Psychiatria Danubina, 2024; Vol. 36, Suppl. 2, pp 361-370
Conference paper

Original research

VIRTUAL REALITY / AUGMENTED REALITY (VR/AR) APPROACH TO DEVELOP SOCIAL AND COMMUNICATION SKILLS IN CHILDREN AND ADOLESCENTS WITH AUTISM SPECTRUM DISORDERS WITHOUT INTELLECTUAL IMPAIRMENT

Darya Astafeva[1], Timur Syunyakov[1,2], Dmitrii Shapievskii[3], Evgeniia Malashonkova[4], Andrei Vlasov[1,3], Svetlana Shport[5], Roman Akhapkin[5], Zarifjon Ashurov[2], Aleksandr Kolsanov[6] & Daria Smirnova[1,3]

[1]International Centre for Education and Research in Neuropsychiatry (ICERN), Samara State Medical University, Samara, Russia

[2]Republican Specialized Scientific and Practical Medical Center of Mental Health, Tashkent, Uzbekistan

[3]Better Reality StartUp, Samara, Russia

[4]Division of Child and Adolescent Psychiatry, Department of Psychiatry, Groupe Hospitalier Nord Essonne, Orsay, France

[5]National Medical Research Center of Psychiatry and Narcology named after V. P. Serbsky, Moscow, Russia

[6]Samara State Medical University, Samara, Russia

SUMMARY

Background: *Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder that affects a significant proportion of the world's population, particularly children and adolescents. The sensory processing issues can be an evidence-based target for therapeutic/corrective interventions by controlling the intensity and targeted replacement of maladaptive sensory stimuli with neutral stimuli using virtual reality or augmented reality.*

Subjects and methods: *We searched for articles on Pubmed. The search query included ((VR or virtual reality) or (AR or augmented reality)) and (children or adolescents) and (ASD or autism spectrum disorder or autism).*

Results: *Our criteria were met by 25 articles. 19 articles used VR, 5 articles used AR and 1 article used MR. Most interventions offer children and adolescents with ASD individualized tasks. Immersive VR games developed collaborative skills. Other systems encourage and teach directed facial gaze. Evaluation of the effectiveness of learning in VR/AR environment is carried out by means of different scales, qualitative analysis of surveys, questionnaires and interviews, studying the number and duration of eye contacts between the participant and the avatar. It should be noted that almost all studies were conducted on small samples, so their results allow us to draw only preliminary conclusions about the effectiveness of VR /AR.*

Conclusions: *The following key areas of VR/AR technologies for children and adolescents with high-functioning ASD can be identified: communicating with an avatar, including answering its questions, tracking the child's gaze and encouraging the child to look at the face, placing it in social situations close to real life, practicing common everyday situations, learning to recognize emotions. A VR/AR-based therapy approach may help children with autism spectrum disorder without cognitive impairment to develop higher levels of adaptation in terms of social and communication skills. However, more research is needed to evaluate the effectiveness of different methods.*

Key words: *adolescents - Asperger's syndrome - AR - autism spectrum disorders - augmented reality - avatar - children - high-functioning autism - immersive environment - mixed reality - social and communication skills - social adjustment - virtual peer - virtual reality - VR*

Abbreviations: *ABC – the Autism Behavior Checklist; ADOS – Autism Diagnostic Observation Schedule; ASD – autism spectrum disorder; AR – augmented reality; CARS-II – Childhood Autism Rating Scale, Second Edition; MR – mixed reality; PEP-3 – Psychoeducational Profile, Third Edition; SCQ – the Social Communication Questionnaire Lifetime; SRS-2 – Social Responsiveness Scale, Second Edition; SSQ – Social Skills Questionnaire; VR – virtual reality; XR – extended reality*

* * * * *

INRODUCTION

Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder that affects a significant proportion of the world's population, particularly children and adolescents. Millions of children and adolescents around the world face the challenges posed by the disorder, particularly the inability to master language and effective social interaction skills (Hashim et al. 2021). Families with patients with ASD face significant direct and indirect costs, including medical therapy costs without truly effective medications, disability, and a reduced quality of life in general (Zhao et al. 2023). In the United States, the prevalence of autism spectrum disorder is estimated at 23.0 per 1,000 children aged 8, with boys affected 4.2 times more often than girls (Maenner et al. 2021). The increasing prevalence of ASD has been observed for many years, with the Centers for Disease Control and Prevention reporting a steady increase in the observed prevalence of autism among children and adolescents in the United States, which is a rate of 18.5 per 1,000 reached children in 2016 (Cantor et al. 2021). This increase in

prevalence can be attributed to a variety of factors, including increased awareness/ psychoeducation, changes in diagnostic criteria, and active research positions by scientific groups studying ASD. Thus, solving sensory processing problems can significantly influence the formation of adaptive functions and behaviors and improve learning ability (Hashim et al. 2021).

The sensory processing issues can be an evidence-based target for therapeutic/corrective interventions by controlling the intensity and targeted replacement of maladaptive sensory stimuli with neutral stimuli in real time using virtual reality (VR), augmented reality (AR), mixed reality (MR) or extended reality (XR) technology – with the important goal of development of behavioral skills, improving social adaptation and academic performance of children with ASD.

Cheng et al. reported AR provides increased opportunities for practice with reduced social pressure for students with ASD (Cheng et al. 2010). Parents and educators of children with ASD report more positive social interactions generalized into their environments from virtually delivered social skill interventions than traditional instruction from humans (Miller & Bugnariu 2016, Stichter et al. 2014). In another study, it was shown that the use of VR allowed teaching emotion recognition and communication skills to ASD patients more effectively (Miller et al. 2020, Moon et al. 2020). AR caused a statistical difference in the ability to identify the 6 core emotions for all participants (Chen et al. 2015). The results showed that it effectively attracted the attention of children with autism spectrum disorders to nonverbal social cues, helped to retain attention, and improved understanding of facial expressions and emotions of storybook characters (Chen & Lin 2016). AR significantly increased students' ability to recognize and understand relationships and appropriate responses to actions (Lee et al. 2018). AR has the potential to generalize instruction better and VR has the potential for providing a practice environment for performance deficits. Combining these two technologies may provide a more cohesive intervention (Mosher et al. 2021).

In our study, we plan to review the existing literature on the topic of VR and/or AR, MR, ER for the following questions:

- What VR and/or AR, MR, ER interventions for the development of social and communication skills in children and adolescents exist?
- What methods are used to evaluate their effectiveness?
- What is the existing evidence on their effectiveness?

SUBJECTS AND METHODS

We searched for articles on Medline (Pubmed) up to and including May 30, 2024. The search query included ((VR or virtual reality) or (AR or augmented reality)) and (children or adolescents) and (ASD or autism spectrum disorder or autism). Inclusion criteria: 1) VR and/or AR intervention for ASD is considered; 2) the target population is children and adolescents; 3) patients with intellectual disabilities are not considered. Exclusion criteria: 1) non-VR and/or AR intervention, MR, ER (computers, mobile devices, etc.; 2) in adults; 3) there are intellectual disabilities.

We found 644 articles. After excluding articles that did not meet the search criteria, 25 articles remained.

RESULTS

Our criteria were met by 25 articles. Among them, 19 articles used VR, 5 articles used AR and 1 article used MR. Figure 1 depicts a flow diagram detailing the review process and results at each stage of the literature search. Study characteristics are shown in Table 1 in detail.

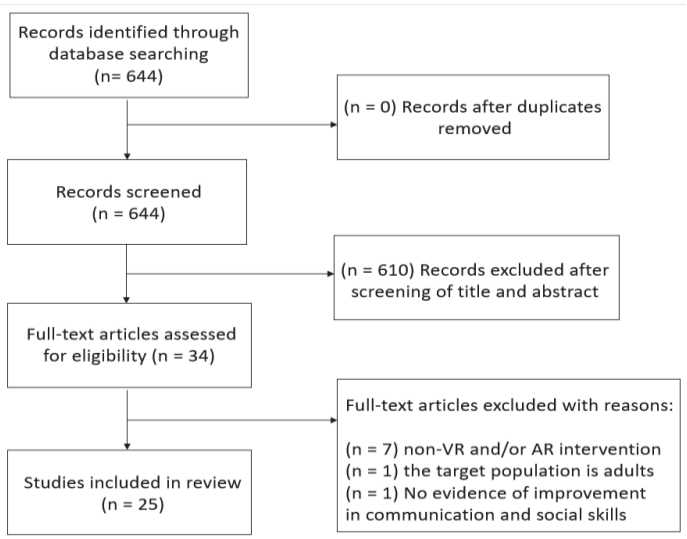

Figure 1. Flow chart for the study selection of meta-analyses on the VR/AR technologies for children and adolescents with high-functioning ASD

Table 1. Characteristics of included studies on the VR/AR technologies for children and adolescents with high-functioning ASD

Authors	Type of intervention	Description of intervention	Evaluation methods	Intellectual impairment	Results
Zhao J et al. 2022	VR	In the virtual scene, children had to hold the cursor on a target or answer questions according to instructions given by virtual characters in different scenes to move on to the next step.	PEP3	N/D	After the intervention, the cognitive abilities and social communication abilities of children in the intervention group were significantly higher than those in the control group.
Frolli A et al. 2022	VR	An intervention to improve emotional literacy using VR involved 3D projection of two sequences of scenes recorded with actors. In Intervention 1, the videos were projected through a 3D TV in VR. In intervention 2, the training included cardboard images used individually by the therapist.	ADOS 2- Modul 3	IQ ≥ 97	The time to acquire primary emotion recognition skills was similar for both intervention methods (VR and traditional). However, when performing tasks involving situations involving the use of primary and secondary emotions, the acquisition time was shorter when using VR.
Elkin TD et al. 2022	VR	The software system created a virtual school classroom to provide a social context for learning activities. The eye tracker measured the participant's gaze in the virtual environment. It tracked how often and how long the participant looked at the avatar's eyes, as well as where else the participant looked in the virtual environment. The avatar asked the participant a series of five questions.	The primary outcome is the number and duration of eye contacts between the participant and the avatar in VR. The secondary outcomes of this study are the number and duration of the child's gaze to the avatar's mouth and facial area.	N/D	Results showed that participants with moderate ASD made eye contact with the avatar more often than participants with mild ASD. It was found that individuals with moderate ASD showed an overall greater tendency to transfer their gaze to the floor after making eye contact with various points on the avatar's face than participants with mild ASD.
Yuan SNV & Ip HHS 2018	VR	Six training scenarios were developed, including a relaxation scenario, four training scenarios, and one consolidation scenario. The scenarios were designed to match as closely as possible the real life of a typical primary school-aged child in Hong Kong.	PEP-3	Children with documented intellectual impairment were excluded from the study.	The results of paired sample t-test showed that children from the training group scored higher on the indicators of expression and regulation of emotions after the training than before the training. Children from the training group also scored higher on indicators of social interaction and adaptation after training than before training.
Zhang L et al. 2020	VR	We developed a CVE system in which children with autism spectrum disorders played a tightly controlled series of games with both an AI and a TD partner. To elicit communicative and cooperative behavior, we conducted 9 trials with puzzles that required participants to communicate with each other and work together to successfully complete the game.	SRS-2 and SCQ	average IQ level	The results offer important preliminary support for the use of technological systems to independently identify and assess behaviors that do not occur in isolation in a virtual environment, but reflect skills exhibited in interaction.
Amat AZ et al. 2021	VR	An eye tracker and mouse recorded data on the participant's gaze in both games, as well as the movement of puzzle pieces in the Tangram Puzzle game.	SCQ and SRS-2	N/D	On average, children with ASD improved by 8 points in the posttest, which was closer to the TD children's game score in the pretest. However, this improvement was not statistically significant.

Notes: ABC – the Autism Behavior Checklist; ADOS – Autism Diagnostic Observation Schedule; ASD – autism spectrum disorder; AR – augmented reality; CARS-II – Childhood Autism Rating Scale, Second Edition; MR – mixed reality; PEP-3 – Psychoeducational Profile, Third Edition; SCQ – the Social Communication Questionnaire Lifetime; SRS-2 – Social Responsiveness Scale, Second Edition; SSQ – Social Skills Questionnaire; VR – virtual reality

Table 1. Continues

Authors	Type of intervention	Description of intervention	Evaluation methods	Intellectual impairment	Results
Cai Y et al. 2013	VR	Activities in the virtual world evolved around a set of social tasks in simulated shared social settings such as the neighbor's house, school, amusement parks, and other public places.	SCQ and SSQ	N/D	The study provided preliminary data on the positive effects of using a virtual reality-based social sandbox on practicing and developing complex social skills in children with ASD. All participants demonstrated a significant reduction in social communication impairment from pre- to post-intervention.
Simões M et al. 2020	VR	In trials in which the participant moved by himself/herself, he/she stopped at a distance at which he/she felt more comfortable. In other trials, the experimenter walked at a steady pace toward or away from the participant and was instructed to say the word "stop" whenever he/she felt the distance was appropriate. They could then adjust this distance by asking the experimenter to move a little closer or farther away.	Interpersonal distance	FSIQ 99.4	Loss of nuanced nonverbal communication, such as the perception of subtle body gestures in virtual environments, results in altered interpersonal distance regulation in the control group, while participants with ASD show similar impairments in the perception of such subtle cues in both environments.
Chu L et al. 2023	VR	VR-CBT consists of 6 stages: game perception, rule-based communication, interactive communication, cognitive training, response inhibition, and complex feedback.	ABC and CARS	IQ>70	After the intervention, there was an effect on total scores on the ABC and CARS scales. A similar trend was observed in the ABC subscales of social assistance and self-help.
Moon J & Ke F 2023	VR	VR training includes various tasks for social interaction in several social scenarios. Each session included one task with a unique scenario simulating real social situations.	SSQ	N/D	Self-rated SSQ scores of participants 1 and 2 improved while those of participants 3 and 4 decreased. The SSQ score obtained by the parents of participant 3 increased while the SSQ scores obtained by the parents of the other participants decreased. There were no statistically significant differences between pre- and post-intervention scores on either the self-report or parent-report SSQ scale.
Chung PJ et al. 2015	AR	The hypothesis was that active video games, compared to sedentary play, would result in increased joint positive affect, increased mutual communication, and decreased aggression in a dyad of a child with ASD and a typically developing sibling.	Primary measures were assessed using a coding guide with measures of positive affect, talk, and aggression as a measure of the social quality of the interaction between participants.	N/D	In one dyad, active video games was associated with an increase in joint positive affect, although this was not maintained across sessions. In other pairs, active video games resulted in unchanged or less social behavior.
Liu R et al. 2017	AR	Children and adults are trained to recognize emotions, directional face gaze, eye contact, and self-regulation of behavior. An augmented reality cartoon face is superimposed on these detected human faces in a way that catches the user's attention.	Caregiver observation	N/D	Caregivers noted improvements in nonverbal communication, eye contact, and social engagement during the intervention.

Notes: ABC – the Autism Behavior Checklist; ADOS – Autism Diagnostic Observation Schedule; ASD – autism spectrum disorder; AR – augmented reality; CARS-II – Childhood Autism Rating Scale, Second Edition; MR – mixed reality; PEP-3 – Psychoeducational Profile, Third Edition; SCQ – the Social Communication Questionnaire Lifetime; SRS-2 – Social Responsiveness Scale, Second Edition; SSQ – Social Skills Questionnaire; VR – virtual reality

Table 1. Continues

Authors	Type of intervention	Description of intervention	Evaluation methods	Intellectual impairment	Results
Soltiyeva A et al. 2023	VR	The system allows children to communicate with the "farmer", ask questions and receive feedback. Having received an answer from a participant, the virtual hero praises him for his answers. The project created a realistic 3D farm with animated pets and birds.	Qualitative analysis of participants' responses during the training session	N/D	The system is best suited for children with ASD group 4.
Gabrielli S et al. 2023	VR	The game is designed for small groups of adolescents in the presence of a therapist who acts as a facilitator in a virtual environment. The target behaviors related to social interaction that are trained in this task are sustained attention, selective attention, inhibition, and turn taking.	SSQ post-session observations Ad hoc user experience questionnaire and semi-structured interview	IQ≥70	Participants demonstrated significantly higher frequencies of positive social interaction and communicative competence after the intervention.
Soltani Kouhbanani S et al. 2021	VR	Recognizing colors and names of geometric shapes, self-care such as washing hands and brushing teeth, and developing fine motor skills such as tying shoelaces and putting on clothes.	CARS-II	IQ >70	Experimental groups had no significant differences in the posttest.
Lahiri U et al. 2013	VR	Participants were asked to try to make their classmate (i.e., avatar) feel as comfortable as possible during the presentation.	Participant engagement level	≥ 80 on PPVT-III	The results of the usability study show the ability of the system to help improve social task performance as well as encourage socially acceptable mechanisms for developing effective social communication skills.
Song W et al. 2017	VR	Learning a combination of gestures, and if the appropriate combination of gestures is done correctly, the dolphin will perform hoop jumps, pick up balloons, etc.	Interviews with special school teachers and parents of the tested children	N/D	Seven of the 11 child subjects showed a significant increase in their respective abilities, while 4 subjects showed a slight increase.
Ravindran V et al. 2019	VR	Users progress sequentially through the learning cards to achieve the goals associated with demonstrating the targeted joint attention sub-skills. An avatar in the virtual environment initiates and responds to requests for joint attention, and can verbally prompt the user when necessary to progress further through the learning card to achieve the goals.	Joint attention assessment	N/D	The joint attention assessment showed positive changes in participants' skills related to total number of interactions, use of eye contact, and interaction initiation.
Lahiri U et al. 2011a	VR	Participants were asked to imagine that the avatars were his/her classmates at school giving presentations on different topics. They were also asked to try to make their classmate feel as comfortable as possible while listening to the presentation.	gaze patterns	≥ 80 on PPVT-III	All participants (except ASD5) fixated on the face of their virtual classmates showing emotion. The physiological eye response of a participant's eyes in VR-based social interaction may indicate whether they are capable of recognizing emotions.

Notes: ABC – the Autism Behavior Checklist; ADOS – Autism Diagnostic Observation Schedule; ASD – autism spectrum disorder; AR – augmented reality; CARS-II – Childhood Autism Rating Scale, Second Edition; MR – mixed reality; PEP-3 – Psychoeducational Profile, Third Edition; SCQ – the Social Communication Questionnaire Lifetime; SRS-2 – Social Responsiveness Scale, Second Edition; SSQ – Social Skills Questionnaire; VR – virtual reality

Table 1. Continues

Authors	Type of intervention	Description of intervention	Evaluation methods	Intellectual impairment	Results
Lahiri U et al. 2011b	VR	Participants viewed the VR environment and avatars in the system from a first-person perspective. Gaze data as well as markers of task-related events (e.g., trial start/stop, participants' responses to system questions, etc.) were recorded in a time-synchronized manner.	Direction of gaze	≥ 80 on PPVT-III	All children were able to show improvements in terms of a) looking longer at the faces of virtual peers (avatars) and b) looking less long at non-social objects as they completed tasks while interacting with our system capable of providing feedback.
Crowell C et al. 2020	MR	Children hold a physical object, a butterfly net equipped with LED lights, which is tracked by the system and through which children interact with virtual elements projected on the floor.	Social behavior was coded using an observation grid	IQ 70	In the log files they saw that joint actions in the game coincided with social initiations with a higher frequency than single actions. This suggests that children working together on a common task enables children with autism to initiate a conversation with a partner.
Chen CH et al. 2015	AR	Participants answered each test question after viewing illustrations of scenes, chose a mask that matched the scenes, and watched 3-D AR facial expressions superimposed on their faces.	Identify facial expressions that correspond to emotions	IQ > 85	The difference in performance level between the baseline and intervention phases was significant for all participants. The mean difference in performance level between baseline and follow-up phases was significant.
Vahabzadeh A et al. 2018	AR	By continuously monitoring engagement indicators, such as the position of the user's head in relation to the facilitator, the system seeks to motivate and guide the user to remain attentive to the facilitator. The system does this, in particular, by providing the user with augmented reality prompts.	ABC	N/D	Improvements in irritability and hyperactivity scores were found depending on exposure to the intervention.
Kuriakose S & Lahiri U 2017	VR	Designed contextually relevant social situations, e.g., classroom, park, hotel, etc. and selected several 3D character faces (avatars) from the available database.	Plethysmogram, electrodermal activity and skin temperature	IQ was above average	An anxiety-sensitive VR system is able to provide training to improve some basic social communication skills for people with autism spectrum disorders in a simulated learning environment.
Nekar DM et al. 2022	AR	Cooperative games included tasks such as doubles tennis, 2 vs. 2 basketball, and a game in which two players work together to catch villains.	SRS-2	Ability to see, hear, and understand basic instructions; ability to read and understand the Korean language	There were statistically significant improvements on all subscales of social skills and cognitive function expected on two subscales of each outcome measured.

Notes: ABC – the Autism Behavior Checklist; ADOS – Autism Diagnostic Observation Schedule; ASD – autism spectrum disorder; AR – augmented reality; CARS-II – Childhood Autism Rating Scale, Second Edition; MR – mixed reality; PEP-3 – Psychoeducational Profile, Third Edition; SCQ – the Social Communication Questionnaire Lifetime; SRS-2 – Social Responsiveness Scale, Second Edition; SSQ – Social Skills Questionnaire; VR – virtual reality

DISCUSSION

Most interventions offer children and adolescents with ASD individualized tasks. For example, social skills training in social scenarios. In the work of Cai Y et al, activities in a virtual world evolved around a set of game and design-based social tasks situated in simulated shared social settings such as a neighbor's house, school, amusement parks, and other public places, as well as individualized tasks (e.g., underwater laboratory, sky city) (Cai et al. 2013). In Moon J & Ke F's study, the cafeteria social conflict resolution task asks children to identify a social conflict, come up with possible solutions, and communicate with NPCS and facilitators to resolve the problem, while the job interview scenario requires children to practice basic social skills during a virtual interview with avatars of school librarian candidates (Moon & Ke 2023). Participants may be required to hold the cursor on a target or answer questions as instructed (Zhao et al. 2022) or ask questions of the virtual character (Soltiyeva et al. 2023). Part of the studies used techniques teaching the correct identification of emotions (Chen et al. 2015, Frolli et al. 2022, Liu et al. 2017).

Immersive VR games, such as trials with puzzles, have been developed to develop collaborative skills and encourage joint problem solving; in some trials, only one user could see the color of the pieces; others required simultaneous movement of the pieces to successfully place the pieces (Zhang et al. 2020). Collaborative play can include tasks such as doubles tennis in which both players play on the same side, 2 vs 2 basketball in which two players play as teammates, and a game in which two players work together to catch villains (Nekar et al. 2022). Collaboration in the game can be encouraged by receiving new challenges or playing a fun tune, as in the virtual environment Lands of Fog, where children work together to catch butterflies with a net (Crowell et al. 2020). Scenarios can include narrative stories where adolescents work together in the presence of a therapist to practice sustained attention, selective attention, inhibition, queuing, and collaboration (Gabrielli et al. 2023). In addition to studies where cooperative work was practiced between children or adolescents with ASD, there was also one where a neurotypical sibling played active video games in a dyad with a child with ASD to increase mutual communication and reduce aggression (Chung et al. 2015).

Other systems encourage and teach directed facial gaze (Amat et al. 2021, Elkin et al. 2022, Lahiri et al. 2011b). They utilize an eye tracker. Participants need to look at the virtual avatar of the interlocutor to make the interlocutor “feel as comfortable as possible” (Lahiri et al. 2011a, 2013). The Brain Power System includes customized smartglasses that superimpose an augmented reality cartoon face over detected human faces to attract the user's attention, and when the user turns to look directly at the augmented reality cartoon, it gradually disappears, exposing the hidden human face (Liu et al. 2017). Empowered Brain continuously monitors engagement metrics such as the position of the user's head in relation to the facilitator and aims to motivate and guide the user to remain attentive to the facilitator. The system does this, in part, by providing the user with augmented reality cues that include displayed arrows pointing at the facilitator and caricature-like masks that are superimposed on the facilitator's face (Vahabzadeh et al. 2018).

In addition, one article trained sustained attention through interaction with a virtual dolphin (waving, feeding, gesture communication) (Song et al. 2017). Another study investigated interpersonal interaction distance (Simões et al. 2020).

To assess the effectiveness of the interventions, firstly, scales were used to quantify communication skills in scores. In the three articles reviewed, the Social Responsiveness Scale, Second Edition (SRS-2) was used. The Social Communication Questionnaire Lifetime (SCQ), the Autism Behavior Checklist (ABC), the PEP-3, and the social skills questionnaire (SSQ) were used in two cases. In one study, the CARS-II scale was used and in another study, the ADOS 2-Module 3 scale was used. Second, specific questionnaires and questionnaires were developed: for example, a specific user experience questionnaire or a semi-structured interview conducted with participants after each session to collect feedback on their satisfaction with the VR game and suggestions for improvement. Third, the number and duration of eye contacts between the participant and the avatar in VR was investigated, in particular the number and duration of the child's gaze on the avatar's mouth and facial area. Fourth, participant engagement was investigated, such as the level of engagement during a recently completed trial of the task. Fifth, social interactions were assessed: interaction distance, measures of positive affect, talk and aggression, scoring instances of social reciprocity (initiating, responding, continuing the conversation after two turns, comments, questions, requests, protests and refusals), responding to a greeting, shifting gaze in response to a pointing, and instances of prolonged eye contact with a person or object. Other methods may include ways to assess anxiety and stress: pulse plethysmogram, electrodermal activity, and skin temperature.

It should be noted that almost all studies were conducted on small samples, so their results allow us to draw only preliminary conclusions about the effectiveness of VR /AR technologies. However, these findings suggest the feasibility of larger studies with a unified design.

For example, in studies that examined cognitive abilities and social communication skills using the PEP3 questionnaire, after they were significantly higher than controls (Zhao et al. 2022). In another study, on average, children with autism improved their performance by 8 points in the posttest, which was closer to the play score of neurotypical children in the pretest (Amat et al. 2021). In the Cai Y et al. study, all participants showed significant reductions in social communication impairment from pre-

to post-intervention (Cai et al. 2013). Self-rated SSQ scores for participants 1 and 2 improved, while participants 3 and 4 decreased. The SSQ score obtained by the parents of participant 3 increased, while the SSQ scores obtained by the parents of the other participants decreased. There were no statistically significant differences between pre- and post-intervention scores on either the self-report or parent-report SSQ scale (Moon & Ke 2023). Caregivers reported improvements in nonverbal communication, eye contact, and social engagement during the intervention (Liu et al. 2017). After the intervention, an effect of the intervention on total scores on the ABC and CARS scales was observed, the intervention also showed a statistically significant effect in behavioral improvement (Chu et al. 2023). In a study by Gabrielli S et al, participants demonstrated a significantly higher frequency of positive social interaction and communicative competence after the intervention (Gabrielli et al. 2023). The results of the Lahiri U et al. study demonstrate the ability of the system to promote improved social task performance (e.g., quantitative improvement in performance metrics) as well as encourage socially appropriate mechanisms (e.g., increased viewing of the communicator's face) to develop effective social communication skills among participants with autism spectrum disorders (Lahiri et al. 2013). No significant difference was found between the number of initiations made by children with ASD between the Lands of Fog play sessions and the control condition, although it was noted that children working together on a common task motivated children with ASD to initiate a conversation with a partner (Crowell C et al. 2020). Students in the implementation and efficacy phases showed improvements (decreases) in irritability, hyperactivity, and social withdrawal compared to baseline and control periods respectively on the ABC subscale (Vahabzadeh et al. 2018). In a study by Nekar DM et al. statistically significant improvements were observed in all subscales of social skills and cognitive function (Nekar et al. 2022).

What about recognizing and expressing emotions? Learning times for recognizing primary emotions appeared to be similar for the VR and control groups, but for tasks involving situations involving the use of primary and secondary emotions, mastery times were shorter with VR (Frolli et al. 2022). Children in the training group showed higher scores on measures of emotion expression and regulation, as well as measures of social interaction and adaptation after training (Yuan & Ip 2018). The difference in performance level (identify facial expressions corresponding to emotions) between the baseline and intervention phases was significant for all participants (Chen et al. 2015). The results also suggest that the physiological eye response of a participant's eyes in VR-based social interaction may indicate whether they are able to recognize emotions, which is similar to what was observed in non-VR-based tasks.

The subject children's movements became more coordinated and their attention span increased significantly (Song et al. 2017). Assessment of joint attention showed positive changes in participants' skills related to total number of interactions, use of eye contact, and initiating interactions (Ravindran et al. 2019). Children showed improvements in terms of a) longer looking at the faces of virtual peers (avatars) and b) less prolonged looking at non-social objects as tasks progressed (Lahiri et al. 2011b).

Parents reported that the program improved their children's social interactions on a daily basis and expressed a desire for their children to remain in the program even after participation in the study ended (Moon & Ke 2023). The virtual reality system worked best for children with autism spectrum disorders in group 4: a girl with autism spectrum disorders group 2 screamed and resisted the first time she tried to put on the virtual reality goggles, and children in autism spectrum disorders group 1 with an anxiety disorder refused and were afraid to put on the VR headset (Soltiyeva et al 2023). Combining VR with risperidone therapy achieved significant differences in social skills and behavioral symptoms compared to the control group, although the experimental groups had no significant differences in the posttest (Soltani Kouhbanani et al. 2021).

CONCLUSIONS

When analyzing the literature, the following key areas of VR/AR technologies for children and adolescents with high-functioning ASD can be identified: communicating with an avatar, including answering its questions, tracking the child's gaze and encouraging the child to look at the face, especially at its key areas, placing it in social situations close to real life, practicing common everyday situations, learning to recognize emotions, encouraging interest in the interlocutor, learning to respond to the interlocutor's behavior. Feedback includes a reward system using sounds, scoring. Hints from leading to more direct are given. Special mention should be made of cooperative games of several children, where communication with a real person (another child with ASD or a neurotypical sibling) is initiated within the VR environment.

Evaluation of the effectiveness of learning in VR/AR environment is carried out by means of scales (SRS-2, SCQ, ABC, PEP-3, SSQ, CARS-II, ADOS 2-Module 3), qualitative analysis of surveys, questionnaires and interviews, studying the number and duration of eye contacts between the participant and the avatar in VR, evaluation of social interactions.

It should be noted that almost all studies were conducted on small samples, so their results allow us to draw only preliminary conclusions about the effectiveness of VR/AR technologies. However, these findings suggest the feasibility of larger studies with a unified design. For example, in studies where cognitive ability and social communication skills were trained, they were significantly higher after the intervention than in the control

group, there was a significant reduction in social communication impairment from the pre- to post-intervention stage, but in other studies there were no statistically significant differences between pre- and post-intervention scores, either by self-report or parental report. That said, parents reported that VR/AR programs improved their children's social interaction on a daily basis.

Limitations of the study

We considered studies with small samples. The small sample was probably due to the pilot nature of the studies, improvement of the design based on subject involvement, and refinement of the designs. There is a need for a unified design for such studies and a large sample study to prove the efficacy of VR, AR, and MR interventions for high-functioning autism in children and adolescents.

Funding:

Current study is a part of the complex longitude multidisciplinary project "Innovative Neuropsychiatry Research Bank" which is supervised by the International Centre for Education and Research in Neuropsychiatry (ICERN PI - Daria Smirnova), and supported by the grant Priority-2030 for Samara State Medical University (№ 075-15-2023-241, dated from 13th February 2023).

Acknowledgements:

The authors express gratitude to Prof. Paul Cumming of Bern University Hospital for critical reading of the manuscript.

Conflict of interest: *None to declare.*

Contribution of individual authors:

Darya Astafeva, Timur Syunyakov, Dmitrii Shapievskii & Daria Smirnova formulated the primary idea, elaborated the research hypothesis and fixed the keywords search algorithm.

Timur Syunyakov & Daria Smirnova designed the study, searched and reviewed literature, extracted data from the studies.

Darya Astafeva & Timur Syunyakov wrote the first draft of the manuscript.

Timur Syunyakov, Dmitrii Shapievskii, Evgeniia Malashonkova, Andrei Vlasov, Svetlana Shport, Roman Akhapkin, Zarifjon Ashurov, Aleksandr Kolsanov & Daria Smirnova contributed to the detailed revision, as well as approved the final version of the article for its submission.

References

1. *Amat AZ, Zhao H, Swanson A, Weitlauf AS, Warren Z, Sarkar N: Design of an interactive virtual reality system, InViRS, for joint attention practice in autistic children. IEEE Trans Neural Syst Rehabil Eng 2021; 29:1866-1876. doi:10.1109/TNSRE.2021.3108351*
2. *Cai Y, Chia NK, Thalmann D, Kee NK, Zheng J, Thalmann NM: Design and development of a Virtual Dolphinarium for children with autism. IEEE Trans Neural Syst Rehabil Eng 2013; 21:208-17. doi:10.1109/TNSRE.2013.2240700*
3. *Cantor J, McBain R, Kofner A, Stein B & Yu H: Where are us outpatient mental health facilities that serve children with autism spectrum disorder? A national snapshot of geographic disparities. Autism 2021; 26:169-177. doi:10.1177/13623613211024046*
4. *Chen CH, Lee IJ, Lin LY: Augmented reality-based self-facial modeling to promote the emotional expression and social skills of adolescents with autism spectrum disorders. Res Dev Disabil 2015; 36C:396-403. doi:10.1016/j.ridd.2014.10.015*
5. *Chen I & Lin LY: Augmented reality-based video-modeling storybook of nonverbal facial cues for children with ASD to improve their perceptions and judgments of facial expressions & emotions. Computers in Human Behavior 2016; 55:477-485. doi:10.1016/j.chb.2015.09.033*
6. *Chen JL, Leader G, Sung, C & Leahy M: Trends in employment for individuals with autism spectrum disorder: a review of the research literature. Review Journal of Autism and Developmental Disorders 2015; 2:115-127. doi:10.1007/s40489-014-0041-6*
7. *Cheng Y, Chiang HC, Ye J & Cheng LH: Enhancing empathy instruction using a collaborative virtual learning environment for children with autistic spectrum conditions. Computers & Education 2010; 55:1449-1458. doi:10.1016/j.compedu.2010.06.008*
8. *Chu L, Shen L, Ma C, Chen J, Tian Y, Zhang C et al.: Effects of a nonwearable digital therapeutic intervention on preschoolers with autism spectrum disorder in China: open-label randomized controlled trial. J Med Internet Res 2023; 25:e45836. doi:10.2196/45836*
9. *Chung PJ, Vanderbilt DL, Soares NS: Social behaviors and active videogame play in children with autism spectrum Games Health J 2015; 4:225-34. doi:10.1089/g4h.2014.0125*
10. *Crowell C, Sayis B, Benitez JP, Pares N: Mixed reality, full-body interactive experience to encourage social initiation for autism: comparison with a control nondigital intervention. Cyberpsychol Behav Soc Netw 2020; 23:5-9. doi:10.1089/cyber.2019.0115*
11. *Elkin TD, Zhang Y, Reneker JC: Gaze fixation and visual searching behaviors during an immersive virtual reality social skills training experience for children and youth with autism spectrum disorder: a pilot study. Brain Sci 2022; 12:1568. doi:10.3390/brainsci12111568*
12. *Frolli A, Savarese G, Di Carmine F, Bosco A, Saviano E, Rega A et al.: Children on the autism spectrum and the use of virtual reality for supporting social skills. Children (Basel) 2022; 9:181. doi:10.3390/children9020181*
13. *Gabrielli S, Cristofolini M, Dianti M, Alvari G, Vallefuoco E, Bentenuto A et al.: Co-design of a virtual reality multiplayer adventure game for adolescents with autism spectrum disorder: mixed methods study. JMIR Serious Games 2023; 11:e51719. doi:10.2196/51719*
14. *Hashim UH, Yunus MM & Norman H: Augmented reality mobile application for children with autism. Stakeholders' Acceptance and Thoughts. Arab World English Journal 2021; 12:132-141. doi:10.24093/awej/vol12no4.9*
15. *Kuriakose S & Lahiri U: Design of a physiology-sensitive VR-based social communication platform for children with*

autism. IEEE Trans Neural Syst Rehabil Eng 2017; 25:1180-1191. doi:10.1109/TNSRE.2016.2613879

16. *Lahiri U, Bekele E, Dohrmann E, Warren Z, Sarkar N: Design of a virtual reality based adaptive response technology for children with autism. IEEE Trans Neural Syst Rehabil Eng 2013; 21:55-64. doi:10.1109/TNSRE.2012.2218618*
17. *Lahiri U, Trewyn A, Warren Z, Sarkar N: Dynamic eye gaze and its potential in virtual reality-based applications for children with autism spectrum disorders. Autism Open Access 2011b; 1:1000101. doi:10.4172/2165-7890.1000101*
18. *Lahiri U, Warren Z, Sarkar N: Design of a gaze-sensitive virtual social interactive system for children with autism. IEEE Trans Neural Syst Rehabil Eng 2011a; 19:443-52. doi:10.1109/TNSRE.2011.2153874*
19. *Lee IJ, Chen CH, Wang CP & Chung CH: Augmented reality plus concept map technique to teach children with ASD to use social cues when meeting and greeting. The Asia-Pacific Education Researcher 2018; 27:227-243. doi:10.1007/s40299-018- 0382-5*
20. *Liu R, Salisbury JP, Vahabzadeh A, Sahin NT: Feasibility of an autism-focused augmented reality smartglasses system for social communication and behavioral coaching. Front Pediatr 2017; 5:145. doi:10.3389/fped.2017.00145*
21. *Maenner MJ, Shaw KA, Bakian AV, Bilder DA, Durkin MS, Esler A et al.: Prevalence and characteristics of autism spectrum disorder among children aged 8 years - autism and developmental disabilities monitoring network, 11 Sites, United States, 2018. MMWR Surveill Summ 2021; 70:1-16. doi:10.15585/mmwr.ss7011a1*
22. *Miller H & Bugnariu NL: Level of immersion in virtual environments impacts the ability to assess and teach social skills in autism spectrum disorder. Cyberpsychology & Behavior 2016; 19:246–256. doi:10.1089/cyber.2014.0682*
23. *Miller I, Wiederhold BK, Miller CS & Wiederhold MD: Virtual reality air travel training with children on the autism spectrum: a preliminary report. Cyberpsychology, Behavior, and Social Networking 2020; 23:10-15. doi:10.1089/cyber.2019.0093*
24. *Moon J & Ke F: Effects of adaptive prompts in virtual reality-based social skills training for children with autism. J Autism Dev Disord 2023. doi:10.1007/s10803-023-06021-7*
25. *Moon J, Ke F & Sokolikj Z: Automatic assessment of cognitive and emotional states in virtual reality-based flexibility training for four adolescents with autism. Br J Educat Tech 2020; 51:1766-1784. doi:10.1111/bjet.13005*
26. *Mosher MA, Carreon AC, Craig SL & Ruhter LC: Immersive technology to teach social skills to students with autism spectrum disorder: a literature review. Rev J Autism Dev Disord 2022; 9:334–350. doi:10.1007/s40489-021-00259-6*
27. *Nekar DM, Kang H, Alao H, Yu J: Feasibility of using multiplayer game-based dual-task training with augmented reality and personal health record on social skills and cognitive function in children with autism. Children (Basel) 2022; 9:1398. doi:10.3390/children9091398*
28. *Ravindran V, Osgood M, Sazawal V, Solorzano R, Turnacioglu S: Virtual reality support for joint attention using the Floreo joint attention module: usability and feasibility pilot study. JMIR Pediatr Parent 2019; 2:e14429. doi:10.2196/14429*
29. *Simões M, Mouga S, Pereira AC, de Carvalho P, Oliveira G, Castelo-Branco M: Virtual reality immersion rescales regulation of interpersonal distance in controls but not in autism spectrum disorder. J Autism Dev Disord 2020; 50:4317-4328. doi:10.1007/s10803-020-04484-6*
30. *Soltani Kouhbanani S, Khosrorad R, Zarenezhad S, Arabi SM: Comparing the effect of risperidone, virtual reality and risperidone on social skills, and behavioral problems in children with autism: a follow-up randomized clinical trial. Arch Iran Med 2021; 24:534-541. doi:10.34172/aim.2021.76*
31. *Soltiyeva A, Oliveira W, Madina A, Adilkhan S, Urmanov M, Hamari J: My Lovely Granny's Farm: An immersive virtual reality training system for children with autism spectrum disorder. Educ Inf Technol (Dordr) 2023; 20:1-21. doi:10.1007/s10639-023-11862-x*
32. *Song W, Sun Y, Yu D: Three-dimensional virtual dolphin treatment system for children with autism spectrum disorder. Sheng Wu Yi Xue Gong Cheng Xue Za Zhi 2017; 34:602-605. Chinese. doi:10.7507/1001-5515.201608008*
33. *Stichter J, Laffey J, Galyen K & Herzog M: Isocial: Delivering the social competence intervention for adolescents (SCIA) in a 3D virtual learning environment for youth with high functioning autism. Journal of Autism and Developmental Disorders 2014; 44:417-430. doi:10.1007/s10803-013-1881-0*
34. *Vahabzadeh A, Keshav NU, Abdus-Sabur R, Huey K, Liu R, Sahin NT: Improved socio-emotional and behavioral functioning in students with autism following school-based smartglasses intervention: multi-stage feasibility and controlled efficacy study. Behav Sci (Basel) 2018; 8:85. doi:10.3390/bs8100085*
35. *Yuan SNV & Ip HHS: Using virtual reality to train emotional and social skills in children with autism spectrum disorder. London J Prim Care (Abingdon) 2018; 10:110-112. doi:10.1080/17571472.2018.1483000*
36. *Zhang L, Weitlauf AS, Amat AZ, Swanson A, Warren ZE, Sarkar N: Assessing social communication and collaboration in autism spectrum disorder using Intelligent collaborative virtual environments. J Autism Dev Disord 2020; 50:199-211. doi:10.1007/s10803-019-04246-z*
37. *Zhao Y, Luo Y & Zheng X: Direct and indirect costs for families of children with autism spectrum disorder in China. Autism 2023; 27:2337-2347. doi:10.1177/13623613231158862*
38. *Zhao J, Zhang X, Lu Y, Wu X, Zhou F, Yang S et al.: Virtual reality technology enhances the cognitive and social communication of children with autism spectrum disorder. Front Public Health 2022; 10:1029392. doi:10.3389/fpubh.2022.1029392*

Correspondence:
Darya Astafeva, MD
International Centre for Education and Research in Neuropsychiatry (ICERN),
Samara State Medical University
78 Nagornaya Street, 443079 Samara, Russia
E-mail: dashasumburova@gmail.com