Artificial Intelligence-Based Interventions to Enhance Joint Attention Skills in Children with Autism Spectrum Disorder: A Systematic Review

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Abstract

Background: Joint attention (JA) is a key component of social, cognitive, and language development, yet children with autism spectrum disorder (ASD) often experience difficulties with it. Despite its crucial role in social interaction and communication, therapeutic interventions have rarely targeted JA directly. With advances in artificial intelligence (AI), particularly in autism research, new methods have emerged to enhance JA and social skills in this population. However, studies evaluating their effectiveness and characteristics remain scattered, highlighting the need for a comprehensive systematic review to analyze the available evidence.

Method: This systematic review followed the PRISMA 2020 guidelines. Major databases (Scopus, IEEE Xplore, PubMed, ERIC, ProQuest) and additional sources were searched using specific and advanced search terms, covering the period 2015–2025, to identify studies on AI-based interventions for improving JA in children with ASD. The search yielded 556 records, of which only 11 met the inclusion criteria after screening**.**

Results: Most AI-based interventions demonstrated moderate to high effectiveness, particularly in controlled environments. The majority of interventions primarily relied on humanoid robots. Nonetheless, variations in intervention protocols, small sample sizes, and short follow-up periods limited the generalizability of findings.

Conclusion: AI-based interventions show promising potential for improving joint attention in children with ASD. However, high-quality studies are urgently needed to assess their long-term effectiveness, applicability in natural settings beyond experimental conditions, and ethical considerations during use.

Keywords: Artificial intelligence; Joint Attention; Autism Spectrum Disorder; Systematic Review.

1. Introduction

1.1. Joint Attention and Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) has shown a notable increase in prevalence over the past decade. According to the Centers for Disease Control and Prevention (CDC, 2022), approximately 1 in 31 children in the United States is diagnosed with ASD. On a global scale, the World Health Organization (WHO, 2023) estimates that 1 in 100 children is affected.

These figures not only underscore the growing scope of the disorder but also point to a clear disparity in incidence rates between males and females. The rising prevalence highlights the urgent need for effective strategies in early detection, accurate diagnosis, and timely intervention.

ASD is widely recognized as a neurodevelopmental disorder that disrupts social interaction and communication. One of its earliest and most critical manifestations appears in children's development of joint attention (JA). As this skill is central to the diagnosis of ASD and is regarded as a cornerstone for language acquisition, social growth, and cognitive development (Mundy & Newell, 2007; Kasari et al., 2008). At its core, JA refers to the neurocognitive ability to create a shared focus of attention with caregivers and others. In typically developing (TD) children, this skill begins to emerge around five months of age, when infants demonstrate the ability to coordinate attention with another person toward a common object or event. Neuroimaging studies have shown that JA is supported by a broad neural network, including (a) the prefrontal cortex, (b) the cingulate cortex, (c) the temporal cortex, (d) the temporal lobe, and (e) the amygdala. This reflects the complex triadic processing of self–other–object interactions within a social context (Mundy, 2018).

As children grow, JA evolves into two distinct but complementary functions. Responsive Joint Attention (RJA) involves shifting attention in response to another person's social cues, such as gaze direction or gestures. In contrast, Initiating Joint Attention (IJA) reflects the ability to actively direct another person's attention, again through gaze or gestures, to share an experience (Mundy, 2016). While this developmental trajectory is typical in TD children, the picture looks quite different in children with ASD. Research shows that they often display deficits in both RJA and IJA as early as 12 to 18 months. These challenges are evident in their limited use of eye contact, emotional expressions, and gestures, behaviors that are fundamental for regulating social exchanges and supporting later communication and social development (Volkmar et al., 2005).

1.2. From Traditional to Technology-Based Interventions: Pathways to Enhancing Joint Attention

Because of its central role in social and language development, joint attention (JA) has become a primary target in intervention programs for children with ASD. Among the most widely used approaches is Applied Behavior Analysis (ABA), a structured therapeutic method aimed at shaping and reinforcing positive behaviors (Leaf et al., 2016). In addition, Naturalistic Developmental Behavioral Interventions (NDBIs), a term introduced by Schreibman et al. (2015), encompass a variety of evidence-based models such as JASPER (Kasari et al., 2006), ESDM (Dawson & Rogers, 2010), and ImPACT (Ingersoll & Dvortcsak, 2007). These approaches have consistently demonstrated effectiveness in enhancing JA skills and social interaction in children with ASD.

However, despite their positive outcomes, several challenges remain. Access to services can be limited, interventions may lack flexibility, and training requirements are often extensive. High financial costs further restrict their widespread application (Bauer et al., 2022). Moreover, these approaches are labour-intensive, rely heavily on direct human interaction, and may not always engage children with limited interest in social communication. Variability

in practitioner expertise and the focus on individualized cases present additional obstacles (Bo Shen et al., 2024). These limitations highlight the need for more adaptable, engaging, and motivating interventions that can be tailored to the unique needs of each child (Kapp, 2012; Grynszpan et al., 2014; David et al., 2020).

In this context, technology-mediated interventions (TMIs), including computer-assisted therapies (CAT) and robot-assisted therapies (RAT), have gained increasing attention as promising alternatives for supporting children with ASD (Warren et al., 2013; Bharatharaj et al., 2017; Meucci et al., 2020; Hughes et al., 2022). Research findings suggest that robotics and virtual/augmented reality (VR/AR) can effectively foster social and academic skills, largely due to their interactive and motivating features. For example, several studies have reported that children with ASD show greater attention to robotic faces and are more likely to establish eye contact with robots than with humans during JA training sessions (Cao et al., 2018, 2019; Pennisi et al., 2016).

Systematic evidence further supports these findings. A review of 13 studies on social robots for JA development revealed consistently positive responses, with participants perceiving robots as engaging social partners (Bozkurt et al., 2021). Similarly, a meta-analysis of 14 studies conducted between 2015 and 2024 concluded that robotic interventions positively influenced children's social, academic, and emotional development (Wang et al., 2025). Reviews on VR/AR interventions also suggest encouraging outcomes for JA improvement, although the small number of studies and methodological limitations indicate that this is still an emerging field (Yazdanin et al., 2023).

1.3. Artificial Intelligence and Autism Spectrum Disorder: Diagnosis and Intervention

The growing reliance on robotics, VR/AR, and other interactive platforms marks a paradigm shift in ASD interventions. Yet, most existing systems follow fixed protocols or rigid training sequences, limiting their ability to adapt dynamically to individual needs or to respond in real time to children's behaviors (Scassellati et al., 2012; Bozkurt et al., 2021; Yazdanin et al., 2023). The rapid progress of artificial intelligence (AI) offers solutions to these challenges. AI, broadly defined as the field of computer science that develops systems capable of simulating human intelligence, including learning, reasoning, and natural language processing (Russell et Norvig, 2021), is increasingly being applied to ASD research and practice.

AI techniques such as machine learning, deep learning, and computer vision are now being used in early diagnosis, individualized treatment, communication support, and real-time progress monitoring (Duda et al., 2016; Thabtah, 2018). A systematic review by (Ahmad et al., 2025) identified early diagnosis as the most prominent area of AI application, demonstrating how AI can reduce dependence on subjective clinical observations and lengthy manual assessments. Tools such as eye trackers combined with intelligent algorithms have shown high accuracy, efficiency, and objectivity in diagnostic processes. Nonetheless, challenges remain, particularly the need for high-quality behavioral and medical datasets, technical integration with electronic health records, and the risk of algorithmic bias.

Other reviews confirm AI's diagnostic potential. (Solek et al., 2025), in a review of 25 studies, reported that AI models improved diagnostic accuracy, reduced assessment time, and minimized human error. Similarly, (Dcouto et Pradeepkandhasamy, 2024) found that deep

learning methods, including CNN, DNN, and GCN, produced strong results in ASD diagnosis. Beyond diagnosis, AI applications extend to genetic research, neuroimaging, and behavioral data analysis, offering new insights into the disorder.

Encouragingly, AI has also begun to be applied to JA assessment. For instance (Zhang et al., 2022) developed RJAfinder, an automated tool using eye-tracking data to detect responsive JA behaviors in children with ASD. Built with MATLAB and R, the tool demonstrated greater accuracy than manual coding in identifying JA events, suggesting opportunities for more efficient evaluation of intervention outcomes.

More recently, AI has moved beyond assessment to actively support intervention. Real-time data analysis enables adaptive therapeutic strategies tailored to each child's behavioral and physiological patterns (Topol, 2019; Esteva et al., 2019). AI-supported platforms, such as social robots (e.g., NAO, KASPAR), interactive systems, and VR/AR environments-can dynamically adjust their responses to maximize engagement. Pilot studies provide promising evidence: (Bekele et al., 2013) tested an adaptive robotic system that automatically modified JA instructions during therapy, achieving high reliability. Likewise, Atturu et Naraganti (2025) evaluated the 'CognitiveBotics AI platform' and reported significant improvements in children's social and language skills, along with reductions in ASD symptom severity.

Despite these advances, the adoption of AI in autism care raises important ethical considerations. Issues such as privacy and data protection, data quality and integration, algorithmic fairness, and concerns about diminishing the human role in therapy require careful attention (Floridi et al., 2018; Ahmad et al., 2025).

1.4. Rationale for the Review

Although research on AI in ASD care has expanded rapidly, studies specifically targeting JA remain limited. Much of the existing literature focuses on AI's role in diagnosis and prediction, which has dominated the field, while fewer studies explore its potential in systematically improving JA skills. Even when JA-focused studies exist, they often examine single interventions, provide limited outcome measures, or fail to distinguish between RJA and IJA. This gap restricts our ability to identify the mechanisms underlying intervention effectiveness and limits the generalizability of findings beyond controlled settings. Moreover, little is known about the long-term sustainability of intervention outcomes, an aspect as important as immediate effectiveness.

This review, therefore, seeks to address these gaps by conducting a comprehensive qualitative descriptive analysis of studies examining AI-based interventions for JA in children with ASD. Specifically, it aims to:

1. Synthesize and critically evaluate the limited body of evidence on AI applications for improving JA in children with ASD, **2.** Provide descriptive summaries of the methodological and technical characteristics of these studies, **3.** Assess the effectiveness of AI-based interventions in enhancing JA skills. In line with these objectives, key research questions were formulated to guide the review.

2. Research Questions of the Systematic Review

Q_1What are the main techniques employed in AI-based interventions to enhance joint attention (JA) skills in children with ASD?

Q_2 What are the defining features of effective AI-based interventions in improving JA skills in children with ASD?

Q_3 Which dimensions of joint attention (RJA/ IJA) are most influenced by AI interventions?

Q_4 To what extent are AI-based interventions effective in enhancing JA in children with ASD?

Q_5 What interactive mechanisms account for the effectiveness of AI interventions in fostering JA in children with ASD?

Q_6 How sustainable and long-lasting are the effects of AI-based interventions on JA skills in children with ASD?

3. Methods

A systematic literature review (SLR) was conducted to examine the scientific evidence on AI-based interventions designed to improve JA in children with ASD. The review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al., 2021). A flow diagram was used to illustrate the study selection process (Figure 1).

3.1. Search Strategy

A systematic search was carried out across five major electronic databases, Scopus, PubMed, IEEE Xplore, ERIC, and ProQuest, covering publications from 2015 to February 2025. Additional references were identified through manual searches of bibliographies to capture any relevant studies that might have been overlooked.

These databases were chosen because each of them covers a large portion of studies relevant to such topics. The search employed Boolean operators (AND/OR) and MeSH terms to maximize precision and ensure relevance to AI-based interventions in applied contexts, while minimizing irrelevant results. The search string was adapted to the requirements of each database:

> ➢ ("artificial intelligence" OR "AI-based tools" OR "AI systems" OR "social robots" OR "robot-assisted intervention" OR "virtual/augmented reality") AND ("joint attention" OR "shared attention" OR "gaze following") AND ("autism" OR "autism spectrum disorder" OR "ASD")

3.2. Inclusion and Exclusion Criteria

The review targeted empirical studies that evaluated the use of AI-based interventions to enhance JA in children with ASD.

- **Inclusion criteria:** **1**. Studies involving children diagnosed with ASD, **2**. Use of AI-based interventions aimed at improving JA, **3**. Experimental designs, including randomized controlled trials, quasi-experimental studies, **4**. Publications between 2015 and 2025, **5**. Full-text articles available in English.

- **Exclusion criteria:** **1**. Studies involving adolescents or adults, **2**. Studies including participants with disorders other than ASD, **3**. Studies not targeting JA improvement, **4**. Research not employing AI or its principles, **5**. Studies focused solely on AI

algorithm development without clinical evaluation, **6**. Studies without clear measurement tools for JA, **7**. Publications outside the time range or in non-English languages, **8**. Theses, dissertations, proposals, and review papers, **9**. Studies lacking a rigorous scientific methodology, **10**. Studies without explicit results regarding JA improvement.

3.3. Study Selection

The initial search retrieved 556 records, which were imported into Rayyan.ai for screening. Duplicates were automatically removed, leaving 414 records. After screening titles and abstracts, 98 studies were retrieved in full text, while 316 were excluded based on the eligibility criteria. Following full-text assessment, 87 articles were excluded, leaving 11 studies for final inclusion in the review (Figure 1).
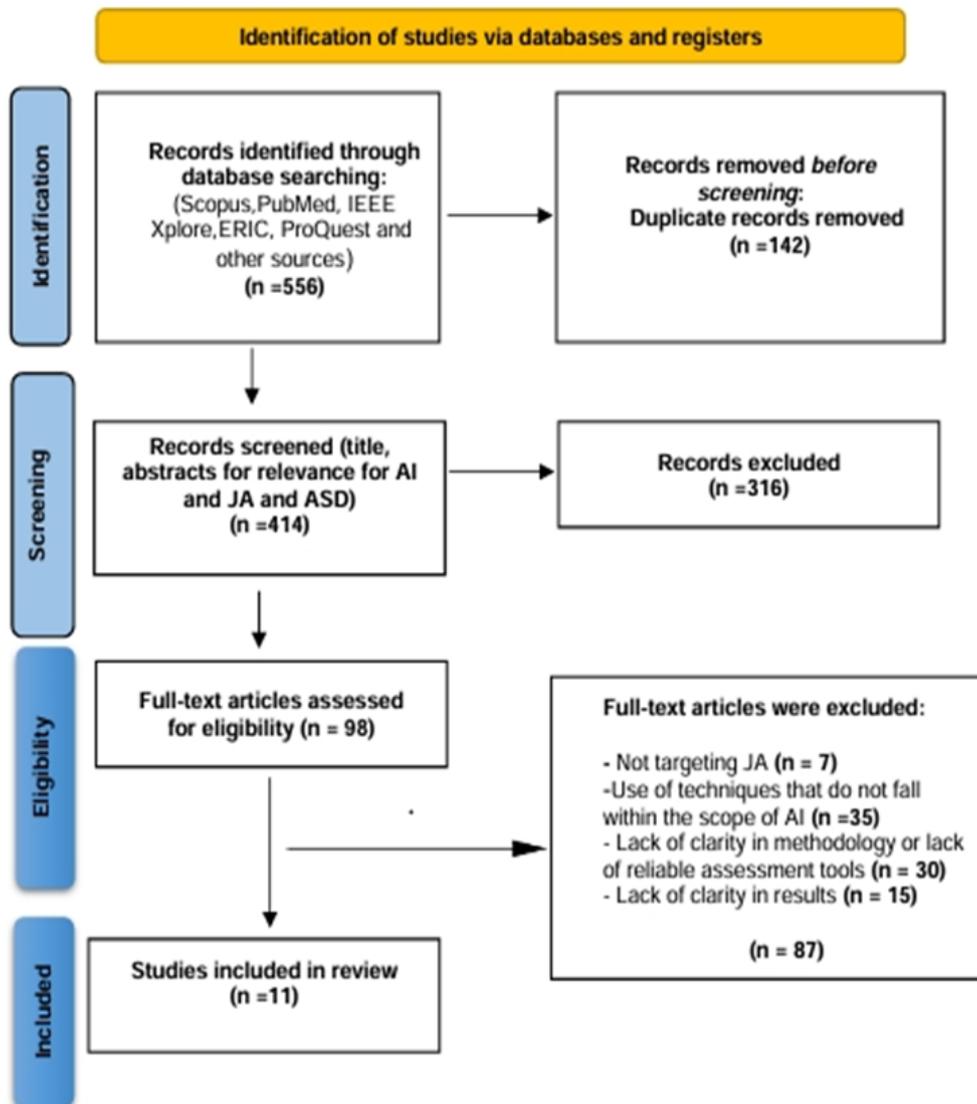

Figure 1. PRISMA flow diagram for study selection.

3.4. Data Extraction and Coding Procedures

Data extraction followed the Cochrane Handbook guidelines (Higgins et al., *2024*). A structured form was used to collect key study characteristics, including: Authors, year of publication, and study design; Participant details (sample size, age, ASD severity); Targeted JA dimension (RJA or IJA), Type of AI-based intervention, Duration of intervention, and Measurement tools employed, and Key findings.

Two reviewers independently conducted coding to reduce bias. Any disagreements were resolved through discussion and consensus. The extracted data were analyzed descriptively and qualitatively (see Table 1).

3.5. Data Analysis and Synthesis

Due to substantial heterogeneity in study designs, outcome measures, and reported findings, a meta-analysis was not feasible. Instead, a narrative synthesis approach was adopted. This method enabled the comparison of study characteristics, identification of common patterns, and discussion of differences across studies. Methodological limitations were also critically assessed to strengthen the reliability of the conclusions, in accordance with Cochrane recommendations (Higgins et al., 2024) and PRISMA 2020guidelines.

3.6. Methodological Considerations: Risk of Bias and Evidence Quality

A formal risk-of-bias assessment was not conducted due to the considerable methodological diversity of the included studies, particularly in research design, outcome measures, and implementation contexts. As noted in the Cochrane Handbook (Chapter 13), such heterogeneity limits the applicability of standardized assessment tools, especially in reviews that include primary or highly divergent research. Instead, the review undertook a descriptive and critical appraisal of each study's strengths and limitations to provide a balanced understanding of the evidence base.

4. Results

This section provides a sanitized overview of the results of the included studies, based on participant characteristics and interventions. It also highlights methodological gaps and limitations to enrich the discussion and offer a clearer picture of current research trends.

Table 1

Characteristics of Included Studies and Participants.

Authors and Year of Publication	Study Design	Participants	JA Types	Type of AI-based Intervention	Duration of intervention	Measurement Tools	Main Findings
Zheng et al. (2016)	Longitudinal experimental study	n=6 children with ASD. Sex: Male. Average age: 2.80 yrs → 3.52 yrs (longitudinally tracked) Degree: varying levels.	RJA	Autonomous Robotic Intervention System NARIS	6 sessions (Phase 1: 4 sessions. Phase 2: 2 sessions after 8 months).	Robotic System Measurements: Target Hit Rate; Prompt Levels Medium; Detect contactless staring in real time; Preferential attention to the robot.	Children with ASD showed significant improvement in JA and task performance within 8 months. The autonomous robot also helped maintain attention and supported continuous progress.
Zheng et al. (2018)	Longitudinal experimental study	n=14 children with ASD. Sex: 12 males, 2 females. Age:1.78to 4.53 years old. Degree: varying levels.	RJA/IJA	Noncontact-Responsive Robot-mediated Intervention System NORRIS	27 days, 4 sessions per participant	Gaze-Tracking Module, Target Hit Rate; Prompt Levels Medium; Collect behavioral data in real time during each trial and session.	The results showed a significant improvement in the participants' JA skills, that their interest in the robot remained constant throughout the sessions, and that the interaction model from least to most was effective in enhancing the children's performance.
Ali et al. (2019)	Longitudinal experimental study		RJA/IJA	Multi-Robot Intervention System - MRIS	6 months total; 2 months active phase (8 sessions per intervention type)		
Ali et al. (2020a)	Quasi-Experimental	n=12 children with ASD Sex: 11 males,1 female Age: 3.7 to 10.4years old. Degree: varying levels.	RJA	Robot NAO, Visual Stimuli (rasta, blink)	2 months, 8 sessions for each visual cue spread over 8 weeks.	EEG; CARS- 3; NAO Robot Cameras; Kinect sensor	Participants showed significant improvement in JA and movement imitation, increased eye contact with robots, and faster gaze-shifting. Improvements in multilateral communication were also observed.
Ali et al. (2020b)	Preliminary longitudinal experimental study	n=12 children with ASD Sex: 11 males, 1 female. Age: 3.5 to 7.2years old. Degree: NR.	RJA	Multi-Robot Intervention System - MRIS	Two and a half months, 10 sessions for each participant over 10 weeks.	Gaze Tracking Module; NAO overhead camera; Evaluation parameters through: "Number of times of eye contact, Total visual contact time".	The 'rasta' visual cue was more effective than 'blink,' leading to greater and more repetitive eye contact. JA improved across both cues, with stronger results for 'rasta.'
		n=8 children with ASD Sex:7 males, 1 female.				CARS; AL Gaze analysis; Command Following Count (auditory, visual,	

		Age: 3.7 to 10 years old. Degree: varying levels.				and a combination of both).	Children with ASD showed an 86% improvement in social communication, significant gains in JA and command following, and higher accuracy of responses post-intervention.

Table 1 Cont.

Authors and Year of Publication	Study Design	Participants	JA Types	Type of AI-based Intervention	Duration of intervention	Measurement Tools	Main Findings
Zheng et al. (2020)	RCT with a waiting list.	n=20 children with ASD (RI: 11; WLC: 9). Sex: NR. Age:1.64 to 3.14 years old. Degree: varying levels.	RJA	Intelligent Robotic Response to Joint Attention Intervention System	3-9 weeks per group 4 sessions.	STAT Score; Within-system measurements (Average prompt level, Target hit rate).	The study reported small, statistically insignificant differences, with no clear improvement in JA or social communication skills; overall results were mixed.
Amat et al. (2021)	Quasi-experimental	n=18 children (ASD=9; TD=9) Sex: 5 males, 4 females. (in each group). Age: 7 to 13 years old. Degree: varying levels.	RJA	Interactive Virtual Reality System, InViRS	Three visits spread over a period of 5 to 10 days.	Eye tracker (Tobii EyeX); Bubble Popping game.	Children with ASD demonstrated improved JA, higher game scores, shorter response times, and more frequent gaze fixation on the avatar's eye area in the posttest.
Patricia Pérez-Fuster et al. (2022)	A multiple baseline single-subject experimental design.		RJA	Augmented reality Technology (Pictogram Room)	12 weeks 6 sessions per child.	ADOS-2; ESCS; An ad-hoc measure.	
Valentim et al. (2023)		n=6 children with ASD Sex:5 males, 1 female. Age: 3 to 8 years old. Degree: varying levels.	RJA/IJA		3 weeks 10 sessions.		All participants showed significant improvements in RJA skills, particularly in gaze tracking and signaling. Gains were maintained one month post-intervention and generalized to real-world settings.
Zahid et al. (2024)	Quasi-Experimental		RJA/IJA	Intelligent Tutoring Systems-ITS	8 months (34 weeks) 30 sessions for each child in each intervention unit (JA, imitation).	ESCS; ITS Algorithms (Performance and Emotion Analysis) + Video/Note.	
Ramnauth et al. (2025)	Quasi-Experimental Longitudinal	n=6 children with ASD Sex:5 males, 1 female. Age:4 to 5 years old. Degree: NR	RJA/IJA	RoboCA3T	One month, 30 sessions per child.	CARS; WebGazer (JA); Tensorflow Lite (imitation).	The ITS proved effective in increasing JA and improving social interaction. Children in Group 1 showed significant gains in IJA, while participants V2 and V3, who initially struggled with both
	experimental study	n=11 children with ASD Sex:8 males, 3 females. Age: 3 to 11		Social Robot Jibo		Automated Gaze Behavior Measures:	

						(RGB cameras; OpenFace software; ELAN software).	RJA and IJA, also improved after using the ITS.
		years old. Degree: varying levels.

n=13 children with ASD
Sex: 8 males, 5 females.
Age: 6 to 12 years old.
Degree of ASD: NR. | | | | | The RoboCA3T system was effective in enhancing JA and imitation skills in children with ASD, with strong statistical evidence supporting positive, skill-based behavioral outcomes.

Long-term home robotic intervention significantly improved JA and gaze behavior in children with ASD, and enhanced social interaction between them and caregivers, with noticeable effects after approximately three weeks. |

Note: AI: Artificial Intelligence; JA: Joint Attention; RJA: Response to Joint Attention; IJA: Initiating Joint Attention; ESCS: Early Social Communication Scales; ADOS 2; Autism Diagnostic Observation Schedule; CARS: Childhood Autism Rating Scale; CARS-3: Gilliam Autism Rating Scale, Third Edition; STAT score: Screening Tool for Autism in Toddlers and Young Children; EEG: Electroencephalography; NR: not reported

4.1. Characteristics of ASD Participants

As summarized in Table 1, all studies involved children diagnosed with ASD. Across the included studies, a total of 126 participants took part in experimental groups. Ages ranged from 1.64 to 13 years, with a stronger emphasis on preschool-aged children. Autism severity varied from mild to severe, rather than being confined to a single level.

Most studies reported a clear predominance of male participants. For example, one study included 11 males versus 1 female (Ali et al., 2019, 2020a), whereas another reported a relatively higher proportion of females (5 females vs. 8 males) (Ramnauth et al., 2025). Sample sizes were generally small, ranging from 6 participants (Zheng et al., 2016; Pérez-Fuster et al., 2022; Valentim et al., 2023) to 20 participants (Zheng et al., 2020), reflecting the limited scope of participant recruitment in this field.

4.2. Study Designs

The studies employed a range of designs depending on the intervention type and context. These included: Longitudinal within-person designs (Zheng et al., 2016, 2018; Ali et al., 2019). Preliminary experimental designs with pre- and post-testing (Ali et al., 2020b), Single-case experimental designs with multiple baselines (Pérez-Fuster et al., 2022). Quasi-experimental designs (Ali et al., 2020a ; Amat et al., 2021 ; Valentim et al., 2023 ; Ramnauth et al., 2025). RCT with a waiting-list control group (Zheng et al., 2020).

This methodological diversity reflects systematic attempts to evaluate intervention effectiveness under both controlled and natural conditions. However, research in naturalistic environments remains rare; only one study (Ramnauth et al., 2025) explicitly did so, limiting the generalizability of findings to real-world settings.

4.3. AI-Based Interventions: Patterns and Features

The interventions demonstrated technological variety and interactive sophistication, using autonomous robots, multi-robot systems, and adaptive digital systems, virtual/augmented reality, and smart applications.

1. Autonomous robotic systems: e.g., NARIS (Zheng et al., 2016) and NORRIS (Zheng et al., 2018), which integrated gaze-tracking and real-time visual sensing to provide progressive social cues. Robot NAO (Ali et al., 2020a), where visual stimuli' rasta-blink' were used to improve JA and eye contact. **2.** Multi-robot systems: e.g., MRIS (Ali et al., 2019, 2020b), expanding interaction by directing attention to multiple stimuli through auditory and visual cues. These often relied on the humanoid robot NAO, known for simulating human-like behaviors and graded responses. **3.** In natural contexts: e.g., Social Robot jibo (Ramnauth et al., 2025) operating in home environments with advanced facial and gaze analysis algorithms (OpenFace, ELAN).

4. Adaptive digital therapeutic systems: e.g., RoboCA3T (Zahid et al., 2024), incorporating embedded adaptability.

5. Virtual/augmented reality: e.g., InViRS (Amat et al., 2021), featuring interactive gaze-based games, and Pictogram Room (Pérez-Fuster et al., 2022), which tracked gaze and movement in desktop-based social scenarios.

6. Smart applications: e.g., Intelligent Tutoring System (ITS) (Valentim et al., 2023), using virtual trainers to guide exercises targeting JA skills.

These diverse approaches reflect ongoing efforts to integrate AI into socially responsive, child-centered interventions.

4.4. Outcome Measures

The studies used a wide range of assessment tools, including both clinical instruments and digital/automated metrics:

Clinical tools: ADOS-2, CARS, ESCS (Pérez-Fuster et al., 2022; Ali et al., 2019, 2020b; Valentim et al., 2023), to assess JA, communication, and social interaction skills, before and after the intervention. In a more advanced framework, some studies incorporate gaze-tracking and visual analysis tools: Tobii EyeX, EyeMMV Toolkit, OpenFace, WebGazer (Amat et al., 2021; Zahid et al., 2024; Ramnauth et al., 2025). Embedded robotic metrics: response time, hit rate, cue frequency, and duration of eye contact (Zheng et al., 2016, 2018, 2020; Ali et al., 2019, 2020a). ITS-integrated performance metrics: accuracy, response time, emotion recognition, plus video analysis (Valentim et al., 2023).

By analyzing the measurement tools used in the studies, it is clear that there is a great tendency towards integration between the clinical and technical approaches, but the choice of tools varied in terms of suitability for the sample, the type of skill targeted, and the ability to monitor dynamic changes during interaction within sessions.

4.5. Intervention Protocols

The duration and intensity of interventions varied considerably:

Short interventions: (e.g., Amat et al. 2021) with only 3 visits over 10 days. Medium-term interventions: (e.g., Ali et al. 2019, 2020a, 2020b) lasting 2–6 months with 8–10 sessions. Extended interventions:(e.g., Zahid et al. 2024), with 30 sessions over 8 months.

Brief robotic sessions: (e.g., Zheng et al. 2016, 2018, 2020), lasting 5–10 minutes across 4–6 sessions. Augmented reality interventions: (e.g., Pérez-Fuster et al. 2022), with 8 sessions split into learning and intervention phases, plus a 3-month follow-up. Home-based programs: (e.g., Ramnauth et al. 2025), with 30 daily sessions of 30 minutes each. Follow-up data were scarce, with only a few studies reporting long-term monitoring (e.g., Zheng et al., 2016; Pérez-Fuster et al., 2022; Zahid et al., 2024).

4.6. Key Findings

Most studies reported positive effects on JA skills following AI-based interventions:

Improved JA continuity and responsiveness (Zheng et al., 2016). Enhanced visual communication through targeted cues (Ali et al., 2020a). Significant gains in IJA/RJA and social engagement (Valentim et al., 2023), though slight regression occurred after treatment ended. Transfer of skills to natural contexts (Pérez-Fuster et al., 2022). Improvements in related social skills such as imitation and multi-party interaction (Ali et al., 2020b; Zahid et al., 2024). However, results were not universally consistent. For example, (Zheng et al. 2020) reported limited improvement, suggesting that the effectiveness of smart systems varies depending on individual variables and implementation context.

4.7. Limitations of the Studies

Despite promising results, the reviewed studies shared several methodological limitations that restrict the strength of the evidence. The most critical limitation concerns sample size. For example, (Zheng et al., 2016; Pérez-Fuster et al., 2022) included only six participants, while

even studies with a relatively high number of sessions, such as (Zahid et al., 2024; Ramnauth et al., 2025), relied on small groups, limiting generalizability.

Another limitation lies in the imbalance between the skills studied. Research has predominantly focused on RJA, whereas IJA, a crucial indicator of spontaneous communication, was largely neglected, appearing in only five studies. In some cases, the general term JA was used without clarification, reducing the precision of interpretation.

The absence of control groups in most studies limits the ability to make accurate causal inferences, except for the study (Zheng et al., 2020), which used a randomized design with a delayed control group, but faced additional limitations, such as the refusal of some children to wear EEG devices, which affected the completeness of the data.

The choice of assessment tools also presented challenges. While some relied on established clinical measures (ADOS-2, CARS, ESCS), others used automated systems (gaze tracking, cue-following). Yet tools like ESCS, as used in (Pérez-Fuster et al., 2022; Valentim et al., 2023), were developed for much younger children (8–30 months), raising concerns about validity when applied to older participants. With regard to AI-based interventions, most remain in the pilot stage, with limited reporting on reliability and validity. Moreover, the heavy reliance on humanoid robots such as NAO raises concerns about replicability across contexts and the lack of personalization to children's language and sensory needs. Finally, many studies did not examine the generalization of acquired skills. Follow-up data were often missing, and some interventions were too brief (e.g., three sessions) to allow conclusions about sustainable behavioral effects.

5. Discussion

This section interprets the findings of the included studies in light of the review questions, highlights methodological and contextual factors that may explain the variability in results, and evaluates the extent to which AI-supported interventions align with the behavioral goals of enhancing JA skills in children with ASD, both in RJA and IJA.

Overall, the studies demonstrated that AI-based interventions are behaviorally and technically diverse, employing different designs, platforms, and measurement tools. While the preliminary results indicated effectiveness in improving components of JA, the interpretation of these outcomes requires deeper consideration of the characteristics of interventions, the interactive mechanisms employed, and the extent of adaptation to children's individual needs.

5.1. Main techniques used in AI-based interventions

Most studies relied heavily on interactive social robots, particularly the humanoid robot NAO (Zheng et al., 2016, 2018, 2020; Ali et al., 2019, 2020a, 2020b) and the Jibo robot (Ramnauth et al., 2025) due to their capacity to integrate verbal and non-verbal cues while simulating human-like behavior in a consistent and engaging manner. The RoboCA3T system (Zahid et al., 2024) also demonstrated potential as a computer-assisted adaptive therapy tool.

In contrast, the use of virtual and augmented reality (VR/AR) technologies was less common, with only two studies (Amat et al., 2021; Pérez-Fuster et al., 2022) exploring their effectiveness despite their ability to present socially enriched contexts.Some studies integrated AI-based software and computer vision systems including gaze-tracking and eye-tracking

technologies (e.g., OpenFace, Tobii EyeX, WebGazer) to monitor children's attention in real time (Zheng et al., 2016; Zahid et al., 2024; Ramnauth et al., 2025). These tools contributed to precise assessment but were mostly limited to laboratory contexts, restricting ecological validity. Additionally, advanced AI algorithms such as CNNs for emotion recognition, Q-Learning for reinforcement learning, and adaptive systems (e.g., LivApp, CalcPerform) (Valentim et al., 2023) enhanced personalization of learning trajectories.

However, current interventions primarily target RJA, with limited focus on IJA, leaving a methodological gap in addressing spontaneous social initiation. Future studies should diversify platforms, integrate multimodal tools, and extend testing to natural settings.

5.2. Characteristics of effective AI-based interventions

Analysis of effective interventions revealed several key characteristics:

1. Adaptive interaction: Real-time responsiveness to child behaviors (e.g., WebGazer, OpenFace, EyeMMV Toolkit) enhanced engagement and reduced frustration (Zahid et al., 2024; Ramnauth et al., 2025). This characteristic adapts instantly, enhancing the child's social integration and responsiveness and reducing the likelihood of frustration or withdrawal during the session. **2.** Duration and frequency: Multi-week interventions with repeated sessions yielded more consistent improvements than short-term programs (Zheng et al., 2018; Amat et al., 2021). **3.** Variety of stimuli: Robots and VR platforms that combined visual, auditory, and movement-based cues provided richer engagement (Ali et al., 2019, 2020b; Amat et al., 2021). **4.** Algorithm integration: Systems incorporating machine learning and reinforcement learning (e.g., CNN, LivApp, Q-Learning) optimized personalization (Valentim et al., 2023). **5.** Naturalistic contexts: Interventions conducted at home or in semi-natural environments achieved greater skill generalization, especially when parents were involved (Ramnauth et al., 2025).In summary, interventions that combine adaptivity, sufficient duration, multimodal stimuli, algorithmic personalization, and real-world implementation show the highest potential for improving JA in ASD children.

5.3. Dimensions of JA most affected (RJA/IJA)

Most interventions targeted RJA, focusing on gaze following, head-turning, or responding to visual/auditory cues (Zheng et al., 2016, 2020; Ali et al., 2020a; Amat et al., 2021; Pérez-Fuster et al., 2022). Improvements in accuracy, speed, and frequency of responses were consistently reported. By contrast, IJA received less systematic attention. While some studies observed incidental improvements (Zheng et al., 2018; Ali et al., 2019; Zahid et al., 2024), these were not consistently measured. A notable exception was (Valentim et al., 2023), who explicitly targeted both RJA and IJA, showing measurable gains in both domains. Thus, while AI interventions are effective for RJA, IJA remains underexplored despite its critical role in language and social development, representing a key research gap.

5.4. The effectiveness of AI-based interventions in improving JA in children with ASD.

According to the results of the reviewed literature, AI-based interventions have generally shown remarkable effectiveness in enhancing JA skills in ASD children, both at the RJA level and to a lesser extent at the IJA level, showing a greater focus in the design of protocols on improving response to external stimuli, without stimulating spontaneous initiative from the child. The effectiveness indicators varied according to the type of technologies used, the type

of interaction within the session, and the nature of the measured outcomes, as the study (Zheng et al., 2016) showed an improvement in response speed and repetition of the target behavior after interactive sessions with the NARIS robot that provides social visual cues gradually and adaptively to the child's performance, and (Amat et al., 2021) showed positive results in enhancing gaze fixation on the eye area after a series of sessions in a virtual reality environment supported by a gaze tracking system. In the same context, a study (Valentim et al., 2023) that effectiveness is proven as a short-term effect of an intelligent educational system based on advanced algorithms, despite observing improvements in RJA/IJA skills immediately after the intervention in both groups. A study (Zahid et al., 2024) showed a significant improvement in both JA and imitation skills through the RoboCA3T intelligent system, which combines gaze tracking and machine learning technologies and automatically adjusts the interaction pattern based on the inputs received. The study (Ramnauth et al., 2025) pointed to positive results and the effectiveness of the social robot Jibo in developing JA and, consequently, improving communication and social interaction in children with ASD in a natural home environment, using precise tools to analyze behavior.

 However, the extent of effectiveness was not the same across all studies, with some clinical trials (Ali et al., 2020a; Pérez-Fuster et al., 2022) showing limited or statistically insignificant results, partly due to the short duration of the intervention or inadequate measurement tools, and few studies addressed the effect of the intervention on IJA skill.

 AI-based interventions show promising potential in improving specific components of JA, especially when these interventions are interactive, adaptive, and supported by real-time analysis of behavioral performance, but effectiveness is influenced by multiple factors including the duration and frequency of the intervention, the nature of the adaptive algorithms, and the extent to which parents or the natural environment are incorporated during the implementation process.

5.5. Mechanisms explaining the effectiveness of AI-based interventions

The observed effectiveness of AI interventions in promoting JA in ASD children cannot be understood only through quantitative results, but must be analyzed in light of the interactive mechanisms that distinguish intelligent systems from other traditional interventions. The included studies revealed three basic mechanisms: **1.** Real-time adaptation. Intelligent systems adjust responses based on child behavior, promoting engagement (e.g., Zheng et al., 2020; Valentim et al., 2023; Zahid et al., 2024). **2.** Clarity of cues, Robots provide simplified, consistent signals (e.g., gaze direction, gestures), reducing social ambiguity, e.g., NARIS (Zheng et al., 2016) and MRIS (Ali et al., 2019, 2020b). **3.** Structured repetition with feedback, AI platforms deliver consistent and varied practice opportunities, reinforcing learning, e.g., InViRS (Amat et al., 2021) and Pictogram Room (Pérez-Fuster et al., 2022), ITS (Valentim et al., 2023). This repetition is a key factor in promoting learning in children with ASD and developmental disorders in general.

It should be noted that these mechanisms do not work in isolation, but rather interact in an integrated environment that combines precise sensory stimulation, adaptive response, and the gradual construction of social behavior, so what distinguishes AI interventions is not only

their use of technology, but their ability to create an interactive dynamic closer to natural social relationships, but in a controlled and measurable form.

5.6. Sustainability of the impacts of AI-based interventions

The included studies indicated preliminary evidence that some improvements in JA skills in ASD children are sustained after the end of AI-based interventions, but this conclusion remains limited by several methodological factors, as most studies focused on immediate (post-test) measurements without subsequent follow-up assessments that can monitor the stability of behavioral changes or generalize them to realistic natural environments outside the context of the intervention.

1. Sustained effects: (Zheng et al., 2016) reported RJA improvements lasting up to eight months. (Pérez-Fuster et al., 2022) observed skill generalization to real-life contexts.

2. Mixed findings: (Valentim et al., 2023) noted post-intervention gains that declined within a week, suggesting limited sustainability without reinforcement.

3. Extended interventions: Long-term designs (Zahid et al., 2024) hinted at more stable changes, though follow-up was limited.

Based on these findings, it can be said that although there are no clear results on the sustainability of the impact, some studies have revealed promising signs regarding the sustainability of JA improvements after the end of interventions, especially those that use interactive techniques and are applied in real-life settings. However, there is an urgent need for further future studies with a rigorous experimental design to confirm the stability of these effects and improve treatment protocols.

5.7. Limitations of the review

Although the review attempted to rely on a qualitative analytical methodology and included recent and technically diverse studies, some fundamental limitations that could affect the level of current evidence should be acknowledged. (1) The exclusion of research in the gray literature could lead to bias in the sample of studies included, (2) The sample size was small due to the strict inclusion criteria set for this study, thus limiting the generalizability of the results, (3) we were unable to formally assess the risk of bias and quality of evidence using standardized tools due to the significant methodological heterogeneity among the included studies. Instead, we relied on descriptive and critical analysis. (4) The review did not conduct a meta-analysis, partly due to methodological differences between the included studies, which prevented this step from being carried out.

These limitations are not unique to this review but rather reflect broader challenges in the emerging field of AI applications for developmental disorders. Given the novelty of this area, the present findings should therefore be interpreted with caution.

5.8. Recommendations for future research

Based on the findings and limitations mentioned, this review recommends that future research adopt more rigorous methodological designs, particularly randomized controlled trials (RCTs), to better evaluate the effectiveness of interventions under controlled conditions. Expanding the sample size to include female participants and individuals of different age groups is also essential to generalize the findings.

Additionally, involving parents and caregivers in the intervention process is advised to promote broader transfer of acquired skills into everyday contexts. Researchers should also evaluate the long-term sustainability of outcomes through post-intervention follow-ups. Finally, comparative studies are needed to examine the effectiveness of AI-based interventions versus traditional approaches in training joint attention (JA) skills, both to clarify the added value of smart technologies in this therapeutic field and to ensure that ethical considerations are carefully addressed.

6. Conclusion

AI-based interventions for individuals with ASD represent a promising and innovative approach that has drawn increasing attention from researchers, particularly after 2015, in parallel with the rapid advances in artificial intelligence. Nevertheless, only a limited number of studies have specifically targeted JA skills in ASD using AI. This paper reviewed the most relevant literature on the clinical applications of AI in enhancing JA skills in children with ASD, a research area that remains in its early stages despite encouraging outcomes. By synthesizing the results of intervention studies, this review sought to contribute to the growing body of knowledge in this emerging field of *AI and ASD*.

Overall, the findings suggest that most studies reported noticeable improvements in joint attention, particularly in RJA, with some also addressing both RJA and IJA. Additional positive effects included gains in social interaction and improved eye contact. However, the therapeutic impact remains inconsistent in terms of sustainability and generalization. This is largely due to the reliance on short-term interventions conducted in structured environments with small sample sizes, limiting their applicability to real-world contexts.

These limitations highlight the need for further research that incorporates long-term follow-up, naturalistic settings, and a broader range of targeted skills. Moreover, real-time interactive assessment within intervention sessions has proven essential for tailoring responses to individual needs and should remain a core component of future AI-based programs.

Compliance with Ethical Standards

For review studies, formal consent was not required.

Disclosure Statement

The authors declare no conflict of interest related to this review.

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