DOI: https://doi.org/10.17816/KMJ593044

Using immersive virtual environments for teaching and socializing children with autism spectrum disorder

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ABSTRACT

The authors' research interests are focused on the development of preschool children with autism spectrum disorder and the potential of virtual reality technologies for teaching and developing children in a gaming environment. The article reviews articles published in peer-reviewed journals and posted in the Scopus database and the Google Scholar search engine for scientific publications over the past 10 years. The objective of the review is to identify international research experience regarding the impact of virtual environments and hardware on children with autism spectrum disorder, their potential effectiveness, recommended conditions and limitations of using virtual reality for social adaptation, development of communication, cognitive and motivational skills. The articles analyzed in the review focus on the following issues: the potential and results of using different types of virtual reality technologies for developing various skills and abilities in children with autism; using virtual reality to work with problems and risks; as well as the features, limitations and safety of using virtual reality headsets by children with autism spectrum disorder. It is recommended to use immersive virtual environments for children with autism under the following conditions: the presence of close and trusted people (caregivers or parents), the presence of real game objects for switching children after exiting the virtual environment and distracting attention from possible negative effects of using gadgets, continuing communication with the child after a virtual reality session in a normal physical space to practice the skill being taught, specific time limits for staying in the virtual environment, etc. It is concluded that the results of using virtual reality technologies remain contradictory, but valid data from scientific research allow us to assert that the use of immersive virtual environments is acceptable, can be effective for teaching children with autism spectrum disorder and, if certain conditions are met, is adequately perceived by them.

Keywords: autism spectrum disorder; autism; virtual reality technologies; video games; child development; spatial learning.

To cite this article:
Kugurakova VV, Guzelbaeva GYa, Sadretdinova EA, Boltushkin AA. Using immersive virtual environments for teaching and socializing children with autism spectrum disorder. *Kazan Medical Journal.* 2024;105(5):782–796. doi: https://doi.org/10.17816/KMJ593044

Received: 26.09.2023 **Accepted**: 22.06.2024 **Published**: 02.10.2024

ECO • VECTOR

DOI: https://doi.org/10.17816/KMJ593044
УДК 616.896: 004.946: 347.157

Использование иммерсивных виртуальных сред для обучения и социализации детей с расстройством аутистического спектра

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АННОТАЦИЯ

Исследовательский интерес авторов статьи направлен на развитие детей дошкольного возраста с расстройством аутистического спектра и возможности технологий виртуальной реальности для обучения и развития детей в игровой среде. Сделан обзор статей, опубликованных в рецензируемых журналах и размещённых в базе данных Scopus и поисковой системе по научным публикациям Google Scholar за последние 10 лет. Цель обзора — выявление международного исследовательского опыта относительно влияния виртуальных сред и аппаратного обеспечения на детей с расстройством аутистического спектра, их потенциальной эффективности, рекомендуемых условий и ограничений применения виртуальной реальности для социальной адаптации, развития коммуникативных, когнитивных и мотивационных навыков. Проанализированные в обзоре статьи сконцентрированы на изучении следующих вопросов: возможности и результаты применения разных типов технологий виртуальной реальности для развития у детей с аутизмом различных навыков и способностей; использование виртуальной реальности для работы с проблемами и рисками; а также особенности, ограничения и безопасность использования гарнитур для виртуальной реальности детьми с расстройством аутистического спектра. Рекомендовано использование иммерсивной виртуальной среды для детей с аутизмом при следующих условиях: присутствие близких и доверенных людей (воспитателей или родителей), наличие реальных игровых объектов для переключения детей после выхода из виртуальной среды и отвлечения внимания от возможных негативных эффектов использования гаджетов, продолжение общения с ребёнком после сеанса виртуальной реальности в обычном физическом пространстве для практики обучаемого навыка, конкретные временные пределы пребывания в виртуальной среде и др. Сделан вывод о том, что результаты применения технологий виртуальной реальности остаются противоречивыми, однако валидные данные научных исследований позволяют утверждать, что использование иммерсивных виртуальных сред приемлемо, может быть эффективным для обучения детей с расстройством аутистического спектра и при соблюдении определённых условий адекватно ими воспринимается.

Ключевые слова: расстройство аутистического спектра; аутизм; технологии виртуальной реальности; видеоигры; развитие ребёнка; пространственное обучение.

Как цитировать:
Кугуракова В.В., Гузельбаева Г.Я., Садретдинова Э.А., Болтушкин А.А. Использование иммерсивных виртуальных сред для обучения и социализации детей с расстройством аутистического спектра // Казанский медицинский журнал. 2024. Т. 105, № 5. С. 782–796. doi: https://doi.org/10.17816/KMJ593044

Рукопись получена: 26.09.2023 **Рукопись одобрена**: 22.06.2024 **Опубликована**: 02.10.2024

INTRODUCTION

Autism spectrum disorder (ASD) is a severe disorder. Modern medicine and psychology are undertaking interventions aimed at improving the daily lives of patients with ASD [1, 2]. Over the past few decades, data indicate a significant increase in the prevalence of ASD [3, 4]. According to latest estimates, autism is detected in 1 in 100 children (1/100) worldwide [5]. In 2022, according to the all-Russian monitoring of the state of education of students with ASD, the number of children with ASD has increased by 187% over the previous 5 years and amounted to 45,888 people [6], although a comparison with global statistics may indicate an insufficient detection of pediatric patients with ASD in Russia and uneven development of the diagnostic system in different regions [7].

ASD is a relevant problem, owing to the increase of its prevalence worldwide, objectively recorded in recent years, and the lack of a unified theory of their etiopathogenesis and complexity of diagnostics and complex therapy [3, 8]. The social significance of ASD is determined by the fact that the core of its symptoms violates social interaction; the life prognosis is not considered favorable in 60%–70% of children and adolescents who require constant external assistance [9]; and the life path of many individuals with autism, from infancy to adulthood, is difficult for them and their families [10].

Pediatric patients with ASD, who differ from neurotypical children in various clinical and psychological characteristics regarding development of intelligence, communication skills, independence, and learning opportunities, represent one of the most complex categories of people with disabilities in terms of social development and from the standpoint of their psychological and pedagogical support [11, 12].

Presently, one of the trends in the field of autism research is expanding educational opportunities for people with autism and their productive development using new technologies [4, 13–15]. Immersive virtual environments that is, simulations of the real world based on three-dimensional (3D) computer graphics, is potentially a relatively safe and effective learning environment for individuals with autism [16–20].

Spatial learning can promote the socialization of children with impaired communication abilities and skills. However, in recent years, several experimental studies have revealed advantages and difficulties in the use of spatial learning and virtual reality (VR) technologies for people with autism [13, 21–26].

The problems were associated with possible side effects and limitations when using immersive environments recreated using VR [20, 27, 28]. Some difficulties may be due to the fact that interaction with virtual objects in immersive environments and navigation in them are supported by processes that rely on perceptual, motor, and cognitive systems [29–31]. Experts highlighted the adverse emotional consequences of interaction with gadgets, video games, and VR, such as sleep disturbances, obesity [32, 33], and depression [34, 35].

To implement practical work on teaching pediatric patients with ASD, it is crucial to analyze the global experience of existing developments and studies on the use of VR technologies for the development of children and adolescents with ASD [36–42].

In recent years, specialists in the fields of medicine, psychology, and neuroscience have conducted various tests and experiments to investigate the impact of IT technologies[1] and computer games on children and adolescents. The present study evaluated VR training and socialization methods aimed at helping pediatric patients with ASD and identified the conditions for their successful use for developing various skills [4, 43–46]. The use of VR technologies is practiced in clinical studies for the diagnosis and treatment of children and young people with autism [20, 41, 47, 48].

Projects that study the effectiveness of interventions with gadgets for the development of social and communicative abilities of children and adolescents with ASD [1, 49–52] and their cognitive, adaptive, navigational, professional, and other skills [18, 19, 33, 53] and assess their risk when using VR and identify ways to reduce them should be considered [27, 54, 55].

Recently, owing to the theory and movement of neurodiversification (neurodiversity), ASD has been regarded an alternative path of neurodevelopment and not a disorder requiring treatment [56–59]. In working with people with autism, critical tasks include social adaptation, development of various skills, etc.; thus, specialists of biomedicine actively collaborate with psychologists and teachers [11, 12, 59].

Using global experience in the application of VR in cases of ASD can be useful for expanding the learning opportunities for children with autism using new technologies. Analysis of the results of international studies is beneficial for increasing the efficiency of the relevant educational and developmental methods and allows to take into account the conditions and limitations of VR applications and games.

Based on this, the international experience of using digital methods and spatial educational simulations to develop communicative, cognitive, motivational, and other skills in pediatric patients with ASD was analyzed, as well as possible positive, neutral, and negative consequences of using VR and emerging ethical issues and concerns of doctors, psychologists, teachers, and parents.

Articles on the use of VR for teaching children with autism published over the past 10 years (since 2013) in the English language in peer-reviewed journals were selected. The principle of selecting studies consisted of searching and selecting articles by terms and keywords, namely, “virtual reality,” “virtual environment,” “device,” “VR,” and “HMD” (head-mounted display or helmet or glasses of virtual reality) for VR; “child,” “children,” “adolescents,” and “students” to denote childhood; and “autism,” and “ASD” to denote ASD.

The interdisciplinary research database Scopus was

[1] IT (information technology)—the use of computer systems or devices to transmit information.

searched. The identification of publications was expanded using the Google Scholar search engine for scientific publications, including the "snowball" technique, which tracked citations in the already selected articles. Moreover, the professional network for scientists and researchers ResearchGate was used to request the full text of articles if unavailable.

Publications that did not provide clear criteria for conducting research, analyzing results, or comparing data were excluded. Overall, 45 sources were analyzed. The geography of the projects reviewed covered the USA, Canada, European countries (i.e., Great Britain, Germany, Italy, Spain, Portugal, the Netherlands, Belgium, and Norway), Asian countries (i.e., China, India, Iran, Singapore, Taiwan, and Japan), Australia, New Zealand, and African countries (Nigeria and Ethiopia).

Types of systems and virtual technologies. VR technology represents a complex technology that allows individuals to immerse themselves in an immersive (providing the effect of presence) virtual world using specialized devices. It creates the effect of presence in another space and ensures the maximum level of plausibility of what is happening.

VR constructs an artificial world transmitted to the user through vision, hearing, touch, and other sensations [21, 25, 37]. A person interacts with a new environment, can manipulate objects, and performs various tasks.

Different variations of VR technologies can be used for various tasks in teaching children with autism. It is possible to interact with VR with the effect of full immersion, which indicates high detail of the interactive world, recognition of user actions in real time, and the presence of special equipment [25, 27]. Furthermore, VR without immersion is possible, which means simulating reality with high-quality sound and image, which are broadcasted to a widescreen, and the user remains only an observer [25, 27]. Other types of VR represent a virtual environment with a generalized infrastructure based on Internet technologies.

A separate option is augmented reality, which involves adding virtual elements to the real world and integrating information with real-world objects using text, computer graphics, audio, and other representations [13, 14, 18, 60]. Augmented-reality technology allows for expanded user interaction with the environment and adaptation of information depending on changing conditions. The types of VR technologies include head-mounted displays (VR helmets or glasses), tactile technologies, augmented reality, 3D display technologies, and network systems [4, 25, 27, 61].

Specialists from the University of Missouri (USA) working with ASD patients [36] analyzed the various possibilities of VR in developing behavioral skills through adaptation to various risks in children and adolescents with ASD. An advantage of VR was found to be the enhanced effect of presence. This is provided by improved navigation, implemented as an increase in the degrees of freedom of virtual movement, photorealism, and a wider field of view and a higher level of architectural detail compared to traditional tools. Enhanced sense of presence is critical for people with behavioral problems, including those with ASD.

Spanish psychologists and educators from the University of Alicante [1] used immersive VR to improve and train the emotional skills of primary school students with ASD. The used game form of VR intervention with a computer vision system for the automatic detection of the child's emotional state showed positive results in the development of emotional response and participation in pediatric patients with ASD, indicating the good perspectives of its use.

In a study in 2019, the same group of Spanish researchers used augmented reality based on visual support to improve the social and communication skills of children with autism. The study participants were offered games with scoring goals and playing with a cow. The experimental group used the augmented-reality application, whereas the other group played without it. Although improvements were recorded in some parameters, the results based on the quantitative approach did not show significant differences between the experimental and control group participants (all participants were pediatric patients with ASD) [60].

In another study conducted in 2022 by the same research team, the skills of daily functioning were investigated using the augmented-reality application Onirix [14]. The authors withdrew from the quantitative strategy and based their conclusions on the test data of the pediatric participants before and after the intervention and detailed field notes. In the posttest, improvements in the operations of daily functioning caused by working with augmented reality in several fields, such as eye contact and responses to the therapist's voice, were noted. Similar findings on the use of augmented reality for skill development in children with autism were observed in a study by Tabataba'i University in Iran [13].

A study by researchers from the University of the West of England (UK) [23] presented the experience of using VR head-mounted displays (helmets or glasses) in schools with children with ASD. The study involved 31 children with autism aged 6–16 years. Based on the children's reports after the VR sessions, their impressions of the type of VR device were determined, taking into account the sensory problems, convenience, and attractiveness of using a VR helmet.

The use of VR head-mounted displays was generally positively perceived by both children and teachers. Several advantages of this device were identified, including increased engagement, motivation, and attention and improved social communication and language skills. The study indicated that the use of VR helmets or glasses is a promising approach for developing learning and social communication in autistic children in a school environment.

Another case of using a head-mounted display was presented by doctors from Holland Bloorview Children's Rehabilitation Hospital in Toronto, Canada [24], with an assessment of its safety and ease of use compared to a video displayed on a monitor. It was observed that it had negative effects similar to those of watching a video on a monitor. Although the participants noted that the VR head-mounted display increases realism and a sense of presence, further research, clarification, and testing are warranted.

An international team of doctors, psychologists, and teachers from Norway, the USA, Germany, and Singapore [37] presented proposals for combining VR technologies with approaches to naturalistic behavioral developmental interventions, which the authors assessed as the most promising technique for pediatric patients with ASD. The new term "virtual naturalistic developmental behavioral interventions" was introduced. Previous researchers used only some elements of naturalistic developmental behavioral intervention approaches in VR interventions [37].

The authors of the project under consideration identified several main components of this type of intervention.

One of them is the nature of learning goals, which involves teaching various skills simultaneously, rather than teaching elements separately. The emphasis is on teaching competencies that guide other types of behavior, such as social communication skills, imitation, and joint attention.

Another component is the nature of learning contexts, which focuses on learning in naturalistic settings rather than in the strictly controlled environment often presented in discrete trial training.

The third component is the nature of developmental strategies, which is presented through combining different elements and strategies to enhance learning in different settings. A conclusion was made about the advantages of VR technologies for ASD interventions.

Development of social, cognitive, and motivational skills. To assess the impact of avatar-based training on the social skills of pediatric patients with ASD, a team of psychologists from Brigham Young University (USA) [44] used a non-overlapping multiple baseline design to study the effect of animation and avatars on the development of social abilities, including social initiatives, of participants in a game experiment in clinical settings and in real-life communication with peers.

Systematic direct monitoring and a system for improving social skills were used to evaluate the impact of the corresponding session using an avatar. Social validity was assessed from the standpoint of the participants and their parents. Notably, social validity is the degree to which the target behavior is useful, the methods for achieving it are acceptable, and a crucial and significant change in the target and accompanying forms of behavior is achieved [62].

After training with an avatar, the percentage of independent steps performed by children in the skill of starting a conversation increased by 80% compared to the initial level. The ability and willingness of participants to conduct a conversation extended to their interactions with peers. Parents reported a minor positive gain in social skills, and other observers of the project noted that the intervention increased social, communicative initiatives and was socially valid. These confirm the need for technological interventions in learning, particularly live animated avatars.

In a study by a team of specialists in physiological psychology and neuropsychology (behavioral neuroscience) from the University of Udine, Italy [30], cognitive and motivational abilities were analyzed in children with ASD in navigation in an urban virtual environment compared to their neurotypical peers. The study included 16 pediatric patients with ASD and 16 neurotypical children in the control group.

After the initial training stage, the children completed two tasks: navigation in an unfamiliar urban environment, which they could freely explore, and navigation in the same space, but with the main task of finding specific target objects, simulating in a playful way a treasure hunt. In task 1, pediatric patients with ASD spent significantly less time actively exploring and examined fewer areas than the children in the control group. In task 2, no differences were noted between the two groups of participants.

These data show that when freely exploring an unfamiliar environment, children with autism concentrate less on the environment compared to children in the control group. When placed in a game format of a space with exciting tasks, pediatric patients with ASD show attention and activity that can reach the corresponding level of neurotypical children. The authors explain the obtained results by neuropsychological features of the analysis of external environmental conditions by pediatric patients with ASD and the influence of increased motivation on concentration level and productivity.

Specialists from Qingdao University, China [45], used the social game FaceMe with a virtual agent based on augmented reality, which they created, to develop social and cognitive functions and emotional involvement in pediatric patients with ASD. Results showed that the virtual agent FaceMe caused active social behavior in children with autism, which subsequently improved their ability to understand facial expressions. The use of virtual games was found to be a promising approach for teaching young patients with ASD.

Specialists from the University of Kansas, USA, reached similar conclusions [46]; their results showed an immediate increase in the level of behavior when completing tasks and a decrease in destructive behavior with each implementation of a VR application for self-monitoring to promote inclusion of elementary school students with ASD. Other examples include successful and safe training in interaction with police officers for adolescents and adults with ASD using VR [18] (noted in a study by psychologists and doctors working with ASD in Philadelphia and Washington DC, USA); effective training of children and adolescents with autism in communicating with peers and their families using games and tests based on augmented reality (Tabataba'i University, Iran) [13]. A series of immersive sessions helped the subjects feel more comfortable in an unfamiliar environment.

A study by psychologists from the Universities of Connecticut, Central Florida, and California, USA [29], demonstrated the negative effects of the unjustified and ineffective use of VR using the example of analyzing conversational speech reproduced by VR technologies to study the strengths and weaknesses of the structural language abilities of pediatric patients with ASD and attention deficit hyperactivity disorder.

The results showed that children with autism presented simpler speech than their neurotypical peers. Moreover, as they immersed themselves in VR, the complexity of speech decreased in all groups of children. This indicates that VR technologies can have an adverse effect on certain skills, particularly speech. Communication in VR does not always contribute to the development of conversational practice in children. The study revealed the importance of selecting options for virtual games and tasks for various categories of children, developing them jointly with medicine, IT, and psychology specialists.

Using VR to deal with problems and risks in children with ASD. Pediatric patients with ASD may acquire comorbidities [2, 63]. Additionally, they are at an increased risk for injury and various phobias; thus, teaching them safety skills is crucial [50–59, 63]. VR technologies allow for training in a safe and realistic environment similar to a natural setting.

A study by specialists from the University of York, UK [39], used the interactive VR game SoundField to address the problem of auditory hypersensitivity to certain sounds in adolescents with ASD. After the 4-week experiment, a comparison of pre- and post-study scores showed a significant decrease in anxiety associated with problematic sounds. It was then concluded that the VR game is well tolerated by participants with autism and is an effective tool for coping with auditory hypersensitivity.

A subsequent extended study by the same authors involving 22 children and adolescents with ASD showed that the use of VR helps reduce negative emotions associated with unpleasant auditory stimuli in the environment. Moreover, VR technologies may be used via consumer mobile gadgets, which increases the availability of therapy, allowing interventions to be performed at home or at school. This increases motivation for therapy and provides its natural conditions [40].

Specialists from the University of Texas, USA, performed behavioral skills training in VR to improve the ability to avoid theft in pediatric patients with ASD [17]. The study involved four children with autism who were taught abduction prevention skills with feedback in situ. During the training, the children had virtual interaction with four types of abductors. The results showed that the children mastered these skills, and VR technology coped with learning the correct response to different types of abductors and was effective in preventing kidnapping.

A joint study by specialists from the University of Virginia, Iowa (USA), and the University of Hasselt (Belgium) [16] presented the feasibility and effectiveness of VR driving simulation training for teaching general driving skills, successfully predicting possible road accidents and solving problems specific to adolescents and young adults with ASD.

A study by researchers from the Interactive Media Institute in San Diego, Speech Tree Therapeutic Center in Chula Vista, and VR Medical Center in La Jolla, California (USA) [19], investigated the effectiveness of VR for adapting pediatric patients with ASD to air travel. The study involved children with autism who underwent a 4-week training in air travel in a VR space. Parents were asked to assess the child's tolerance of flying on an airplane before the start of the experiment and after 4 weeks. All the children showed improved tolerance of air travel.

Two studies (a project with a core center at the University of Michigan (USA) [42] and a study by the Kessler Foundation (USA)) have examined the use of virtual interview training by adolescents with ASD [38]. Both studies involved high school seniors who were randomly distributed to the experimental and control groups. The results indicate that virtual interview training is a promising approach to improve job interview performance in high school graduates with autism. The VR intervention was implemented in a school setting, which demonstrated the feasibility of its inclusion in the curriculum.

Application of VR technologies in clinical studies with pediatric patients with ASD. Owing the increasing number of adherents of the movement that considers autism not as a disorder but as an alternative path of neurodevelopment, it is not so much therapy that is becoming relevant in working with ASD patients, as training, adaptation, and development of various skills [56–58].

Doctors from the Children's Hospital of the Medical Center of the University of Washington, USA [20], studied visual/motor function, postural stability, and motion sickness in young children with autism. Fifty pediatric patients were examined. The Sony PlayStation VR headset was worn during two consecutive gaming sessions, of 30 minutes each. The 3D video game Eagle Flight was used, which simulates an eagle flying around the city, building a nest, and interacting with other animals. The player, acting as a flying eagle, is required to modify the head movement of the 3D bird to control the flight path (pitch, yaw, and roll axes).

Baseline testing was performed prior to VR exposure. Each VR session was accompanied by diagnostics of binocular visual acuity, strabismus, refractive error, stereoacuity, and postural stability (imbalance). Visually induced motion sickness was tested using the pediatric-modified simulator sickness questionnaire. Adaptation of the visual vestibulo-ocular reflex was tested before and after the experiment in five children. Safety was assessed by changes from baseline in visual/motor performance.

The experiment results showed that young children with ASD tolerate immersive 3D VR gaming without significant effects on visual/motor performance. The VR game did not cause significant postural instability or vestibulo-ocular reflex maladaptation. Comparison with similar data on the adult cohort indicated that the prevalence of discomfort and aftereffects in children may be lower than in adults.

Social–cognitive difficulties in ASD can significantly impact daily life, affecting the development and maintenance of relevant social relationships [50–59, 63]. Social cognition training is commonly used to improve social functioning;

however, its drawback is the inappropriateness of experimental conditions and inability to effectively simulate realistic social situations [64].

The development of VR interventions aimed at enhancing social interaction skills can improve the effectiveness of social cognition training in the context of adaptation and treatment of ASD by offering safe, interactive, and practical learning environments that promote generalization of knowledge and skills to the real world [65].

In a study on the results of dynamic interactive social cognition training in VR in 26 young and middle-aged patients with ASD, psychiatrists from the Netherlands recommended the use of VR to develop social communication [65]. The virtual environment developed for people with schizophrenia spectrum disorder was adapted for ASD patients. Participants in the ASD group received the VR intervention in addition to their usual treatment. Three assessments were recorded: before the intervention, after it, and after 12 weeks. The pre-, post-, and follow-up assessments included identical instruments, whereas the assessment some time after the intervention was supplemented by an evaluative interview and a questionnaire.

To enhance the relevance of the intervention and promote generalization of the learning content to everyday life, participants personally selected relevant social targets. The immersive VR worlds were a shopping street, a supermarket, an office, and a bar. Social cognition, emotion recognition, mental flexibility, social anxiety, empathy, and social responsiveness were exposed and assessed. More than 90% of the participants were satisfied with the number, intensity, and duration of the sessions and stated that they had learned a lot and enjoyed the practical training in a virtual environment accompanied by a real therapist.

Overall, the therapists rated the treatment results positively. The study showed that the majority of participants and therapists found the VR intervention acceptable, feasible, and effective in developing social–cognitive skills.

Neuroscientists from Newcastle University, UK [47], presented a study on the use of VR technologies to help pediatric patients with ASD suffering from fears and phobias. The study involved eight children aged 8–12 years. Each of them had anxiety about a specific situation (e.g., crowded buses) or stimulus (e.g., pigeons). They received cognitive behavioral therapy with graded exposure in a VR environment. Up to 50% of the participants reported a positive effect of the VR intervention, as they were able to act without fear.

In an earlier similar project by the same research team, significant improvements were registered in 8 of 9 children, with 4 of them overcoming their phobia completely [41]. The effect was maintained 12 months after the intervention. The results indicated that VR combined with cognitive behavioral therapy is a promising approach for reducing specific phobia in adolescents and young adults with ASD.

Traditional treatments may not be fully effective and suitable for children and adolescents with ASD if used without adaptation. Traditional interventions have limitations; for example, they require long periods of time and are inconvenient for children with special needs. Thus, alternative interventions are required.

Specialists from Anhui Medical University, China, conducted a VR study involving pediatric patients with ASD [48]. They concluded that intervention therapy using VR and augmented reality, based on theories of cognitive rehabilitation and social–emotional learning, enables participants with autism to overcome communication barriers.

Features, limitations, and safety of using VR headsets in children with autism. Despite various studies that positively evaluated VR for the development and education of pediatric patients with ASD, these technologies can have an adverse effect on their condition, which is associated with the abuse of VR and is expressed in uncontrolled, long-term immersion sessions in VR [21, 37].

The negative consequences of using VR in physical development include visual impairment, cardiometabolic disorders, obesity, cybersickness, sleep disturbance, and fatigue. For example, problems associated with confusion may arise in children when mixing the virtual world with the real one. Additionally, not all pediatric patients with ASD can tolerate head-mounted helmets. However, the reality is that children are increasingly involved in virtual worlds, including children with autism [21, 27, 37].

The World Health Organization warns of the risk associated with possible gaming addictions and problematic behavior [29]. However, whether such behavior is caused by the Internet, virtual worlds, or gaming technologies remains unclear [37, 38]. Nonetheless, even those studies that indicate a negative impact of VR and games on children associate these findings with the unlimited and uncontrolled use of such technologies [21, 37, 61].

Long-term studies are required because new technologies, both software and hardware, are constantly emerging [24, 27]. They are safe to use if health and safety requirements are met, especially regarding the duration of use. This applies to both neurotypical and autistic children [37]. When safety conditions are met, the use of VR gives positive results for the cognitive, motivational, emotional, and social development of children with autism.

Preliminary instruction outlining the aims and requirements of VR sessions is a key condition for the most effective and safe use of VR for working with children with ASD [4]. It is recommended that parents or other close relatives study the content and goals of the VR session and accompany and support the child during and after the intervention [30].

Researchers from the SSN College of Engineering, India [26], and Newcastle University, UK, [41] argue that when working with pediatric patients with ASD, this requirement should be met with particular thoroughness, considering the specifics of reaction of each individual child to various gadgets, experience of using virtual environments, communication with peers and specialists, etc.

DOI: https://doi.org/10.17816/KMJ593044

Owing to the systematic and comorbid nature of disorders in ASD, the organization of comprehensive support is possible only with an interdisciplinary approach [66–68]. This is because of the need for special support conditions (i.e., training, methodological support, and interaction with parent communities) and correction of specific disorders characteristic only of children with autism [66–71]. Another recommendation is that VR programs should be customizable to meet the diverse needs of users with developmental disabilities of the nervous system [22, 28].

Studies conducted at the University of Massachusetts and Florida State University, USA, revealed potential barriers to the use of VR in patients with ASD [15, 31]. They showed that deficits of language understanding may negatively impact the ability of adolescents with ASD to follow instructions in VR environments, thereby preventing users from accessing virtual technologies. It has been noted that users with autism may be distrustful and averse to specific design features of VR, such as programs that use negative feedback, and that some children may react negatively to requests to participate in competitive games in multi-user VR [31].

The lack of time and difficulty in managing the physical and virtual worlds in the classroom have been identified as potential barriers to VR implementation in studies of school interventions for users with ASD and intellectual disabilities [15].

Another major concern is the confusion the children may experience when mixing the virtual world with the real world and the potential dangers this poses. The user of VR technology may become overly immersed in imaginary worlds, sometimes leading to identification with avatars or characters [27, 37]. Different forms of media can manipulate human experience, especially that of children. Adults should help children understand the difference between fantasy and reality.

While the American Academy of Pediatrics recognizes the potential benefits of mobile/interactive technologies in children, especially through well-designed educational materials, it expresses concerns about their overuse during a period of rapid brain development [25, 72].

Controlled studies of the impact of virtual technologies on ASD patients should be continued. Our previous studies presented experiences in developing immersive environments for teaching people, including adolescents and primary school children [73–75]. Moreover. we believe that the use of digital and especially VR technologies can contribute to earlier adaptation of pediatric patients with ASD and improve their socialization and learning.

CONCLUSION

The study results confirm the feasibility of using VR technologies to develop various skills in children and adolescents with ASD that is, from general communication and cognitive skills to specific operational skills. The impact of VR technologies can be both positive and negative, which casts doubt on the universality of virtual technologies and indicates the need for a more comprehensive analysis of the conditions of their use.

When using VR for work and education of pediatric patients with ASD, several conditions should be met:

– The presence of parents or caregivers during the use of VR for the most comfortable environment and good emotional state of the child

– A combination of general free navigation in an unfamiliar environment with specific tasks of searching for objects, memorizing them, selecting them, interacting with them, etc., using animated avatar assistants

– Time restrictions in the form of a limit on the duration of a VR session

Generally, VR applications appear promising to experts. Researchers of VR capabilities for children and adolescents with ASD concluded that VR technologies can provide a safe authentic environment that many children use without resistance or difficulties, and because of which it is possible to form and develop various skills (e.g., social, communicative, cognitive, and adaptive).

ADDITIONAL INFORMATION

Authors' contribution. V.V.K. — conceptualization, formal analysis, writing — review and editing, supervision; G.Ya.G. — conceptualization, formal analysis, methodology, investigation, writing — original draft; E.A.S. — writing — review and editing, validation, supervision; A.A.B. — writing — review and editing, validation.

Funding source. The work was carried out using funds from the Strategic Academic Leadership Program of Kazan (Volga Region) Federal University (PRIORITY-2030).

Competing interests. The authors declare that there is no conflict of interest in the presented article.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. В.В.К. — концептуализация, анализ, редактирование рукописи, общее руководство; Г.Я.Г. — концептуализация, анализ, методология, исследование, создание черновика; Э.А.С. — редактирование рукописи, валидация, общее руководство; А.А.Б. — редактирование рукописи, валидация.

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Конфликт интересов. Авторы заявляют об отсутствии конфликта интересов по представленной статье.

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