Technology-Based Interventions for Autism Spectrum Disorder: A Systematic Review

Rehmat Sumra sumranbi@hotmail.com,
Dr. Bushra Sumra, sumra_b@hotmail.com,
University of Nairobi.

Abstract
Introduction: Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by deficits in social communication and repetitive behaviors. Its prevalence has steadily increased, with the CDC reporting a rise from 1 in 100 children in 2006 to 1 in 44 in the United States by 2021. ASD manifests in a spectrum of symptoms, requiring tailored interventions to address each child's unique needs. Recent advancements in technology have shown promise in aiding children with ASD, particularly through robotics and socially assistive robots (SARs). This systematic review explores the impact of technology-based interventions on children with ASD, assessing their efficacy in enhancing social skills, communication, and behavior regulation.
Methodology: This review followed PRISMA guidelines, screening 46,580 articles across databases such as PubMed, Cochrane, Science Direct, Google Scholar, and PsychInfo. After applying inclusion and exclusion criteria, 254 studies were selected for in-depth review. The review focused on technology-based interventions, including robotics and socially assistive robots, with MeSH terms such as "Technology," "Artificial Intelligence," "Autism Spectrum Disorder," and "ASD."
Results: Technology-based interventions, particularly SARs, demonstrated significant improvements in social interaction, emotional regulation, and communication for children with ASD. Robots such as LEGO Mindstorms and "Kaspar" were effective in enhancing eye contact, cooperation, and emotional recognition. However, results varied depending on the type of technology used, study design, and participant characteristics.
Conclusion: While technology-based interventions hold promise for children with ASD, further research is needed to standardize intervention protocols, dosage, and long-term outcomes. These tools offer a non-invasive, scalable solution for enhancing social and cognitive skills, but variability in study designs limits definitive conclusions.

Keywords:
Autism Spectrum Disorder, Technology, Robotics, Socially Assistive Robots, Communication, Cognitive Skills, Applied Behavioral Analysis

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder which presents in several different forms including social interactions, speech, stereotypical interests and repetitive compulsive behaviors. The main cause of autism is still unknown however there have been various theories as to why an individual may have autism, including neuroinflammation where some areas of the brain are thought to be inflamed due to deficiency of various micronutrients which provide a cytokine surge that leads to neuroinflammation.
It is essential to diagnose ASD using the DSM-5 criteria the main symptoms which appear in the early stages of brain development. Some of the most common symptoms include speech difficulty, cognitive, sensory and motor and emotional functioning and maintaining eye contact. ASD is noted to be a spectrum of symptoms and hence children present with an array of presentations ranging from intelligence to speech and finally sensori-motor difficulties.

The prevalence of ASD has noted to be rising from 1:100 children in 2006, through to 1: 44 in the United States according to the CDC (2021). The prevalence of the male gender was 4 times higher than the females.

ASD children are known to have less social, emotional and physical meltdowns if they adhere to a tightly bound schedule, their response to change if compared to their neurotypical peers is rather negative. Every child with ASD has different abilities, these may not seem obvious at first but some are creative minds who can practice drawing, painting and sewing perfectly, others can take picture perfect memories in photographs, whereas others thrive in culinary arts, yet again there are some who thrive with numbers, scientific facts and individuals with photographic memory. A personalized program is therefore crucial in ensuring that each ASD individual can achieve their maximum potential. In the past decade there has been an overwhelming amount of therapeutic interventions which have designed for children, the most common one includes Applied Behavioral Analysis (ABA), the TEACCH Autism Program, the Picture Exchange Communication System (PECS), Sensory Integration therapy, the SPELL framework (Francis 2005).

Technology is one of the fastest growing fields on the planet and has exponentially grown over the past decade. Technology has also been a robust aid for children on the spectrum, it is used in the form of assistive devices, these may act as speech aids also referred to as information and communication technology (ICT), in the form of assistive technology, several children with ASD have noted improvement of skills and communication. Since a computer does not generate emotions, and is relatively stable in communication, it removes emotional transitions associated with humans, and appears to be less intimidating when used as a tool for education. (Robins 2005)

Computer technology has branched further to incorporate artificial intelligence, engineering and electronics to form a new field of technology, Robotics. A robot therefore can be simply defined as an automated device with preprogrammed actions, intended to substitute human beings to accomplish a certain task.
There are three kinds of robots based on functionality:
Service robots, these perform help to people in need
Social robots, these robots can engage in communication with the human and have a conversation with gestures and speech
Assistive robots, which help people with special needs which is more often motor disabilities.
Socially Assistive Robots (SARs) is a new emerging field which helps bridge the gap between the assistance of robotics and the emotional humanoid component, where the robots can exhibit facial expressions to emotional indicators. For children with ASD this provides first and foremost a gauged constant emotion, which helps them familiarize with emotions. Children on the spectrum require an intervention which aids in first understanding social skills and redundancy of stereotypical behaviors. A program set up in form of a toy which helps a child learn to engage in communicative back and forth acclimatizes a child for conversation. As an ASD child practices repetitive functioning, a SAR will engage in the repetition and challenge the frustration that comes with an inherent human-to-human interaction, there is a reduced probability for outbursts and having the SAR can make the individual feel “in-control” of the situation and social interaction. In addition to a safe environment, SARs can be programmed to work on a single task at a time which ensures that learning is focused and simplified for the child.
When using robots to engage in one-on -one play, there have been several kinds of SARs that have been suitable, they are deceptively packaged as toys which ensures attractiveness and increased probabilities In engaging in play (Amran 2018). It was noted that a majority of ASD children have a clear preference for robotic toys as opposed to the non-robotic counterparts and that the children respond faster to the robot versus the human (Bekele 2013, 2014).

When particular conditions are met, SARs can be used in research and in ASD intervention programs. These conditions include interacting with the surrounding environment and others and utilising cues for social interaction.

SARs can be used as a mediator that helps people communicate emotions and behaviours that they otherwise might not, as a model that shows social behaviour, and as a toy that acts as a "bridge" for communication with others (Scassellati et al. 2012). Mutual attention between the child with ASD and the robot may be facilitated when the robot has human-like face features, such as a mouth, eyes, nose, etc.

In addition to humanoid robots, LEGO robotics has become more and more popular. The most well-known LEGO model is called "Mindstorms," and it includes modular sensors, motors, and LEGO pieces that may be employed, as well as an intelligent "brick" computer which controls the entire robot. In their study of seven autistic youngsters, Wainer and colleagues (2010) used LEGO NXT robots. They found that the robotics led to certain social behaviours, like greater cooperation among the participants. Furthermore, in other circumstances, a positive affect was generated and later showed up (Wainer et al. 2010).

It was also shown in a study, children with ASD had an increases eye contact with the use of “kaspar” robot. Iot was noted that a human face appeared more intimidating to the ASD child than the predictable and less expressive robot (Amran 2018)

Another interesting phenomenon was the integration pf a robot in a classroom, wher eit is controlled by a teacher. The “Wizard of Oz” technique where a teacher can control the robot and the teachings imparted from across the room or a different room without the child noticing, this is via a software downloaded on an external device such as a smartphone. (Scassellati 2012)

Table 1: Types of ASD Interventions and Their Benefits

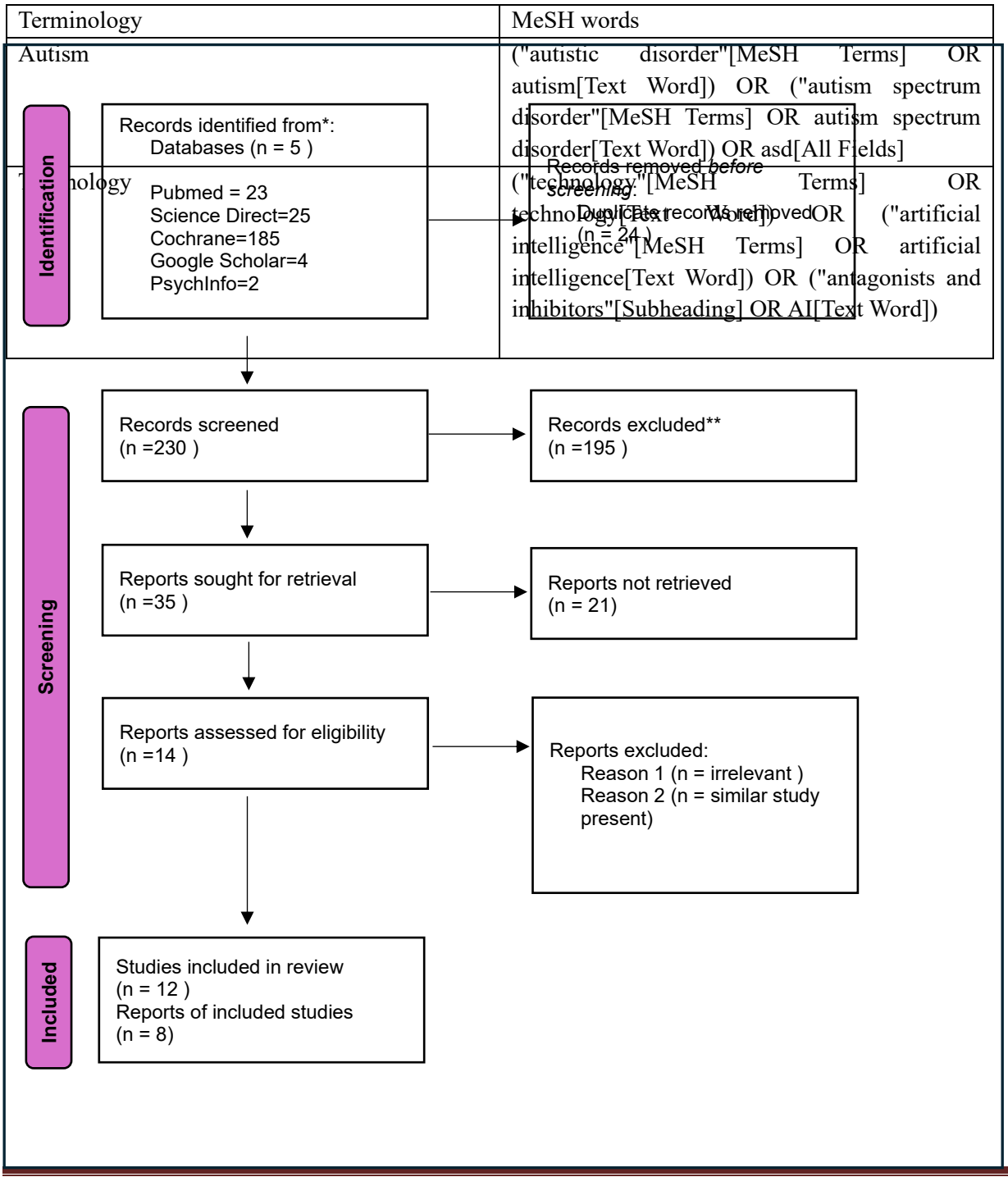
Intervention Type	Description	Key Benefits
Applied Behavioral Analysis (ABA)	Therapy focused on improving specific behaviors like communication, social skills, and adaptive learning	Tailored interventions for each child's unique needs
Picture Exchange Communication System (PECS)	Uses pictures to help children communicate needs and develop communication skills	Enhances communication for non-verbal individuals
Sensory Integration Therapy	Focuses on helping children manage sensory sensitivities through exposure and adaptive responses	Improves sensory processing and reduces meltdowns
Socially Assistive Robots (SARs)	Robots that aid in social and communication skills while engaging children in a less intimidating environment	Facilitates controlled social learning with predictable emotional cues
LEGO Mindstorms	Robotics kits that allow children to engage in problem-solving and cooperative play	Encourages collaboration and enhances social skills

REVIEW

Materials and Methods

The Preferred Reporting Items for Systematic Reviews (PRISMA 2020) guidelines were utilized to maintain transparency in the review process. All duplicate articles were truncated using EndNote, where the abstracts were reviewed after the titles were screened individually. This included a systematic search across Pubmed, Cochrane, Google Scholar, Science Direct and PsychInfo. MeSH terms and combinations were limited to "Technology" OR "Artificial intelligence" OR "AI" AND "Autism spectrum" OR "autism spectrum disorder" OR "ASD" OR "autism". A total of 46,580 were screened which after the inclusion and exclusion criteria were applied they were finalized to 254 finalized documents. The table below shows the MeSH words that were used to screen the papers.

Terminology	MeSH words
Autism	("autistic disorder"[MeSH Terms] OR autism[Text Word]) OR ("autism spectrum disorder"[MeSH Terms] OR autism spectrum disorder[Text Word]) OR asd[All Fields]
Technology	("technology"[MeSH Terms] OR technology[Text Word]) OR ("artificial intelligence"[MeSH Terms] OR artificial intelligence[Text Word]) OR ("antagonists and inhibitors"[Subheading] OR AI[Text Word])



Inclusion Criteria

- Articles published in peer-reviewed journals between 2009 and 2021
- Studies involving participants aged 2 to 18 years diagnosed with Autism Spectrum Disorder
- Studies that assessed cognitive, social, or emotional outcomes in children with ASD using technology-based interventions
- Full-text articles available in English

Exclusion Criteria

- Studies involving participants older than 18 years or younger than 2 years
- Studies that focused on non-human trials or animal models
- Studies that did not provide access to the full text or were published in languages other than English
- Conference abstracts, meta-analyses, and systematic reviews without original data

After applying these criteria, 254 articles were selected for full-text review. A further 43 articles were excluded due to insufficient data or lack of relevance, leaving 211 articles for detailed analysis. Among these, 11 studies met the final inclusion criteria, focusing specifically on technology-based interventions for children with ASD.

Results

The studies reviewed highlighted the potential of technology-based interventions, particularly socially assistive robots (SARs), to improve social communication, emotional regulation, and cognitive development in children with ASD. The interventions varied in duration, ranging from a few weeks to one year, and employed different types of technology, including robotic toys, virtual reality systems, and interactive computer programs. SARs were the most commonly studied technology, with robots such as "Kaspar" and LEGO Mindstorms showing significant promise in enhancing social interaction and reducing anxiety in children with ASD.

Key Findings:

1. **Social Interaction**: SARs were particularly effective in improving eye contact, emotional recognition, and turn-taking in children with ASD. Robots with human-like facial features, such as "Kaspar," facilitated social engagement by providing predictable emotional cues. Studies showed that children were more likely to initiate social interactions with the robot than with human therapists, suggesting that the consistency and predictability of robotic interactions reduce anxiety and promote learning [5].

2. **Emotional Regulation**: Several studies demonstrated that SARs could help children with ASD regulate their emotions by providing structured interactions and feedback. For example, the robot "Kaspar" was programmed to respond to the child's emotions with specific facial expressions, helping the child recognize and understand emotional cues. This interaction not only improved emotional regulation but also reduced behavioral outbursts during therapy sessions [6].

3. **Cognitive Development**: Cognitive skills, including memory, attention, and problem-solving, were also enhanced through the use of technology-based interventions. LEGO Mindstorms, a robotics kit that allows children to build and program robots, was found to improve cooperative play and problem-solving skills. Children who

participated in LEGO robotics activities showed greater engagement and were more likely to collaborate with peers, demonstrating the potential for technology to support social and cognitive development simultaneously [7].

Challenges and Limitations:

Despite the promising results, several challenges were noted across the studies. Variability in study design, participant characteristics, and intervention types made it difficult to generalize the findings. Some studies used a combination of SARs and traditional therapy, while others relied solely on robotic interventions. Additionally, the duration of the interventions varied significantly, with some studies lasting only a few weeks and others extending to one year. This variation in intervention duration likely contributed to differences in the outcomes reported.

Another limitation was the small sample size of many of the studies. While SARs have shown potential in improving social and cognitive skills, larger, more robust trials are needed to confirm these findings and determine the long-term efficacy of these interventions. Furthermore, the studies lacked standardized outcome measures, making it difficult to compare results across different trials.

Conclusion

Technology-based interventions, particularly socially assistive robots (SARs), have shown significant potential in improving the social communication, emotional regulation, and cognitive development of children with Autism Spectrum Disorder. SARs provide a structured, predictable environment that allows children to practice social skills without the emotional complexity of human interactions. The consistency of robotic interactions helps children with ASD navigate social cues and develop critical communication skills.

However, the variability in study designs and intervention types limits the generalizability of the findings. Future research should focus on standardizing intervention protocols, including the dosage and duration of SAR-based therapies. Larger, more comprehensive studies are also needed to assess the long-term impact of these interventions on cognitive and social outcomes in children with ASD.

Despite these challenges, the current evidence supports the integration of technology-based interventions into therapeutic programs for children with ASD. These interventions offer a non-invasive, scalable solution for enhancing social and cognitive skills, and with further research, they have the potential to become a key component of ASD treatment.

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