Exploring Effects of Interactive Virtual Reality Sensory Environment on Anxiety Reduction in Adolescents with Autism

Amaya E. Keys
Howard University
USA
woodomcoleman2011@gmail.com

Oyewole Oyekoya
CUNY Hunter College
USA
oo700@hunter.cuny.edu

Daniel Chan
CUNY School of Professional Studies
USA
daniel.chan@spsmail.cuny.edu

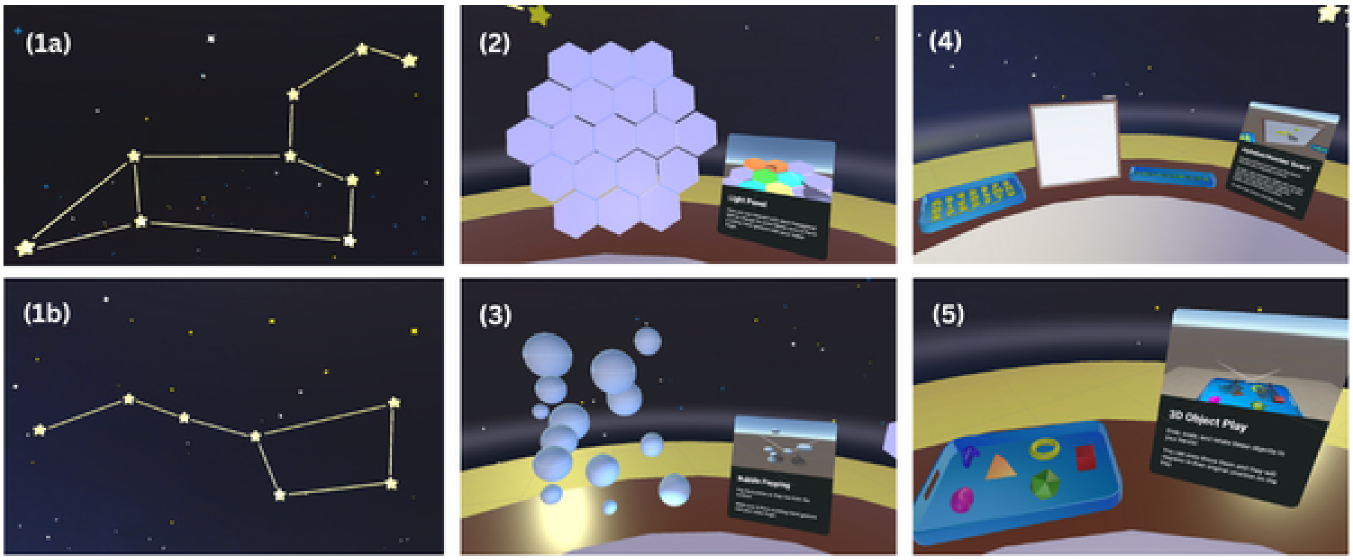

Figure 1: Five interactive activities present within the virtual environment: (1a) Leo Constellation, (1b) Big Dipper Constellation, (2) Light Panel, (3) Bubble Popping, (4) Alphabet and Number Board, (5) 3D Object Play.

Abstract

Autism Spectrum Disorder (ASD) is a developmental disability often characterized by sensory processing difficulties that can lead to anxiety, particularly in children and adolescents. Previous research on virtual reality-based anxiety intervention tools focuses on using social skills training, exposure therapy, and meditative coaching to mitigate social and phobia related anxiety. However, minimal work has specifically evaluated the effects of virtual multi-sensory environments for people with ASD, often only testing feasibility. This pilot study aims to build on previous work by investigating how various auditory, visual, and interactive components contribute to user satisfaction and sensory-related anxiety reduction. The objective is to gain a better understanding of what features are significant towards developing a successful virtual anxiety intervention tool. Results suggest using interactive activities that promote fine motor skills can provide a healthy outlet for self-mediated stress relief. Future development aims to incorporate task-based activities, and enhance audio, visual, and lighting displays. The deployment of a full-scale study with a larger sample size and target participant pool is warranted to substantiate these initial findings.

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• **Human-centered computing → Virtual reality**; • **Computing methodologies → Virtual reality**.

Keywords

virtual reality, autism spectrum disorder, anxiety, sensory environment, interactive, unity

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1 Introduction

In recent years, researchers have studied the use of virtual reality (VR) as a treatment tool for people experiencing severe anxiety and panic, such as individuals diagnosed with social anxiety disorder and generalized anxiety disorder. It is most commonly used as a preparation tactic for future anxiety-provoking events and as a tool to reduce heightened anxiety caused by external stimuli. This method has been modified and replicated to aid individuals diagnosed with Autism Spectrum Disorder (ASD) experiencing anxiety. While ASD is a heterogenous condition characterized by differing symptoms and severity levels, common indicators include social and communicative impairments as well as restricted and repetitive behaviors onset from youth [12]. Children and adolescents with ASD are also more likely to experience higher levels of anxiety than their neurotypical counterparts, interfering with their daily functioning and quality of life [13]. VR-based anxiety intervention for people with ASD is often performed in one of three techniques: 1) social skills training to combat challenges with navigating social interactions, 2) exposure therapy to overcome specific phobias such as animals, crowded spaces, or interviews and 3) calming virtual environments and meditative coaching to manage stress [20].

Sensory processing difficulties are prevalent in individuals with ASD and often co-exist with anxiety [11]. Physical sensory spaces, referred to as Snoezelen rooms or multisensory environments (MSEs), utilize stimulating and relaxing sensory equipment to facilitate relaxation and learning for persons with developmental disabilities [5]. While extensive research has been conducted using the above VR techniques for anxiety reduction, less work has been done to transform these sensory environments into virtual spaces. One of the first implementations of a VR-based sensory room for individuals with disabilities, called the Evenness sensory room, showed both quantitative and qualitative evidence of decreased anxiety [19].

This study aims to investigate the efficacy of the use of interactive, sensory stimulating VR for anxiety reduction in adolescents with ASD , both during and post-exposure. VR-based sensory rooms provide a more accessible, portable, individualized and lower cost alternative to traditional MSEs. There exists a highly interconnected relationship between sensory experiences, pain and anxiety for individuals with ASD—all of which are intensified in the presence of one another [8]. Thus, there is a significant need for further developed anxiety management techniques and coping strategies for individuals with ASD, particularly adolescents and those with additional developmental comorbidities. With this study's focus on such, we hope to gain a better understanding of VR's capabilities as a beneficial anxiety intervention tool.

2 Related Work

A large majority of research that has gone into the use of VR for anxiety management in individuals with ASD targets social and phobia-related anxiety through virtual reality exposure therapy (VRET). About 40% of youth with ASD have a comorbid anxiety disorder (e.g., obsessive compulsive, specific phobia, or generalized anxiety disorders) or clinically elevated levels of anxiety—inflicting functional limitations on daily treatment and care [24]. Children with fears like crowded environments or animals showed improvements in mitigating their phobias immediately post-VRET treatment as well as 2 weeks to a year post-treatment [14–16]. Additionally, when used to divert one's attention from painful or uncomfortable dental procedures, interactive VR has output statistically significant results ($p < 0.05$) for positively influencing anxiety reduction scores in children diagnosed with ASD [17, 23]. However, this mode of intervention is not successful with all participants. Morag Maskey and her colleagues [14] found that one child experienced no change in response to exposure to anxiety-provoking stimuli, another child's symptoms worsened, and in several other studies, only high-functioning individuals on the spectrum were included [18].

A similar contrast in outcomes has occurred when VR is used for social and emotional skills training for children with ASD that have difficulty navigating social situations. Improved performance in emotion expression and regulation, sense of self-worth, proactive interaction initiation, and interpersonal conflict management has surfaced following immersion in virtual social scenarios [9, 25]. This research has also been limited to the inclusion of only individuals with high-functioning autism in experimental groups, calling for a need to assess intervention for varying ASD severity levels. The variability in outcomes between subjects for social skills training and specific phobia therapy has led researchers to identify persuasibility as an important feature towards the efficacy of VR interventions.

Aside from operative, social, and phobia-related anxiety, a fourth cause for anxiety prevalent in adolescents with ASD is sensory processing difficulties. These challenges manifest in the form of sensory overresponsivity, sensory underresponsivity, or sensory seeking behaviors—behaviors that all pose a threat to carrying out environmental demands [22]. Multi-sensory environments are one treatment method that aims to provide a safe space for the child to be in control of their own sensory intake and stimulation. These spaces provide a range of visual, tactile, and auditory stimuli at the child's disposal, such as bubble tubes, ball pools, sound boards, projectors, and fiber optic lighting [5]. Autistic children with exposure to these multi-sensory environments have shown improvements in anxiety levels as well as challenging sensory behaviors (i.e., sensory seeking or avoiding) [10]. Due to accessibility limitations with physical sensory environments, there has been further exploration into the development of interactive virtual spaces. Implementation of virtual sensory games and spaces such as the Evenness sensory room, Blue Room, Magic Room, DEEP and numerous others have produced similar outcomes to their physical predecessors [2, 6, 19].

Despite promising results in this field of study, there are several factors that prior research has revealed as points of improvement for future implementation. The work presented in this study aims to build on previous research to advance understanding of the relationship between virtual reality intervention, sensory processing related anxiety, and autistic adolescents. While earlier work focused on assessing the feasibility of VR as an anxiety management tool, we focused on how the inclusion and application of various interactive factors affects recipient satisfaction. Previously developed virtual multisensory environments primarily provided auditory and visual stimuli, and while the results proved the occurrence of anxiety reduction, passive VR has been less successful in capturing a child's attention and reducing anxiety levels than interactive VR [4]. VR games for adolescents with ASD reap the benefits of interactivity but have been found to be demotivating in the instance of less than perfect performance. In an environment like ours, we can study the positive effects of interactivity and dynamics without the negative effects of discouragement evoked by a game. Furthermore, Bartoli et. Al [1] devised a set of guidelines for features to be included in technology-based interventions for children on the autism spectrum, two of which were clear instructions, and repeatable and predictable tasks. Mills et. Al [19], in the use of the Evenness sensory room, found that users' experiences were enhanced when demonstrations and verbal prompts were given by staff, suggesting positive outcomes if such were to be incorporated into the environment itself. Users would be able to familiarize themselves with the system, predict its expectations, and subsequently be able to develop a routine.

3 Methodology

3.1 Environment Overview

The virtual environment was developed using the 2022 version of the Unity3d game engine. It was equipped with hand tracking and interactive functions compatible with the Meta Quest 2 headset using the XR Interaction Toolkit and Meta Interaction SDK. The user spawns into the space surrounded by a round surface topped with various activities. To limit unnecessary confusion or frustration from needing to teleport to various areas around a large room, each element the user wishes to interact with can be reached by taking small steps in each direction.

3.2 Interactive Components

The virtual space has five key sensory activities for the user to interact with: an alphabet/number board, a color changing light panel, bubble popping, glowing stars, and 3D object play. The alphabet/number board aims to resemble a magnetic surface that users can freely move letters and numbers upon. They must first press the desired character from the tray and a clone of it will appear on the board. It can only be dragged along the x- or y-axis up to the borders of the frame. To remove all characters from the board surface, the user must press the 'clear' button above the frame. The light panel is arranged in a hexagonal grid pattern, with each hexagon scripted to change color upon touch. Each hexagon on the panel also has a button visual and audio, emulating the sensation of an actual button press. At the bubble popping station, users can interact with an infinite stream of bubbles rising from the counter surface. Upon touch, the bubble disappear and play a popping sound effect. The 3D object play includes a tray of 3D shapes (i.e., a cube, heart, arrow, torus, pyramid, and icosahedron) that can each be picked up, scaled or rotated by hand, or thrown, upon which it respawns on the tray in its original size and position. Lastly, the user can look towards the ceiling to see an array of 3D stars upon a dark sky-like background. Users must aim the ray extending from their hands at each star and perform a pinching gesture of the index finger and thumb to "activate" them. When a user activates two stars, they each brighten, and a glowing path is drawn between them. With each star lit and all paths activated, the user will be able to visualize two constellations known as the Big Dipper and Leo. To deactivate the stars and their paths, the same pinching motion must be performed.

3.3 Visual and Auditory Components

Beside each interactive element is a text interface detailing how to interact with each object to get the intended result as well as a short video demonstration. The user will have the option to play ambient audio, such as piano music, rain or ocean sounds that can be turned on or off at any time while immersed in the environment. Each activity has a sound effect associated with its action to enhance interactivity and dynamics (e.g., button presses, star lighting or bubble popping).

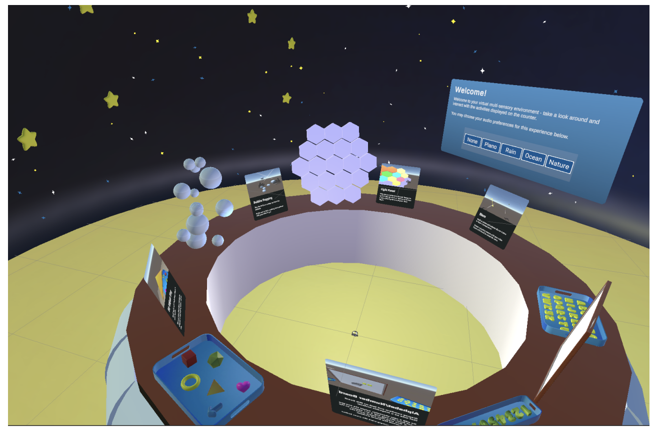

Figure 2: Full view of the virtual environment

3.4 Study Protocol and Measures

Staff members and fellow student researchers were recruited as participants. Upon arrival for the study, participants were briefed on its purpose as well as potential risks and benefits. They were then prompted with general pre-determined scenarios of potentially overwhelming sensory stimuli, such as harsh lighting, crowded spaces, loud or persistent sounds, "busy" details, and unpleasant tactile sensations. They were then prompted to imagine sensory scenarios that are specific to their personal dislikes. Any prominent feelings or emotions of anxiety and worry pre-exposure were documented through an 11-question anxiety questionnaire modified from the Glasgow anxiety scale for people with intellectual disabilities (GAS-ID) [21]. They rated the following questions on a 3-point scale of (0) no, (1) a little or (2) a lot, allowing for a maximum possible score of 22:

- Do you feel wound up, worked up or uptight?
- Do you currently have a lot of thoughts in your head?
- Are you worried that something bad will happen in the current moment?
- Are you currently worried about what will happen in the future?
- Are you hot and sweaty?
- Is your heart beating fast?
- Are your hands and legs shaking?
- Are there butterflies in your stomach (knots or a fluttering sensation)?
- Is it currently hard to breathe?

- Are you having difficulty sitting still/relaxing?
- Do you feel panicky?

Finally, after being informed that they may stop participation at any time due to discomfort or sickness, the headset was fitted for the user, and they were instructed to explore the environment for as long as they would like while the researcher kept record of time. After completion of the experience, feelings of anxiety and worry were again documented using the anxiety questionnaire. Participants were then asked to rate how each interactive, auditory or visual element contributed to satisfaction and perceived feelings of anxiety relief on a 5-point numeric rating scale followed by open-ended feedback expanding on each of their ratings. Lastly, they were asked to offer their likes and dislikes with the environment, what changes they would recommend, and if they view this application as a practical anxiety intervention tool.

4 Results

The pilot study was completed by 7 neurotypical participants between the ages of 20 and 44, consisting of 3 females and 4 males. Results revealed a statistically significant decrease (p=0.008) in self-reported anxiety scores from pre-intervention (M=7.43, SD=3.83) to post-intervention (M=2.00, SD=1.83), with a medium to large effect size (η^2=0.72). Scores decreased by a mean value of 5.43 from pre-intervention. Participants remained within the environment for an average of 5 minutes and 15 seconds.

The post-intervention survey results revealed an average overall satisfaction rating of 4.57 and an average of 4.23 in perceived overall effectiveness of anxiety reduction. An analysis of individual element ratings revealed that the sound effects and 3D shapes made the greatest contribution towards user satisfaction, both with a mean of 4.57. The elements with the lowest contribution towards user satisfaction were the video demos and color changing light panel, both with a mean of 3.43. Similarly, the element with the highest contribution towards perceived anxiety reduction was the 3D shapes, with a mean of 4.43. Tables 1 and 2 summarize further results on individual element ratings toward user satisfaction and anxiety reduction.

Written feedback revealed users received gratification and enjoyment from the sound effects, 3D shapes and bubble popping, supporting the above ratings of the most liked elements. Comments also noted the creativity and uniqueness of the activities as well as the abundance of choices as highlights of their experience. Many users experienced difficulty with the selection of stars despite visual and verbal instruction. Recommendations for improving the lighting and audio displays were offered as potential solutions to creating a further integrated system (i.e., less harsh lighting, option for a daytime setting, 'dialed down' audio to reduce distractions, and audio buttons that highlight on select). One user also expressed that the circular layout of the environment brought confusion.

5 Discussion

Participants reported high ratings of overall satisfaction and anxiety reduction with the use of the virtual environment, namely due to their interaction with the 3D shapes, bubble popping, and action-based sound effects. All participant anxiety scores reflected a

Table 1: Average ratings of features' contribution towards satisfaction with environment.

	Mean Rating
3D Objects	4.57
Sound Effects	4.57
Bubbles	3.71
Text Instructions	3.71
Constellations	3.57
Ambient Audio	3.57
Light Panel	3.43
Video Demos	3.43

Table 2: Average ratings of features' contribution towards anxiety reduction.

	Mean Rating
3D Objects	4.43
Bubbles	4.14
Light Panel	3.86
Constellations	3.57
Sound Effects	3.71
Ambient Audio	3.57
Text Instructions	3.14
Video Demos	3.14

statistically significant decrease in anxiety post-exposure indicated by the p-value and a moderate to high strength in relationship between VR intervention and the decrease in anxiety scores indicated by the effect size. These findings suggest that the effects associated with the relationship between sensory play, play therapy and stress management can be replicated in a virtual environment. Applying one's fine motor skills using various sensory objects for exploratory play provides a healthy and engaging method for self-soothing and self-regulating stress [3, 7]. While this study does not include the process of verbally working through challenges with a trained professional as traditionally provided in cognitive behavioral play therapy, it does reap the therapeutic powers of play. The shape manipulation and bubble popping were simple and achievable, yet engaging activities that served as an outlet for stress relief and a distraction from real-world surroundings. Conversely, while participants liked the concept of the constellation activation task, they found that executing it was complicated and difficult. Consequently, it was rated lower on the user satisfaction and anxiety reduction surveys. Additionally, the average duration of time that participants spent within the environment was lower than anticipated, likely due to a feeling that they had exacerbated all options for interaction. Future technical development can address both matters by incorporating more achievable task-based activities to keep the mind busy and increase the length of immersion. This can include the fitting of the 3D objects into same-shaped receptacles similar to traditional shape sorting toys, and prompts read out during interaction with the alphabet/letter board to encourage the spelling of words or creation of simple stories. Future work will also aim to enhance the audio and visual systems based on gathered user feedback such as adjustable lighting settings and the option for multiple room layouts (e.g., a seated version or a rectangular counter surface). 'Read aloud' buttons within each text interface would also allow for the accommodation of children of various ages, reading levels, and preferences. It was observed that participants often disregarded the instructions and demos unless reminded, and instead resorted to asking questions first or attempting to work it out on their own. Therefore, a major target for refining the study protocol will be to provide a more in-depth explanation of the nature of the environment pre-exposure to reduce overwhelming feelings and ease transition into the space.

Despite hopeful findings, this study has a few limitations to consider. The execution of a preliminary study has the advantage of gathering insights to prepare for a full-scale project, but the disadvantages of an insufficient sample size and subject group. Due to time constraints, the sample consisted of only 7 participants, all of which are adults without autism or a history of sensory-related anxiety. The results obtained in this study may not accurately reflect results that would be obtained from a sample of children and adolescents with ASD and anxiety. Additionally, data could not be collected on the contributions ambient lighting and the alphabet/number board made to satisfaction and anxiety reduction as they were not included within the survey questions. The data collected on pre- and post-intervention anxiety scores was self-reported and, accordingly, ran the risk of being under or overexaggerated. Future work may incorporate the use of biofeedback to measure physiological body signals in conjunction with self-reported anxiety scores to receive a comprehensive assessment of anxiety reduction.

6 Conclusion

In this study, we investigated the effects of various auditory, visual, and interactive activities on anxiety reduction within a virtual reality sensory room. This work utilizes interactive 3D spaces and gesture-based interfaces to advance the field of mental health for individuals with developmental disabilities. Further evolved applications of this nature open the door to more accessible forms of anxiety intervention. While previous work solely evaluated feasibility, our work underscores the relevance and significance of individually evaluating the elements that contribute to these outcomes. An analysis of results provides us with notable points of improvement in both technical development and experimental design to further optimize the environment for its target audience. Although further testing is required to accurately and precisely investigate the effects of the environment on adolescents with autism, this preliminary study reveals the potential for VR developers to work with researchers and health professionals to provide the most optimal virtual experience for this group facing sensory anxiety.

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