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A First-Person Immersive VR Experience Framework: Perceiving the World Through the Lens of Individuals with Autism Spectrum Disorder

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Abstract. Individuals with Autism Spectrum Disorder (ASD) often face public misunderstanding due to their sensory processing abnormalities and social information interpretation biases, leading to insufficient social inclusion and low compliance with clinical rehabilitation. Existing applications of Virtual Reality (VR) technology in the ASD field primarily focus on social training for patients, lacking first-person experience frameworks tailored to public cognitive empathy. Additionally, these applications suffer from poor individual adaptability and low scene realism. This study constructs a three-in-one VR first-person experience framework (scene modeling, sensory simulation, and interaction design) based on mature VR technical solutions and clinical research data on ASD from the past five years. By integrating existing literature cases and clinical data, this study demonstrates that the framework can improve the public's understanding of ASD-related sensory issues and increase family members' compliance with rehabilitation programs. This research provides a theoretical reference and implementable design paradigm for VR-assisted cognitive empathy and rehabilitation support for ASD, enriching interdisciplinary studies at the intersection of human-computer interaction technology and special education.

Keywords: VR Technology, Autism Spectrum Disorder (ASD), First-Person Perspective Experience, Sensory Simulation, Cognitive Empathy

1. Introduction

Data from the World Health Organization shows that the global incidence of Autism Spectrum Disorder (ASD) has reached 1 in 160. One of its core characteristics is sensory processing heterogeneity, manifested as hypersensitivity to specific frequency ranges of sound or flickering light, and biases in interpreting multimodal social signals (e.g., language, facial expressions, and tone) [1]. However, public understanding of ASD still remains at the level of "behavioral manifestations" (e.g., social avoidance, repetitive behaviors), lacking empathy for core sensory differences such as sensory overload-induced emotional outbursts and social misunderstandings caused by signal interpretation biases. A domestic survey indicated that only 32% of the public could understand that ASD children's resistance to going out stems from sensory overload, while

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68% of parents had been misunderstood as poorly disciplined when their children had emotional outbursts in supermarkets [2]. This cognitive disconnect severely hinders the effectiveness of ASD rehabilitation and the construction of an inclusive social environment.

VR technology, with its unique advantage of first-person immersive experience, allows experiencers to experience firsthand the perceptual world of individuals with ASD. However, existing research has obvious gaps: first, application scenarios focus on patient-side training (e.g., virtual social dialogues), with insufficient empathy experience frameworks for the public cognitive end [3]. Second, the few existing experience programs adopt "one-size-fits-all templates" that do not incorporate clinical sensory data of ASD, resulting in low scene realism and poor individual adaptability [4].

This core goal of the study is to design a logically consistent, parameter-traceable, and clinically aligned VR first-person experience framework based on existing mature VR tools (e.g., open-source modeling software, classic sensory simulation algorithms) and clinical research findings on ASD. This research deeply combines the characteristics of VR technology with the sensory pathological features of ASD, filling the theoretical gap in VR-based empathetic experience for public cognition.

2. Literature review and theoretical foundation

2.1. Research on core sensory characteristics of individuals with ASD

Consensus-based conclusions on ASD-related sensory differences have been formed in domestic and international studies, providing direct references for the parameter design of VR scenarios:

Auditory Dimension: A follow-up study of 300 children with ASD by Baranek et al. ound that 70% of patients are hypersensitive to high-frequency noise (2000–4000 Hz, e.g., supermarket checkout beeps, children's screams) [1]. When noise intensity exceeds the daily environment by 30%–50%, they exhibit symptoms such as increased heart rate (>100 beats per minute) and emotional outbursts. Additionally, patients lack the ability to automatically filter out irrelevant noise, leading to auditory overload as background noise floods their perceptual systems without differentiation.

Visual Dimension: Experiments by Simmons et al. showed that individuals with ASD are significantly more sensitive to dense color blocks and flickering light sources than the general population [5]. When visual stimulus density exceeds 15 items per square meter (e.g., dense product labels in supermarkets) and flickering frequency ranges from 5–10 Hz (e.g., some LED lights), 62% of patients experience visual overload symptoms such as difficulty concentrating and eye discomfort. The eye-level height of child patients (approximately 1.2 meters) further amplifies low-level visual interference (e.g., floor patterns, others' foot movements).

Social Information Processing Dimension: Tager-Flusberg's social cognition research notes that individuals with ASD struggle to integrate multimodal signals (e.g., language, facial expressions and tone) [6]. Approximately 68% of these individuals cannot recognize "jokes" through facial expressions and may interpret sarcastic remarks such as "You did 'great' on the exam" as literal praise or criticism [6]. Moreover, the "magnified eye details" (e.g., pupil changes, eye movements) during eye contact cause sensory stress, leading 83% of patients to actively avoid eye contact.

2.2. Application status of VR technology in the ASD field

Existing VR applications for ASD can be divided into into two categories: "patient training" and "cognitive science popularization," with obvious limitations in the latter.

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Patient Training: For example, a review by Lorenzo et al. showed that 85% of programs focus on social training (e.g., virtual supermarket shopping dialogues, classroom question simulations) to improve patients' adaptability through gradual desensitization [3]. Some programs also integrate physiological feedback devices (e.g., heart rate bracelets) to adjust scenario difficulty. However, these programs all take patients as the main experience subjects and do not address the need for public empathy.

Cognitive Science Popularization: Sensory stimulus intensity is uniform (e.g., 50% noise amplification), which fails to match the sensory spectral differences of individuals with ASD. As a result, only 30% of experiencers believe the experience aligns with clinical descriptions [4].

2.3. Supporting role of cognitive empathy theory

Cognitive empathy theory provides a core logic for the value of VR experiences: Understanding others requires three stages, including cognitive recognition, emotional empathy and behavioral transformation [5]. Traditional science popularization (e.g., reading manuals) can only achieve cognitive recognition (knowing that individuals with ASD are sensitive to noise), while VR first-person experiences can trigger emotional empathy, allowing experiencers to understand the pain of noise overload through personal experience, which in turn transforms into inclusive behaviors (e.g., lowering voice volume in public) or optimized care actions (e.g., cutting off clothing tags).

This theory clarifies the core goal of the framework in this study: activating emotional empathy through sensory immersion to ultimately promote positive cognitive and behavioral transformation.

3. Design of the VR first-person experience framework

All module designs are grounded in existing mature VR technologies and clinical data on ASD, ensuring implementation without original development.

3.1. 3D scene modeling module

Tool Selection: Blender 3.6, an open-source software, is used for modeling. This tool supports high-detail 3D reproduction and is compatible with clinical data import (e.g., adjusting eye-level height). It has been verified by Zhang et al. in VR medical projects to meet the scene reproduction needs for ASD [7].

Basis for Scene Selection: Referring to the "Ranking of High-Frequency Emotional Problem Scenarios for Children with ASD" in the Guidelines for the Prevention and Treatment of Autism Spectrum Disorder in China, four core scenarios are selected: supermarket (68% of emotional problems occur here), classroom (45% of attention problem scenarios), family dining table (32% of communication conflict scenarios), and park social interaction (28% of social misunderstanding scenarios) [8].

Key Parameter Design: The density of product labels is set to 18 per square meter (referring to Simmons et al.'s conclusion that "the visual overload threshold for children with ASD is >15 items per square meter") [5]. The distance between the checkout counter and queuing crowds is 3 meters (matching clinical data that "children with ASD are most sensitive to crowd movements within 1.5–3 meters").

Classroom scenario: The distance between desks and chairs is 0.8 meters (to avoid "interference from others' movements at close range"), and the font size on the blackboard is 3 cm (based on visual clarity tests for children at an eye-level height of 1.2 meters) [9].

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All scenarios adopt either a “1.2-meter child eye-level height” or a “1.6-meter adult eye-level height” to match the real perceptual height of individuals with ASD across different age groups.

3.2. Sensory simulation module

Auditory Simulation: The FFT audio filtering algorithm, widely used in medical VR is adopted to amplify the intensity of high-frequency noise (2000–4000 Hz, the sensitive frequency range for ASD) by 40% (referring to "overload threshold for patients with moderate sensitivity") [1]. The automatic background noise filtering function is disabled to simulate the state of undifferentiated noise influx.

Visual Simulation: Physically Based Rendering (PBR) technology (a built-in function of the Unity engine, no development required) is used to enhance visual interference. Edge highlighting is added to dense color blocks (e.g., product labels), and the flickering frequency of light sources is set to 5 Hz [5].

Social Information Simulation: Based on Tager-Flusberg’s research on social interpretation biases, ,when a friend tells a joke, their expression shows no obvious smile, and their tone is close to serious, with only literal language information retained to simulate the "lack of social signals" faced by individuals with ASD [6].

3.3. Interaction design module

The principle of minimal operation is followed to avoid diverting the experiencer’s attention from sensory perception:

Perspective Control: A first-person perspective is fixed throughout the experience, and free perspective rotation is disabled (to simulate the state of "inability to actively avoid interference" in individuals with ASD).

Operation Functions: Only two basic operations are retained—walking (controlled by the VR controller joystick) and pausing (triggered by the controller button). There are no functions for reducing noise or avoiding eye contact to evade interference.

Feedback Design: A 2–3 second response delay is set in social dialogue scenarios (referring to clinical observations of "social rhythm dislocation in children with ASD") to enhance the realism of the experience.

3.4. Modular design of experience content

Content is divided into daily high-frequency scenarios and key social scenarios based on the real needs of individuals with ASD. Each scenario clearly defines design basis + simulation goal to ensure alignment with the actual needs of individuals with ASD.

3.4.1. Daily high-frequency scenario module

This module focuses on scenarios that individuals with ASD encounter daily to help experiencers understand the root causes of their daily discomfort.

Supermarket Checkout Scenario: 68% of children with ASD have emotional outbursts at checkout counters with the core trigger being "dual auditory + visual overload";

Simulation Dimensions: Auditory (40% amplification of checkout beeps, crowd chatter, and cart friction sounds), Visual (edge highlighting of product labels, 5 Hz flickering of LED lights), Tactile (VR controller vibration to simulate crowd collision tactile sensation).

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Experience Goal: Allow experiencers to feel the fatigue of simultaneous multi-sensory overload and understand that"resistance to going out" is not due to introverted personality but sensory stress.

Family Dining Table Dialogue Scenario: 32% of family communication conflicts stem from multi-threaded information overload , such as simultaneously receiving family dialogue, kitchen noise, and TV sound.

Simulation Dimensions: Auditory (simultaneous playback of three types of audio to create multi-threaded interference), Visual (local magnification of family members' faces during speech to highlight eye detail stress), Information Processing (insertion of rhetorical questions like "Why aren't you eating your vegetables again?" in dialogues to simulate difficulties in interpreting linguistic ambiguities).

Experience Goal: Allow experiencers to feel the confusion of inability to focus on dialogue and understand that lack of response is not due to intentional non-cooperation but limited sensory processing capabilities.

3.4.2. Key social scenario module

This module focuses on social scenarios prone to misunderstandings to help experiencers understand the triggers of social avoidance.

Park Greeting Scenario: 83% of children with ASD avoid eye contact, with the core reason being visual stress during eye contact [6].

Simulation Dimensions: Visual (close-range eye contact with friends, 3x magnification of eye details), Auditory (sudden increase in the friend's tone to simulate tone interpretation bias), Feedback Delay (2-second delay in the friend's response after the experiencer speaks).

Experience Goal: Allow experiencers to feel eye contact stress and social rhythm dislocation and understand that avoiding eye contact is not due to impoliteness.

Classroom Joke Scenario:

Design Basis: 68% of children with ASD cannot recognize jokes and tend to misinterpret teasing as criticism [6].

Simulation Dimensions: Visual (no smile on the classmate's face when telling a joke), Auditory (weakened teasing tone, close to seriousness), Information Interpretation (only literal content is presented, with no contextual cues for jokes);

Experience Goal: Allow experiencers to feel the confusion of social misunderstandings and reduce negative evaluations of individuals with ASD as sensitive or overly serious.

4. Demonstration of the framework's application value

Based on case data and clinical effects from existing literature, the application value of this framework is demonstrated from three dimensions—public cognition, care optimization, and clinical rehabilitation. All conclusions are derived from "existing effects of similar programs and derivations from the optimization points of this framework to ensure the rigor of the demonstration.

4.1. Enhancing social inclusion for public cognition

Existing VR science popularization cases have verified that immersive experiences are superior to traditional science popularization, and this framework can further improve effectiveness through scenario optimization.

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ASD-related sensory differences was 42% higher in the traditional VR science popularization group (without social scenarios and clinically aligned parameters) than in the text science popularization group, and the proportion of people willing to provide help in public increased from 35% to 68%. The optimization points of this framework include: first, adding social misunderstanding scenarios (e.g., joke interpretation scenarios) to cover the social cognitive gap not addressed by existing science popularization. Second, designing scenario parameters based on clinical data (e.g., 18 labels per square meter), improving experience realism. Referring to Li et al.'sresearch conclusion that every 10% increase in scenario realism leads to an 8% increase in understanding, the increase in understanding through this framework can reach over 50%, and the proportion of active help willingness can rise to approximately 75%.

4.2. Improving care accuracy and compliance

Perceptual empathy among parents and teachers directly affects care effectiveness, and this framework can help them understand "the sensory causes behind behaviors.

A case showed that after parents participated in basic VR experiences (without personalized parameters), their understanding of children's resistance to new clothes due to tag friction increased from 25% to 68%, and the number of "conflicts in family care decreased by 35% [8]. This framework further strengthens caregivers' sensory empathy through scenario detail optimization (e.g., adding tactile feedback simulation of clothing tag friction).

4.3. For clinical rehabilitation: assisting program communication and personalized treatment

VR experiences can serve as rehabilitation program communication tools to improve family compliance while providing references for practitioners.

Clinical data from showed that after rehabilitation specialists used "basic VR experiences" to assist program communication, family compliance with sensory desensitization training (e.g., gradual exposure to mild noise) increased from 62% to 89%, and the rehabilitation cycle for children was shortened by 15% [8]. The framework can match patients with corresponding scenarios (e.g., auditory sensitivity-specific scenarios) based on their sensory type (e.g., auditory sensitivity, visual sensitivity), helping families understand why this program is designed for their child. Second, using scenario parameters as treatment references (e.g., rehabilitation specialists can adjust the intensity of desensitization training based on the patient's response to 40% noise intensity).

5. Discussion

5.1. Limitations

Although the framework's parameters are designed based on clinical data, ASD sensory differences exhibit spectral characteristics (e.g., some patients are sensitive to 2000 Hz noise, while others are sensitive to 4000 Hz noise). Existing fixed-parameter scenarios still cannot fully cover all individuals. Professional VR equipment (e.g., PC-based headsets) costs highly, which is difficult for grassroots rehabilitation institutions and families in remote areas to afford, limiting the framework's promotion. Meanwhile, existing cases mostly focus on short-term cognitive changes after experience, lacking tracking data on how experiences affect care behaviors and social inclusion in the long term.

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5.2. Future directions

Personalized Scenario Matching: Referring to Li et al.'s (2024) "scale-scene binding" idea, the patient's sensory sensitivity type (e.g., auditory sensitivity) and intensity level (moderate) are determined through the SPM scale, and the corresponding scenario module (auditory sensitivity scenario) and parameters (40% noise amplification) are automatically matched.

Mobile AR Alternative Development: Developing a mobile AR alternative version that uses the mobile phone camera to recognize real scenes (e.g., family dining tables, supermarkets) and overlay sensory simulation effects (e.g., amplifying environmental noise, flickering screen color blocks) [10].

Long-Term Behavioral Tracking: based on Decety & Jackson's cognitive empathy theory, after the experience, the ASD Care Behavior Scale and Public Inclusive Behavior Questionnaire are used to conduct 3-month and 6-month follow-ups with parents and the public, respectively, recording behaviors such as whether care methods were adjusted" and "whether help was provided in public." Tracking data can be collected through "online questionnaires" without complex experimental design, filling the research gap in long-term effects [11].

6. Conclusion

Based on existing mature VR technical solutions and clinical research data on ASD, this study constructs a three-in-one VR first-person experience framework (scene modeling, sensory simulation, interaction design) and designs a dual-module content system covering daily and social scenarios. All parameters are anchored to core literature conclusions from the past five years, ensuring the framework's technical feasibility and clinical adaptability. By integrating secondary cases and data, this study demonstrates the framework can improve the public's understanding of ASD-related sensory differences and increase family members' compliance with rehabilitation programs. It provides a theoretical reference and implementable design paradigm for VR-assisted cognitive empathy and rehabilitation support for ASD.

However, this study focuses on short-term experiences and its scope is relatively limited. Future research can explore on personalized scenario generation and long-term behavioral transformation tracking to further improve the theoretical system and practical application of VR technology in the ASD field.

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