills. Students enjoyed interaction and dancing with the Milo, which was a reward for good behavior. The technology can be used to improve social, communication, and emotion regulation skills. However, using a computer-based or tablet-based solution resulted in autistic children who interacted with technology only and avoided interaction with humans [43]. Thus, Milo was utilized to deliver verbal interaction and social narratives resulting in reduced repetitive actions [43].

3.8 Other robots

The Pepper robot has different features such as a high-level human interaction, advanced capabilities, attractive face design, emotional robot, advanced voice recognition ability of several variations in the human voice, cameras, ability to use body language, and the ability to recognize 20 languages, to list a few. The Pepper robot was used to improve the emotions and learning of special-need children [44]. A study evaluated different robot features based on their impact on improving the social and communication skills of autistic children [45]. The ifbot, a small sphere-shaped robot, was used in the experiments. Results indicated that the robot's face and moving limb drew children's attention and improved facial expression skill. However, it did not improve other social and communication skills. Further, the robot's verbal communication feature achieved better interaction with low-functioning autistic children than human interaction. The AIBO Dog robot improved mutual interaction, verbal engagement, and authentic interaction [46]. Another work utilized the Tito Mobile robot with two autistic children. Robot-based intervention results indicated improved attention in visual contact and physical proximity and imitating smiling compared to the human-based intervention [47]. In [48], the Aisoy1 is an interactive robot that performs educational games and activities to improve emotional, communication, self-confidence, self-stability, and kinetic and cognitive skills [48].

3.9 Discussion

Despite the presented research using robots with autistic children, the evidence of robot-based treatment's effectiveness is still limited. Indeed, this is mainly because many studies did not cover all types of deficits related to autism, such as social, communication, emotional, educational, behavior, imitation, and gesture production abilities. Further, many papers based their developed methods on the fact that autistic children share common characteristics. However, these papers did not pay much attention to the fact that each child is affected by autism to a different degree. This makes it extremely difficult to develop a comprehensive robot-based intervention solution that aids diverse autistic children in the most suitable way. Also, using an appropriate number of robots, and the dependence on human operators to control the robots are usually associated with high therapy costs and other overheads.

Further, the robot's integration as a worldwide educational tool for students is still early. Also, the best practices of using the robot in the autism field are mainly determined by industry professionals rather than autistic therapists and educational practitioners. In addition, guidelines were suggested as a roadmap to robot-mediated intervention but still not widely standardized. Moreover, not all studies involved autistic therapists and parents in the experiments.

We summarized the experiments discussed in the previous sections [1, 10, 20–22, 24, 26–28, 30, 31, 33, 36–38, 42, 45–48, 85, 86] in Table 1, and in Fig. 1 in terms of performances. Figure 1A shows statistics of the targeted skills in the surveyed papers. As the figure shows, the most targeted skills are Interaction, Attention, eye contact, and facial expressions. Figure 1B shows statistics of the targeted autistic children ages. As the figure shows, the most targeted ages are 5–8 years. Further, the average number of targeted children per experiment is 17.2, where some works targeted one child while others targeted 73 children.

4 Virtual reality-based intervention

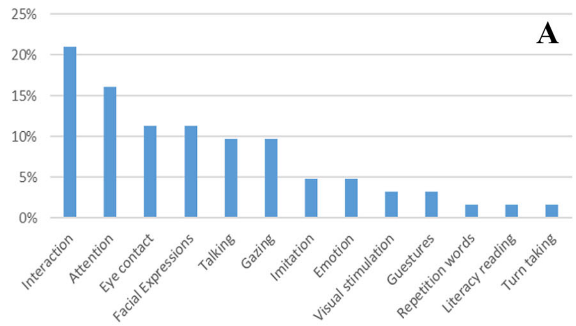
Virtual reality (VR) offers a virtual environment and interactive video gaming, based on computer systems, where sound and sight are the primary sensory stimuli. Virtual reality is considered an interactive intervention tool in the autism field, where actions received from autistic children are partially reflected in the artificial environment. The VR utilizes various technologies, such as monoscopic display, stereoscopic display, user technologies, and augmented reality, to integrate the virtual world with the natural world [49].

The literature reported using virtual reality as a treatment tool in different areas such as diagnosis [50], rehabilitation [51], training on surgery [52], and raising patient's emotional wellbeing [53], to name a few. Moreover, virtual reality can treat mental disorders such as post-traumatic stress disorders, phobia, autism spectrum disorder, and obsessive–compulsive disorders. In addition, VR is also used to improve various social interactions, communication, emotional response, social skills, and executive functions.

The use of virtual reality in treating autism spectrum disorder includes many benefits over traditional interventions, such as offering a controlled and safe training environment, adapting the environment to the skills of the autistic child, allows emulating everyday life skills, and providing a realistic training environment [49]. Furthermore, the VR offers the ability to receive different measures of the child's performance, offer suitable real-time feedback, and adapt the scenarios [54].

If we consider a sample of literature papers, the targeted autistic children consisted of 142 boys and 22 girls aged between four and seventeen years with an average age of 10 years [55–75]. In this sample, five papers utilized virtual reality scenarios, environments, and avatars to improve emotional skills [55, 56, 59, 69, 70]. Another article used virtual reality scenarios and driving modules to enhance daily living skills such as shopping in a supermarket and driving [76]. Another work utilized virtual reality and augmented reality in improving the communication skills of autistic children [62, 73]. In [56], virtual reality scenarios and mobile object identification were used to improve attention skills. Other work utilized virtual reality devices, such as SenseW armband, BodyMedia, and immersive stereoscopic surround-screen, in improving children's physical activity [74]. Another experiment used a blue room virtual reality environment as an intervention tool to reduce phobia [75].

One of the virtual reality applications in the autism field is reducing the habit of unconsciously copying other people's actions. Studies show that autistic children usually copy the observed activity's goal with differences in their mimicry [77]. A two-dimensional VR environment was used to induce the mimicry where 26 autistic children played an imitation game with two avatars; socially engaged and socially disengaged [77]. The virtual reality graphics were displayed on a projector screen. Autistic children used two electromagnetic markers to record their finger movements and to establish eye contact with avatars. Results indicate that participants mimicked avatar motions,



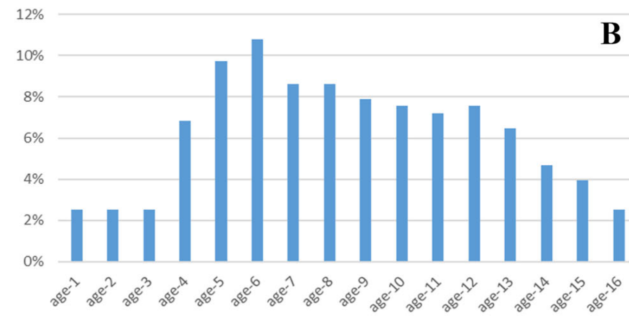


Fig. 1 **A** statistics of targeted skills and **B** statistics of the targeted age

with minor differences, to achieve the observed action. Results also suggest that VR can be used as a training and diagnostic tool.

In [78], an interactive scenario-based VR system, made up of five modules, was developed to improve the communication skills of autistic children. These modules are the display and trackers module, speech recognition module, gesture recognition module, virtual environment and avatars module, and auto-navigation module. Further, a VR classroom greeting scenario was developed, where an interaction between the avatar and the children took place. Two groups of children were used; ASD children and typically developed children. Two scenarios of 20 min each, on two separate days, were proposed to each participant on three different setups of the VR system: desktop environment, computer augmented reality environment (CAVE), and head-mounted display (HMD). Results showed that for both ASD and TD children, a satisfaction rate exceeds 82% for CAVE and 78% for HMD. For the desktop environment, the performances were averaged at 60%. Also, the children with ASD showed more interest in desktop environment comparing to TD children.

The study in [66] used virtual reality technology as a therapeutic tool to treat phobias in autistic children. Results showed a decrease in phobia intensity in 25% of the children over two therapy sessions. Another work developed a tutoring system based on integrating the NAO robot and virtual reality [65]. In this work, a virtual teacher taught sight words to three autistic children and the NAO robot that emulated a peer. Experimental results indicated that autistic children could memorize and absorb all the sight words explicitly as instructed. Further, children learned about 94% of the sight words exclusively taught to the NAO robot. In [79], an interactive learning environment was developed for behavioral training for children with autism based on the picture exchange communication system and face-to-face interviews. The participants of the study consisted of children and their parents. A virtual toilet was designed for behavioral training per request from parents. Results indicated that younger parents were more nervous and depressed while dealing with their children, while older parents showed a better understanding.

In [80], a VR environment was developed for autistic children to improve their communication and social skills. The VR environment used a fish shop game as an interactive environment, where the autistic children had to use a wearable Oculus Rift VR headset and a microphone. The fish shop game was chosen since it had fewer social skills and behavior challenges where the context was related to pets and animals like dogs, cats, and fish. In addition, the system was built to track the child's eye contact during the conversation to record visual attention in a safe environment.

Despite the presented research in using VR with autistic children, the evidence of VR-based treatment's effectiveness is still limited. This limitation is because many studies did not use a control group of autistic children with the same characteristics that received other intervention-based treatments compared to VR-based intervention [49]. Besides, the same questionnaire should be conducted at the same time during the intervention program. Also, most of the studies used a low number of autistic children in their experiments. Furthermore, some works researched male autistic children only while others did not maintain the 3:1 male to female autistic children ratio in the chosen sample [81]. Finally, some papers conducted their research on high-performance autistic children. Therefore, results and conclusions obtained from these papers cannot be generalized to the autism field.

5 Augmented reality-based intervention

Children with autism suffer from a lack of understanding and interpretation of social situations and generate the appropriate response in the proper format. Therefore, augmented reality (AR) has been considered to increase the motivation of children with ASD. The authors in [82] proposed implementing a social story through an augmented reality environment to improve autistic children's skills. A social story is a short story describing situations, skills, interactions, and behaviors, in a written or a visual format that ASD children can understand. The experimentations had been conducted with three children accompanied by their therapists. The therapists evaluated the system's performance, who filled out a questionnaire about the level of conformity of the system. The Likert scale and the obtained results showed that 71% of respondents agree that the system can support social story therapy.

In [83], a novel collaborative virtual environment (CVE) platform using various technologies was developed to enable autistic children to communicate and interact in a naturalistic approach. The two remotely and separated players should synchronize and coordinate their hand movements to complete the game. The system included an application module to manage game connection and execution, a communication module, and an eye tracker module. A leap motion detector had been used to track the player's hand movement and gestures to manipulate the virtual objects. Further, the CVE had three collaborative games: puzzle game, collect game, and delivery game. The proposed system was tested with 12 typically developing (TD) children and 12 children with ASD. The 12 groups, one TD child and one ASD child, were used to imitate real-life interaction settings. In addition, a training session had been conducted with six different collaborative games. The study tested the acceptability of the system among autistic children using five-Likert surveys. Results showed that autistic children enjoyed the games, and their interaction progressively improved.

6 Conclusion

Autistic children prefer to interact with new technologies, such as robots, virtual reality, and augmented reality, since these technologies offer predictable, enjoyable, interactive, and straightforward environments. Further, during the learning process, there is no need for autistic children to consider socio-emotional expectations, which should decrease their social anxiety. The current advancement in these technologies offers eye contact, non-verbal communication skills, and self-initiated interactions, to list a few. In this paper, which represents the first phase of a multi-year project, the recent research findings in utilizing robots and virtual reality as intervention tools in supporting the therapy of improving different skills among autistic children are investigated. Despite the presented research using the robot and virtual reality interventions for autistic children, the evidence of treatment's effectiveness is still limited. Many studies did not cover all types of deficits, based their developed methods on the fact that autistic children share common characteristics, followed best practices of the industry professional instead of autistic therapists and educational practitioners, or did not involve autistic therapists and parents in the experiments.

To build a networked robot system capable of effectively participating in different activities, several technological challenges must be addressed, such as the robot's ability to perceive persons and the objects in the room, robot motion and head rotation to apply the mind-reading mechanism, robot's decision-making system to consider the existing state of the environment and plan the subsequent actions, and additional features such as an LCD for facial expressions. These features aim at attracting and focusing the child's attention as well as improving the interaction. Finally, symbiotic interaction should also be considered in case the robot cannot perform some actions.

The second phase of this project should focus on developing a comprehensive technology-based intervention considering that each child is affected by a different degree of autism. The developed solution should also reduce therapy costs, reduce dependence on human operators, follow autistic therapists and educational practitioners' practices, involve parents in the experiments, and involve more symbiotic interactions.

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