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Exploring the Application of Virtual Reality (VR) Technology in Early Intervention for Social Skills Development in Children with Autism

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SUMMARY: *The current state of education and intervention of children with autism is still faced with numerous challenges but the innovations made by virtual reality technology have created opportunities of solving such problems. The research explores the application of virtual reality (VR) during initial-stage training of social skills in autistic children and presents an optimization plan that will enhance the outcomes of interventions by enhancing the virtual visual environment. This strategy was subsequently evaluated on its feasibility based on a controlled experiment using statistical calculations such as chi-square test, independent-samples t-test, and repeated-measures ANOVA. The results revealed that the autistics had a higher score in four visual scenes after donning the VR headsets. The immersion levels of these scenes were placed in order of ranking, the highest to the lowest as colorful landscape gallery, colorful entertainment space, animal identification wall, and colorful animal weathervane with respective scores of 45.7, 45.2, 43.9 and 39.5 respectively. In all the four dimensions of social skills, namely social tendency, social cognition, social communication and self-regulation, the post-test performances of the experimental group who underwent VR-based intervention were significantly higher than the performances of the control group who received the intervention through conventional methods. The research widens the outlooks and practical solutions to social-skills intervention of autistic children in integrated educational environments.*

KEYWORDS: *chi-square test; independent samples t-test; repeated measures ANOVA; virtual reality technology; social skills of autistic children*

1 Introduction

Autism Spectrum Disorder (ASD) is a general neurodevelopmental disorder that starts early in childhood and it is characterized by the presence of core symptoms including social communication and interaction impairments, circumscribed interests, and repetitive stereotyped behavior [1]. The research conducted by Maenner, M. J. states that the incidence of ASD is 2.78% in the United States as of 2023 [2]. China Report on the Development Situation of Autism Education and Rehabilitation indicates the prevalence rate is 0.7% in Chinese children and 36.9% of children with mental disabilities are autistic. This means that autism is the most frequent mental developmental disorder among Chinese children, where over 2 million of them are autistic children aged between 0 and 14 years [3]. Therefore, ASD has also become one of the main problems in world health care and has received much attention in the world [4, 5]. Due to the high number of people affected, the importance of timely and effective early intervention in autistic children is evident and highly practical.

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With the further development of knowledge about autism, there has been a slow convergence among researchers on what the main manifestations of autism are. Currently, numerous scholars are conducting systematic and detailed research on the social interaction capacity of children with autism. With various assessment tools and experimental methods, they investigate the social communication performance of autistic children and the determinants of this quality. There is a variety of factors that can determine the social interaction performance in the given group. Numerous studies suggest that autistic children have different patterns of neural development and brain structure than typically developing children, and differences in brain information-processing systems might also play a role in social interactions problems [6-8]. According to the hypothesis of Bernhardt, B., et al., changes in the sensory cross-modal brain hierarchy could be one of the potential mechanisms responsible for non-typical information processing in autism. Increasing behavioral, cognitive, computational and neural properties of autistic children can increase brain connectivity, which can lead to improved communication and social interactions as well as alleviate the core symptoms [9]. Martinez-Sanchis, S. proposed that brain information-processing abnormalities were linked to the medial prefrontal cortex (mPFC) of patients with ASD. Improving the function connectivity across the mPFC could be useful in alleviating social interaction deficits in autistic children [10].A meta-analysis carried out by Yamasaki, T. and others has shown that impairment in social-skills of individuals with ASD occurs due to anomalous functional & structural connectivity in visual and attentional networks which is a pathological mechanism that could be referred to as a connectivity disorder [11]. Rane, P. et al. reviewed magnetic resonance imaging studies on connectivity in subjects with ASD and identified extensive decreases in white matter integrity, decreased long range neural connectivity, decreased functional connectivity between cortical regions, decreased fractional anisotropy in areas of white matter, and increased mean diffusion rate in white matter [12]. Similarly, Sato, W. and Uno, S. have reported that the behavioral and social impairments seen in ASD have a basis in atypical gray matter volume and diminished functional connectivity [13].

The social impairment of autistic children is mostly demonstrated in poor social communication, poor eye contact, and poor verbal expression. Most commonly, they have poor interests in interpersonal relations, poor ability to share feelings or love, and poor ability to communicate over long periods of time and actively engage in social contacts [14]. Social problems of autistic children were noted by Holton, J. et al. as usually including decreased eye contact with others, absence of social smiling, refusal to be touched physically, inability to form friendships with peers, and difficulties in perceiving and reacting to the emotions of others [15]. Chevallier, C et al.'s research indicates that children with ASD exhibit noticeable social behavioral abnormalities as early as age 1, such as lack of facial expressions and vacant stares [16]. Additionally, they struggle to initiate social behaviors like conversing upon request, sharing toys, or recounting experiences. Freeman, S et al. found that during social interactions, children with ASD exhibit visual attention deficits and abnormal eye contact patterns. This impairs their ability to accurately process external information and hinders their grasp of effective social cues, significantly affecting the development of their social functioning [17]. Williams-White, S et al. identified social impairments in autistic children encompassing speech, language habits, and interpersonal interactions. Common problem areas include social pragmatic deficits, poor speech prosody, tendency to fixate on specific topics, difficulty understanding and expressing emotions, and challenges interpreting non-literal language [18]. Building on prior research into social skills, scholars have categorized these into three major domains: social cognitive abilities, social interaction skills, and social communication competencies. In a study examining social skills interventions for ASD individuals, Reichow, B and Volkmar, F noted that social cognition represents a higher-level skill, while social interaction encompasses self-initiation, turn-taking, and responsiveness. Social communication skills, meanwhile, involve reciprocal joint attention and proactive communication [19]. Similarly, enhancing social competence has become one of the most important goals in dealing with social disability in children with ASD.

Moreover, there is an increasing literature proving that early intervention is very important in developing social interaction abilities among people suffering from ASD. Studies have also found that the earlier the intervention began, the more it was beneficial to children with autism as compared to intervention that began later. Early intervention can assist in achieving social skills and behaviors that help them adapt to social situations better [20-23]. Peer-mediated interventions were conducted on ASD children by Krebs, M. et al. and their social actions were contrasted with typically developing peers using observation and recording. The results showed that the social behavior, such as eye contact, social engagement, initiation, and intimate interaction increased significantly [24]. Feasibility and effectiveness of a parent-led, intensive early intervention program of children with ASD was studied by Krishnan, R. and his team. They found that this intervention could be applied in contexts of limited resources because it demonstrated a moderate to high effect in various areas [25]. Video modeling was utilized by Alzyoud, M. et al. to provide four social-skills interventions to five children with ASD and they reported positive learning results which included positive performance in terms of maintenance and transfer across participants [26]. To investigate children with ASD who had been given the Early Denver Model intervention, Estes, A. et al. undertook a two-year follow-up study. The findings showed that the intervention group had a consistent level of intellectual functioning, adaptive behavior, and symptom severity, as well as higher social-skill scores than the control group, which received standard community-based care[27].

Since the population of children with ASD is increasing and there is greater focus on the nation on their rehabilitation, the social cost related to conventional early intervention strategies is also rising. In the future, it is probable that digital auxiliary therapies will be one of the main trends in autism rehabilitation studies, enabling services to extend to a greater number of children with ASD[28-30]. The introduction of virtual reality (VR) technology gives children with ASD access to a highly interactive medium of learning and practicing skills in personalized, controlled, and secure settings that are readily available to them [31, 32]. Currently, there are some researchers who have come up with VR-based intervention techniques. For instance, Botella, C. et al. created Virtual Reality Exposure Therapy (VRET) as a treatment of phobias. This new method simulates the impact of behavioral exposure therapy by using the software with very realistic audiovisual simulation, as an alternative to face-to-face exposure therapy [33]. Fu, W. et al. came up with a novel early intervention approach for children with ASD based on VR which emphasized on its realism, flexibility and engagement. Their findings showed great changes in social skills, emotional state, daily living skills and attention of the children with ASD [34]. As the field of computer graphics technology advances rapidly and more sophisticated virtual engines are being created, early-intervention VR environments of children with ASD can offer more rich interactive experiences due to the technical capabilities of the current generation. Nevertheless, the application of VR in early intervention with children with ASD is just in its initial stages. Many rehabilitation educators still lack the necessary technical skills to plan and create virtual intervention spaces customized to children with ASD.

This paper explores the application of VR technology to intervention in children with autism under five dimensions, which are social-skills training, emotional and cognitive development, attention and emotion regulation, assisted diagnosis and assessment, and educational support tools, especially the feasibility of the approach in social-skills intervention. Then, on the basis of the feedback of the autistic children, a VR-based virtual visual environment is developed and optimized. The ultimate VR visual environment is finally used to intervene in social-skills and its effectiveness is measured using statistical techniques such as the chi-square test, the independent-samples t-test, and repeated-measures ANOVA.

2 Research on the application of VR technology in social skills intervention for children with autism

2.1 Social skills interventions for children with autism

Autism spectrum disorder (ASD) is a severe neurodevelopmental disorder that is often characterized by impairments in social interaction and repetitive and stereotyped behavior. The question of how to offer effective care and treatment to children with ASD has consequently become a matter of general social interest.

So far, the pathogenesis of ASD is not clear and there is no effective chemical drug. The current intervention training for children with ASD, such as psychological and behavioral therapy, speech therapy, music therapy, etc., is mainly aimed at improving their self-care ability, hoping that they can participate in various social activities like normal children. However, due to the great heterogeneity of ASD patients, the efficacy of various therapies has not yet achieved consistent results, and some therapies are not very effective. Psychobehavioral and speech therapies based on applied behavior analysis (ABA) require professionals with long-term systematic training to implement, with huge financial, human, and time investments. In addition, there is a lack of formal hospitals or intervention training institutions in some areas that can provide professional services for children with ASD. The above factors seriously constrain the rehabilitation training of children with ASD.

The alternative to more traditional methods of social skills training, including simple emotion recognition tasks or role-play exercises, is that virtual reality (VR)-based social training has its own special benefit: it has the potential to generate safe, versatile, and realistic typical contexts where children with ASD can practice various social scenarios, e.g., going out to eat with another person at a restaurant or sending an invitation to a friend to come to their birthday party. As a result, an increasing amount of research has included VR tools and wearable gadgets in intervention plans of children with ASD.

In this context, the paper explores the application of intelligent technologies, particularly VR, to early social-skills intervention among children with autism, and goes on to explore the practical effectiveness of the intervention with experimental confirmation.

2.2 Specific applications of VR and AR technology in interventions for children with ASD

The research conducted on the application of virtual reality and augmented reality to autistic children who have problems with social-skills training has primarily focused on the following areas.

(1) Social skills training

Virtual reality may be used as the creation of an isolated and controlled environment where autistic children can interact socially by simulating actual life events. Moreover, the VR systems have the ability to dynamically change the content of scenarios based on the current developments in the socio-motor skills of autistic children. This technology also enables them to learn and comprehend social rules and behavioral patterns and facilitate situation transfer, thus enhancing their social competence by reproducing various contexts.

(2) Emotional and cognitive development

Taking advantage of the visual strengths of autistic children, using augmented reality technology and combining real scenes and virtual elements, training can be conducted anytime and anywhere according to the autistic children's situation and living or learning scenarios, thus promoting their emotional understanding and cognitive development.

(3) Attention and Emotion Management

Interactive or task-focused games, when combined with real-life situations, may be used by VR and AR technologies to effectively hold the attention of autistic children. They can also help children control their emotions and regulate their own emotional state through game design and direction by NPCs. It leads to increased learning motivation and more involvement in social activities.

(4) Assisted Diagnosis and Evaluation

By analyzing the behaviors and reactions of autistic children in virtual environments, especially environments that cannot be constructed under natural circumstances or in certain areas where natural conditions are not sufficient, such as remote and impoverished areas, etc., these techniques can help special educators to more accurately assess the symptoms and the type of interventions that are needed for autistic children.

(5) Educational support tools

Virtual reality games are becoming a form of educational game which can be used to help children with autism acquire vocabulary, read digitally and learn to program. With the cooperation of technology companies and universities, these technologies may offer more robust assistance to teachers in improving the educational performance of autistic children. Its application to teaching might be useful in fostering the education and growth of children with autism on various tiers.

2.3 Specific research methods

The current research focuses on how the virtual indoor spaces designed in the form of VR technology may be used to improve the social skills of autistic children, as well as the practical applications of VR in social-skills interventions in the initial stages of autism. The questionnaire data were organized using SPSS 28.0, and descriptive analysis, the chi-square test, the independent-samples t-test, repeated-measures analysis of variance (ANOVA), and simple-effects analysis were performed.

2.3.1 Chi-square test

Chi-square test [35] Chi-square test is a statistical method that determines the degree of association between theoretically predicted and observationally measured values of a sample. In general, the higher the value of chi-square the more significant the discrepancy relationship between them. Chi-square statistic is denoted by χ and its formula of computation is shown in Equation (1):

$$\chi^2(F_i, C_j) = \frac{m \times (a \times d - b \times c)^2}{(a+b) \times (c+d) \times (a+c) \times (b+d)} \tag{1}$$

where: the variable F_i denotes the feature. C_j denotes the feature category. m denotes the number of texts within the training dataset. a denotes the number of C_j class texts containing F_i. b denotes the number of non-C_j class texts containing F_i. c denotes the number of non-C_j class texts that do not contain F_i. d denotes the number of texts of class C_j that do not contain F_i.

2.3.2 Independent samples t-test

Since the study is a statistical test, ANOVA and t-tests are needed to analyze the results of the intervention. Levene's test for ANOVA [36] is a more liberal functioning test of variance chi-square, which is used to test whether the variances of multiple data sets are equal. And it is very effective in dealing with non-normal distribution and outliers. The statistic W, as shown in (2):

$$W = \frac{1}{MSe} \frac{N(\bar{Z} - \bar{Z}_i)^2}{r-1} \tag{2}$$

In equation (2), $\bar{Z}$ indicates the mean of the overall transformed data, and $\bar{Z}_i$ indicates the mean of the i th group of the transformed data package.

t-test, mainly used for smaller sample content, including samples and means between, paired information between, between the two samples mean comparison of three kinds, the three formulas can not be confused. Independent samples t-test [37] statistics, as shown in equation (3):

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{3}$$

In equation (3), $\bar{X}_1, \bar{X}_2$ denotes the two-sample mean, n_1, n_2 denotes the two-sample capacity, and S_1^2, S_2^2 denotes the two-sample variance.

The significance level is an estimate of the probability that the overall parameter falls within a certain interval of possible error, denoted by α. Significance is in terms of the degree of variation, with different levels indicating that the cause of variation may be conditional or random. Its a criterion for determining in advance a small probability that can be allowed as a judgmental boundary when conducting a hypothesis test. The level of significance is an important parameter in hypothesis testing because it controls the probability of false positives and false negatives. Significance is a test to determine whether the probability of arriving at a hypothesis is less than a certain level of significance, such as 0.05, 0.01, or 0.001, and thus whether to reject the hypothesis when performing a statistical analysis. $P > 0.05$ means that there is no statistically significant difference in statistical inference, whereas $0.01 < P < 0.05$ means that there is a significant difference and $P < 0.01$ means that there is a highly significant difference.

The degrees of freedom are written as df, which alludes to the number of variables which can be freely varied when computing a statistic. In particular, the degree of freedom is the number of independent variables less the number of derived constraints, which is given in Equation (4).

$$df = n - k \tag{4}$$

In Eq. (4), n denotes the number of samples, and k denotes the number of conditions or variables that are constrained, or the number of other independent statistics used in the calculation of a given statistic. The number of variables is defined as the sample minus the mean, i.e., a derived quantity that is determined by the sample and thus has $N-1$ degrees of freedom for N random samples.

Two-tailed test is a statistical test used to find out whether there is a significant difference between the sample and population means, or whether a particular result of a sample can be substantially different than a hypothetical number, without presupposing that the difference should necessarily be positive or negative. Such a test is applicable when the professional experience of the researcher cannot help him/her to foresee the direction of the deviation. To determine if the calculated sample statistic is too large or small compared to the hypothesized parameter on both sides, the probability of error is given equal weights across the two tails of the distribution. As an example, suppose the significance level Sig. = 0.05, then the probability allocated to both tails of the curve is 0.025.

A confidence interval is a range estimate of population parameters based on sample statistics. It is used in statistics to give a range in which a given probability distribution is likely to contain the corresponding population parameter. A 95 percent confidence level implies that, with repeated sampling, 95 out of 100 constructed intervals will include the unknown true parameter, and the other 5 will not capture it. The length of a confidence interval depends on several factors including confidence level and sample size. With a constant confidence level, higher sample sizes tend to lead to smaller intervals. Conversely, if the sample size is held constant, the increase in the confidence level will typically increase the width of the interval.

2.3.3 Repeated Measures ANOVA with Simple Effects Analysis

Repeated-measurement data are records of data that have been measured at >3 different time points for each study subject with >3 different treatments, or after receiving the same treatment, and have been obtained the corresponding number of times. In each record of repeated-measures data, multiple measurements obtained at different time points or with different treatments come from the same study subject, so there is some correlation between the data. The main basis for determining whether the research data are repeated measurement data is whether the same research object is measured several times and the same number of results are obtained. Repeated-measures ANOVA [38] is a method to statistically analyze repeated-measures data.

Mauchly's test, where the covariance matrix of repeated measurement error is transformed by orthogonal contrast to be proportional to the unit matrix, is first executed to assess the applicability of the data. If the test results satisfy the conditions, no correction of the test statistic is required. Instead, the appropriate corrections were required and the Greenhouse-Geisser corrections were referred to. The results of ANOVA on the group-by-time term were then analyzed to see if there was also an interactive effect of those two factors. This term only requires the consideration of the principle effects of group and time when it does not achieve statistical significance. After the interaction achieves significance, however, the meaning of the general main effects is no longer meaningful and the analysis must focus on the individual effects, i.e., simple-effects analysis.

Simple effects analysis covers two aspects: first, fixing the level of the repeated measures of the factors and analyzing separate effects for the intervening factors, i.e., fixing the time point of measurement, comparing group differences, and making two-by-two comparisons between groups. The second is to fix the intervening factor and analyze the level of the repeated-measures factor, i.e., fixing the groups, comparing differences at different time points, and again making two-by-two comparisons between groups. Throughout the statistical analysis, a two-tailed test was used, with $P<0.05$ as the criterion for determining the significance of differences.

3 Innovative design of VR-based social skills intervention environment for children with autism

The chapter will offer an experimental study of visual conditions using VR to promote early social skills development among children with autism, improve the design of scenes in virtual worlds, and explore the intervention programs designed to suit their requirements so as to come up with comfortable areas of social interactivity.

3.1 Subjects and Methods

In this experiment, 20 autistic children, all aged 7-12 years old, were selected as research subjects. All the children were diagnosed as autistic by the hospital, and all the subject children had an autism rating scale (ABC) score of 52, and excluded individuals with an IQ of less than 70, who were not capable of simple verbal expression, who had vertigo to 3D virtual scenes, and who had a history of significant movement disorders with neurological disorders or psychiatric symptoms. The researcher and the guardians of the children participating in this experimental study signed an informed consent form with them after explaining the principles of the experiment clearly. Comparative experiments, questionnaires, recorded observations and experiments were used to obtain experimental results and corresponding conclusions.

3.2 Virtual visualization program design and production

The animal vignettes and cartoon vignettes in some landscape elements are selected and designed to be applied in the visual perception space according to the preference score selection, combined with the virtual technology, and presented in the form of virtual immersion, so that the autistic children can have naked-eye and virtual VR experience in the state of relaxation for the vision respectively.

Experimental vision 1: Colorful animal weathervane. The 2D image of animals is placed on the upper part as the color vane of the whole space, so that autistic children can enter the scene and interact with the visual device to try to autistic children's social interaction ability and stereotypical behavior.

Experimental Vision 2: Color Landscape Corridor. The whole scene is designed with landscape design elements such as green plants that autistic children love, and the whole color corridor is composed of different color blocks. Under the sunlight, it produces visual stimulation, so as to produce different visual stimulation feelings for autistic children and improve their ability to identify colors.

Experimental Vision 3: Animal Recognition Wall. The whole scene design selects the landscape design elements such as animal sketches and plants that autistic children love, and the whole visual experience area adopts the design of disc sketch animal stepping. When autistic children walk into the designed stepping area, the stepping area will show different animals of different colors, and at the same time, the 3D wall presents animal images, making the whole area full of fun. Not only visual color recognition, but also body balance exercise, so that autistic children can interact with the space and improve visual cognitive impairment. The area is equipped with evergreen trees that do not block the view, and the space is presented as an open space so that the user group can better integrate into it.

Experimental Vision 4: Colorful Entertainment Space. The entire interior of the scene is composed of colorful staircases and slides. Playing is the nature of children, and autistic children were able to generate a strong sense of interaction as well as effectively improve behavioral stereotypical disorder during the experiment.

3.3 Experimental Procedure and Conclusion

3.3.1 Experimental procedure

The experiment was conducted in the activity room of a special education institution with the conditions of silence and without any interruptions. It consisted of one participant who attended every session along with a system operator, a facilitator, a data recorder and a member of the staff who took care of emotional soothing. The operator handled the computer program and commanded the VR devices. The facilitator took the child to the virtual scene, provided verbal instructions, explained the desired activities, and helped to perform the process. The recorder recorded all the data that was produced during the whole process, and the soothing staff member kept track of and smoothed the emotional state of the participant.

The whole experiment process is divided into two parts, the first part of the bare eyes for visual perceptual space preference cognitive selection, the second part of wearing VR glasses for visual scene preference cognitive selection. The experimental scene is imported into the Unreal Engine UE4, the virtual device is connected to the computer, and the experimental visual perception scene is displayed in numbered order, and the experimental subjects who cannot be described accurately by language are selected by body.

The autistic children listen to the instructions and then select the scene preferences, record the scene cognitive performance of the subjects after the completion of the experience, and at the same time, record the scene immersion performance of the subjects after the completion of the experience, and after the completion of the experiment, the scene cognitive degree score and the immersion degree score are sorted out and analyzed in a comparative manner to draw conclusions.

3.3.2 Experimental results and analysis

According to the scene cognition scale scores, the mean comparison of the four visual scenes as well as the standardized variance were counted, and the descriptive statistics of the visual scene scores were obtained as shown in Table 1. It can be seen that after wearing the VR glasses, the scores of the four visual scenes were significantly improved, and the standardized variance of visual 1~3 increased except for visual 4. This reflects that VR technology can enhance the sense of immersion and cognition of visual scenes for autistic children.

Table 1: Descriptive statistics of visual scene scores

	Scene category	Min	Max	M	SD
Naked eye	Visual 1	11	15	13.80	1.752
	Visual 2	15	16	15.60	0.528
	Visual 3	13	15	14.70	0.905
	Visual 4	14	16	15.10	1.021
Wear VR glasses	Visual 1	15	20	17.20	1.893
	Visual 2	17	20	19.20	1.664
	Visual 3	17	20	18.30	1.528
	Visual 4	18	20	18.80	0.936

The results of the test for differences in pretest scores for the visual scenes are shown in Table 2. Friedman's test found no significant difference ($P=0.194>0.05$), so the four visual scenes are comparable.

Table 2: Visual scene pre-test score difference test

Scene category	Rank average	X^2	P	df
Visual 1	1.80	4.905	0.194	3
Visual 2	3.40			
Visual 3	2.50			
Visual 4	3.10			

After the cognitive experience of the virtual visual scenes, the scores of the post-test were subtracted from the scores of the pre-test as the score increment, and the descriptive statistics of the score increment of the visual scenes are shown in Table 3. It can be seen that the mean value of the score increment of Vision 2 in the visual space, 3.80, is greater than that of the other scenes, and that the score increment of Vision 4, 3.70, is ranked second in order.

Table 3: Incremental descriptive statistics of visual scene scores

Scene category	Min	Max	M	SD
Visual 1	2	5	3.50	0.849
Visual 2	1	5	3.80	1.528
Visual 3	2	5	3.50	1.805
Visual 4	2	6	3.70	1.752

The results of the comparison of the visual scene immersion scores are shown in Table 4. The immersion degree of the four visual scenes are Visual 2, Visual 4, Visual 3 and Visual 1, with corresponding scores of 45.7, 45.2, 43.9 and 39.5, respectively.Therefore, according to the scene cognition and immersion scores, it is concluded that Visual 2 is the optimal solution in the overall visual spatial design and will be applied in the overall design scheme, and Visual 4 will be optimized for the subsequent scheme design.

Table 4: The comparison results of the scores for the degree of visual scene immersion

Scene category	Visual 1	Visual 2	Visual 3	Visual 4
M	39.5	45.7	43.9	45.2

3.4 Experimental optimization and feedback

Optimize the design of vision 4, in the experimental process of vision 4, it is understood that autistic children prefer the stairs and slides on the left side, while on the right side of the scene is too monotonous, and autistic children are not interested, so when optimizing the vision 4, the cartoon character Smurf, which is loved by autistic children, is placed inside and outside, and simple cognitive elements are added to the right wall to increase the visual attraction. The comparison of experimental scores before and after optimization of Vision 4 is shown in Table 5. It can be seen that after the completion of the experiment, the autistic children's enjoyment and immersion scores of the optimized Vision 4 were higher, so the optimized Vision 4 was unanimously considered to be effective.

Table 5: Comparison of experimental scores before and after Visual 4 optimization.

		Degree of cognition		Degree of immersion	
Scene name	Subjects	Before optimization	After optimization	Before optimization	After optimization
Visual 4 optimization	Subject 1	17	20	39	48
	Subject 2	21	23	47	52
	Subject 3	21	25	45	51

Finally, during the immersion experience of the scene, the heart rates of the three autistic children were collected to obtain the heart rates of the autistic children after Vision 4 optimization as shown in Figure 1. Based on the data analysis of the heart rate in the first and third minutes of entering the scene, it can be seen that the optimized scene played a role in calming the heart rate of the autistic children, so the Vision 4 optimized scene was applied to the overall design scheme.

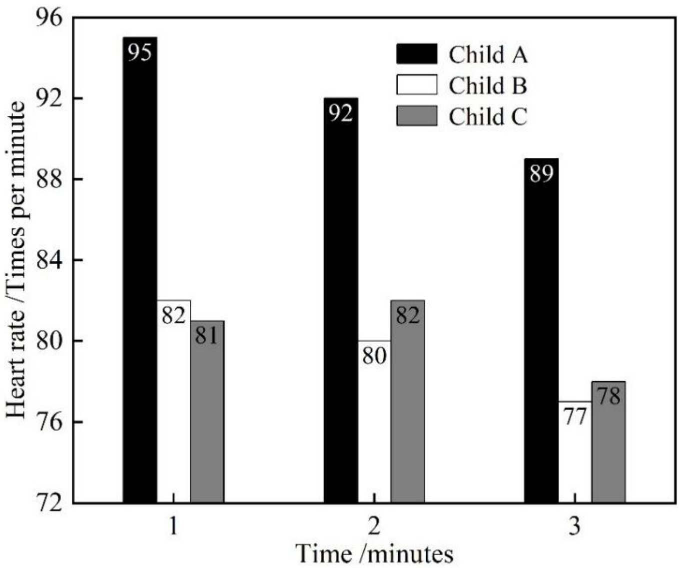

Figure 1: Heart rate of children with autism after visual 4 optimization

4 Analysis of the intervention effect of VR technology on social skills of autistic children

The purpose of this chapter is to discuss the effect of enhancing the social skills of autistic children in a VR-based visual environment on intervention results in order to confirm the fact that virtual reality technology could be used in early support of social development of children with autism.

4.1 Subjects of study

Based on the previously set criteria, 40 children with autism in 12 regular primary schools in city D were registered into the study. Then their level of impairment was measured using the Childhood Autism Rating Scale (CARS). Those with similar degrees of impairment were randomly divided into an experimental group and a control group by applying a randomized numbering process with 20 people per group. Table 6 shows the demographic features of participants in both groups. There were no statistically significant differences in gender, biological age, or severity of impairment between the two groups ($p>0.05$).

Table 6: Comparison of demographic data

Variable		Experimental group	Control group	χ^2	t	p
Gender						
	Male	17	13	0.783		0.385
	Female	3	7			
Physiological age		9.92±2.23	10.47±2.51		-0.648	0.527
Degree of disability						
	Mild to moderate	15	16	0.169		0.684
	Moderate to severe	5	4			

4.2 Research tools

The Autism Social Skills Scale (ASSS) has been used as a measure of social functions of autistic children of ages 4-16 years. The scale consists of 50 items that address five dimensions of social tendency, social cognition, social communication, social participation, and self-regulation. Every item has five response choices, i.e., Never, Occasionally, Sometimes, Often, and Always and is rated on a scale starting at zero and increasing as more positive responses are given to indicate improved social skills of the participants. This tool had high internal consistency, the value of Cronbachs alpha being 0.97 on the overall scale and 0.93-0.97on the individual dimensions. The retest reliability was found to be 0.93 on the complete scale and 0.87-0.95 on every factor, and good fit indices of the validated factor analysis model (χ^2/df==2.07, RMSEA=0.078, NFI=0.97, NNFI=0.96, NNFI=0.97, and NNFI=0.97). NNFI=0.96, CFI=0.98, IFI=0.96, TLI=0.97, and GFI=0.92), indicating that it possesses good reliability and validity. The scale was then selected as a tool used to conduct the current study and filled by the children classroom teachers to assess the change in their socio-economic skills before and after the intervention.

4.3 Experimental design

The independent variable in this experiment was the use of a VR-based virtual visual scene program designed to intervene in the social skills of children with autism, whereas the dependent variable was the change in autistic children’s social abilities before and after the intervention. Considering that the participants came from multiple schools and differed in school stage, a balancing strategy was adopted to control irrelevant variables. On the one hand, both groups were ensured the same frequency and quality of daily social education training. On the other hand, the two groups also received individualized social intervention at the same frequency and quality.

Participants in the control group were given only routine social behavioral intervention, while those in the experimental group received virtual visual scene intervention supported by VR technology on this basis and carried it out independently.

The study also performed a fidelity assessment using the Peer Execution of Social Behavioral Intervention Fidelity for Children with Autism protocol, taking a score of ≥9 as the baseline criterion for good intervention fidelity. Statistically, the mean fidelity score in this research was 9.64, indicating a satisfactory level of intervention fidelity.

4.4 Experimental results and analysis

The descriptive findings of pre-intervention and post-intervention ASSS scores of both participants groups are given in Table 7. Initially, an independent-samples t test was conducted to compare the social-skill levels of the two groups prior to the intervention and no statistically significant value was obtained ($t_{(38)}$=-0.92, p>0.05, d=-0.014). In order to explore more deeply the intervention effects on the social skills of the participants, a 2 (group: experimental and control) x 2 (measurement occasion: pretest and posttest) repeated-measures ANOVA was later conducted with the total ASSS score and its five dimensions as the dependent variables.

On the total score, there was a significant main effect of group ($F_{(1,38)}$=7.538, p<0.01, η^2=0.182), a significant main effect of time ($F_{(1,38)}$=1324.826, p<0.001, η^2=0.983), and a significant interaction between the two ($F_{(1,38)}$=81.467, p<0.001, η^2=0.712). Simple effects analyses revealed that, controlling for group, the difference between pretest and posttest scores was significant for subjects in the experimental group ($F_{(1,38)}$=991.825, p<0.001, η^2=0.973), as well as for subjects in the control group ($F_{(1,38)}$=364.251, p<0.001, η^2=0.924), and posttest scores for both groups were significantly lower than those in the pretest. For control time, there was no statistically significant difference between the scores of the two groups of subjects in the pre-test ($F_{(1,38)}$=0.235, p>0.05, η^2=0.008), and the scores of the two groups of subjects in the post-test were significantly different ($F_{(1,38)}$=29.523, p<0.001, η^2=0.459), and the experimental group of subjects' scores in the pre-test were not significantly different from the control group, and their scores in the post-test were significantly lower than that of control group subjects.

On the social tendency factor, the main effect of group ($F_{(1,38)}$=81.467, p<0.001, η^2=0.712), the main effect of time ($F_{(1,38)}$=842.635, p<0.001, η^2=0.972), as well as the interaction between the two were significant ($F_{(1,38)}$=110.537, p<0.001, η^2= 0.756). A simple effects analysis revealed that when controlling for group, the difference between the pre and post-test scores of subjects in the experimental group was significant ($F_{(1,38)}$=764.829, p<0.001, η^2=0.963), as well as the difference between the pre and post-test scores of subjects in the control group ($F_{(1,38)}$=185.161, p<0.001, η^2=0.849), and that pre-test scores of subjects in both groups were significantly higher than the posttest. At control time, there was no significant difference between the scores of the two groups in the pre-test ($F_{(1,38)}$=0.238, p>0.05, η^2=0.006), and the scores of the post-test were significantly lower than those of the control group ($F_{(1,38)}$=52.372, p<0.001, η^2=0.608).

On the social communication factor, there was a significant main effect of group ($F_{(1,38)}$=5.864, p<0.05, η^2=0.151), a significant main effect of time ($F_{(1,38)}$=324.619, p<0.001, η^2=0.915), and a significant interaction between the two ($F_{(1,38)}$=18.252, p<0.001, η^2=0.348). The simple-effect analyses followed. With group as an invariant, the experimental and control groups demonstrated statistically significant differences between the pre- and post-test scores (p<0.001) with the post test findings of both groups being statistically significantly lower than the pre-test findings. At posttest, there was a significant difference between the two groups when time was constant($F_{(1,38)}$=12.614, p<0.01, η^2=0.265); however, there was no significant difference between the two groups at pretest ($F_{(1,38)}$=1.208, p>0.05, η^2=0.037). Such results suggest that the experimental and control groups were not significantly different prior to the intervention, but the experimental group scored significantly lower on the posttest than the control group following the intervention.

On the social participation factor, the group main effect ($F_{(1,38)}$=16.384, p<0.001, η^2=0.325), the time main effect ($F_{(1,38)}$=521.432, p<0.001, η^2=0.947), and the interaction between the two ($F_{(1,38)}$=175.203, p<0.001, η^2=0.842) were all significant. Simple effects analysis showed that in the control group, there were significant differences in the scores of the experimental group ($F_{(1,38)}$=642.645, p<0.001, η^2=0.958), and the difference in the scores of the control group was also significant ($F_{(1,38)}$=48.593, p<0.001, η^2=0.586), that is, the scores of the two groups were significantly lower than those in the previous test. Controlling for time, there was no statistically significant difference between the scores of the two groups of subjects in the pre-test ($F_{(1,38)}$=4.286, p>0.05, η^2=0.114), and a significant difference between the scores of the two groups in the post-test (F(1,38)=113.725, p<0.001, η^2=0.766).

On the self-regulation factor, the group main effect was not significant ($F_{(1,38)}$=2.571, p>0.05, η^2=0.072), and the time main effect ($F_{(1,38)}$=359.637, p<0.001, η^2=0.920) as well as the interaction between the two ($F_{(1,38)}$=5.384, p<0.05, η^2=0.141) were significant . Simple effects analyses were then conducted and found that when controlling for group, the difference between the pre and post-test scores of subjects in the experimental group ($F_{(1,38)}$=227.446, p<0.001, η^2=0.875) and the pre and post-test scores of subjects in the control group ($F_{(1,38)}$=142.653, p<0.001, η^2=0.806) was significant, indicating that post-test scores of both groups were significantly lower than the pre-test were significantly lower. When controlling for time, there was no significant difference between the scores of the two groups of subjects in the pre-test ($F_{(1,38)}$=0.242, p>0.05, η^2=0.009), and the scores of the experimental group of subjects in the post-test were significantly lower than those of the control group ($F_{(1,38)}$=5.258, p<0.05, η^2=0.115).

While on the social cognitive factor, the main effect of group was not significant ($F_{(1,38)}$=0.341, p>0.05, η^2=0.009), the main effect of time was significant ($F_{(1,38)}$=321.495, p<0.001, η^2=0.914), and the interaction between the two was not significant ($F_{(1,38)}$=0.175, p>0.05, η^2= 0.006). The post hoc analysis revealed that there was no statistically significant difference between the scores achieved by the two groups of participants. Conversely, the difference between pretest and posttest outcomes was found to be statistically significant and this time it was posttest outcomes that were significantly low compared to pretest outcomes.

In summary, it can be seen that the virtual visual environment based on VR technology helps the early intervention of social skills of autistic children, and can effectively improve the level of social skills of autistic children.

Table 7: Descriptive statistics of the ASSS pre - and post-test scores (M±SD)

Variable	Experimental group (N=20)		Control group (N=20)	
	Pre-test	Post-test	Pre-test	Post-test
Total score	94.52±5.94	124.27±5.89	93.62±6.49	113.41±8.56
Social trend	20.62±1.71	28.04±1.52	20.74±1.91	24.35±1.83
Social cognition	22.04±1.83	28.01±1.98	22.49±2.02	28.42±2.84
Social communication	16.27±1.87	20.35±1.91	15.83±1.93	18.34±2.41
Social participation	19.15±1.38	26.44±1.42	20.25±1.82	22.16±1.35
Self-regulation	16.85±1.54	22.58±2.13	16.14±1.35	21.05±2.42

5 Conclusion

The research creates a novel VR-based virtual visual setting, which has been experimentally proven to be effective in the initial social-skills training of autistic kids.

Compared with the bare-eye situation, the scores of the autistic children samples in the four visual scenes were significantly improved after wearing the VR glasses, which indicates that VR technology can enhance the sense of immersion and cognition of the visual scenes of autistic children. Among the four visual scenes, Vision 2 Color Landscape Corridor has the highest immersion score of 45.7, which is the optimal solution in the overall visual space design, followed by Vision 4 Colorful Entertainment Space. After optimizing Vision 4, its popularity and immersion were significantly increased, and the optimized scenario had a heart rate calming effect on autistic children.

Combining Vision 2 and Optimized Vision 4, a sample of autistic children was selected for social skill intervention experiments. Compared with the control group that was trained in daily social education, the experimental group that used the VR visual scene effectively improved the social skill dimensions of social tendency, social cognition, social communication, social participation, and self-regulation ($p<0.05$), which verified the feasibility of the proposed intervention method.

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