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A Virtual Reality Application with Autistic Children

Abstract

Using the advantages of the sense of presence generated by virtual reality, a system to help children with autism was developed. Two case studies with children showed virtual reality has the potential to provide a safer, customized learning environment for individuals with autism. A model of reality that discusses historical and perceptual rules as well as input stimuli in forming a sense of presence is described.

1 Introduction

The American with Disabilities Act (ADA), Individuals with Disabilities Education Act (IDEA), and Section 504 of the Rehabilitation Act of 1973 have made the education of all children in the United States, including those with special problems, a guaranteed right. Unfortunately, effective treatment methods for children with serious learning problems do not always exist. Individuals with autism have proven particularly difficult to educate. Over half never learn to speak and simple actions can take years of personalized instruction. Autism symtomology involves an internal distortion of the external world. Virtual reality (VR) allows controlled distortion of the environment to better match the expectations of an individual. The purpose of this study was to determine if children with autism could respond to VR, and if they might benefit from the controlled, limited-input version of reality that VR can deliver.

2 Autism

High-functioning adult patients who can speak describe an overpowering world, "My hearing is like a hearing aid stuck on 'super loud'," according to T. Grandin (1992).

"I have an interfacing problem, not a core processing problem," writes J. Sinclair (1992).

> I can't always keep track of what's happening outside of myself, but I'm never out of touch with my core. Even at worst, when I can't focus and I can't find my body and I can't connect to space and time. . . . I taught myself how to read at 3, and I had to learn again at 10, and yet again at 17, and at 21, and 26. The words that took me 12 years to find have been lost again, and regained, and lost, and still have not come all the way back to where I can be reasonably confident they'll be there when I need them. It wasn't enough to figure out just once how to keep track of my eyes and ears and hands and feet

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all at the same time; I've lost track of them and had to find them again and again. But I have found them again. The terror is never complete.

2.1 Definition of Autism

Although there are inconsistent profiles across individuals diagnosed with autism (Tsai, 1992; Ritvo & Freeman, 1978; Rutter, 1978), three commonly found traits involve abnormal response to input stimuli, lack of human engagement, and the inability to generalize between environments. It is postulated that those with autism lack the ability to synthesize input stimuli (Mesibov, Schopler, & Kearsey, 1994; Wing, 1972; DesLauriers & Carlson, 1969). This profound abnormality in the neurological mechanism controls the capacity to shift attention between different stimuli, leading to distorted sensory input and over selectivity in attention to input stimuli (Courchesne, 1989; Orintz, 1985; Lovaas, Schreibman, Kroegel, & Rehm, 1971).

An inability to recognize and process similarities between different scenes may also account for the lack of generalization skills. This results in rigid, limited patterns of action and compulsive or ritualistic behaviors (Rutter, 1968).

2.2 Why VR May Be Useful with Autism

Both the strengths and limitations of VR appear well matched to the needs of autistic learning tools (Strickland, Marcus, Hogan, Mesibov, & McAllister, 1995). The following features are useful in mastering an autistic world and are attainable with VR:

Controllable Input Stimuli. Virtual environments can be simplified to the level of input stimuli tolerable by individuals with autism. Distortions in size and character of the components of reality can allow matches to the user's expectations or abilities. Distracting visual complexity, sounds, and touch can be removed and introduced in a slow, regulated manner.

Modification for Generalization. Minimal modification across similar scenes may allow generalization and decreased rigidity. A person taught to cross a virtual street in one scene might generalize to another street scene if the differences are reduced until the similarities are recognizable. An example might be two streets that are identical except for one building color. Differences could be increased slowly to teach cross-recognition.

Safer Learning Situation. A virtual learning world provides a less hazardous and more forgiving environment for developing skills associated with activities of daily living. Mistakes are less catastrophic and overall stimuli can be reduced. Dynamically adjustable programs permit complex skills, such as judging approaching car speeds when crossing streets, to be tested safely. Environments can be made progressively more complex until realistic scenes help individuals function safely in the real world.

A Primarily Visual World. VR presently stresses visual responses. Visualization has been effective in teaching abstract concepts to autistic children (Park & Youderian, 1974) and individuals with autism indicate their thought patterns are primarily visual (Grandin & Acariano, 1986).

Individualized Treatment. Individuals with autism vary widely in their strengths and weaknesses. Each individual may even demonstrate tremendous variation in skills and behavior between different days (Gregory, 1991; Kaplan & Sadock, 1990). Given this nonhomogeneity of abilities, an individualized approach to placement and training based on a careful, personalized assessment is essential (Schopler, 1987). Computers allow dynamic environments to compensate for changing patterns of development and inconsistent responses.

Learning with Minimal Human Interaction. The complexity of social interaction can interfere when teaching individuals with autism. As early as 1968, computers were used to assist language development therapy with autistic children (Colby, 1968). Advantages of computer learning aids have been reported in multiple studies (Chen & Bernard-Opitz, 1993; Plienis & Romanczyk, 1985; Panyan, 1984).

Vestibular Stimulation. An interesting match may exist between latency problems of trackers and abnormal vestibular functioning related to autism. Vestibular confusion appears to be less disturbing to individuals with autism, and in fact may be a positive reinforcer (Grandin, 1992). Sensory integration training interventions have been based, in part, on these vestibular responses (Ray, King, & Grandin, 1988).

3 A Learning Tool for Autism

Because of profound variations among people with autism and inconsistencies of response by any one individual from day to day, a case study approach using personalized world modification and assessment was selected for the tests. Two autistic children, a 7-year-old girl and a 9-year-old boy, took part in the study, which consisted of over 40 virtual exposures during a 6-week period. This allowed reverification of actions over a series of trials with each child. For safety considerations, no exposure was over 5 min.

Both children had been unequivocally diagnosed as autistic, based on test results, parent and therapist reports, behavioral observations, and early history. Neither child was classified as high-functioning.

3.1 Project Team

The project was a collaborative effort between the North Carolina State University Computer Science and Computer Engineering Departments along with staff and therapists from the Division for Treatment and Education of Autistic and other Communications Handicapped Children (TEACCH) at the University of North Carolina at Chapel Hill School of Medicine. Also active in the tests were parents, siblings, and teachers of the children.

3.2 Equipment Used

A ProVision 100 fully integrated VR system provided by DIVISION Inc. of Chapel Hill, NC was used. The ProVision contained Pixel-Plane hardware for fast image calculation, texture mapping of objects, and true perspective correction at up to 997 million pixels/sec with 24 bit color. Graphics performance was 300 K polygons per second with Phong shading and z-buffering. Software consisted of an object-oriented virtual reality development environment called dVS and a world authoring and simulation program dVISE designed to create virtual worlds on the DIVISION Inc. system. The tracker was a Polhemus Fastrak™. The headset was the Divisor made by DIVISION Inc. with a field of view of 41° vertically and 105° horizontally, with 75° per eye. Resolution was 345 horizontal by 259 vertical pixels. Stereo images were individually adjusted for the child's smaller IPD.

3.3 Learning Situation

The test design chosen was to duplicate a real-life training effort. The initial test was to train a child with autism to recognize a common object, which in our trials was a car within a street scene. Eventually the tests extended to attempting to train a subject to find an object in the environment, walk to it, and stop. Instructional training by therapists, several months previous to our tests, attempted teaching this skill to one of the subjects, with limited success. Eventually, such a skill could lead to the ability to cross a street alone.

Both children were minimally verbal. They could use a few select words such as car and blue, but could neither speak nor understand many normal sentence structures. Their color recognition was limited. To avoid complex instructions or hand controls, a potential problem in the only previous published work that attempted to use a virtual environment with autistic individuals (Kijima, Shirakawa, Hirose, & Nihei, 1994), short verbal instructions were used. Responses from the children were either one previously known word or performing the requested actions, such as turning their heads to find a car.

3.4 Specialized Test Adaptations

Because of extreme resistance to unfamiliar experiences shown by children with autism, familiar schedules, work, and play activities were introduced into the physi-

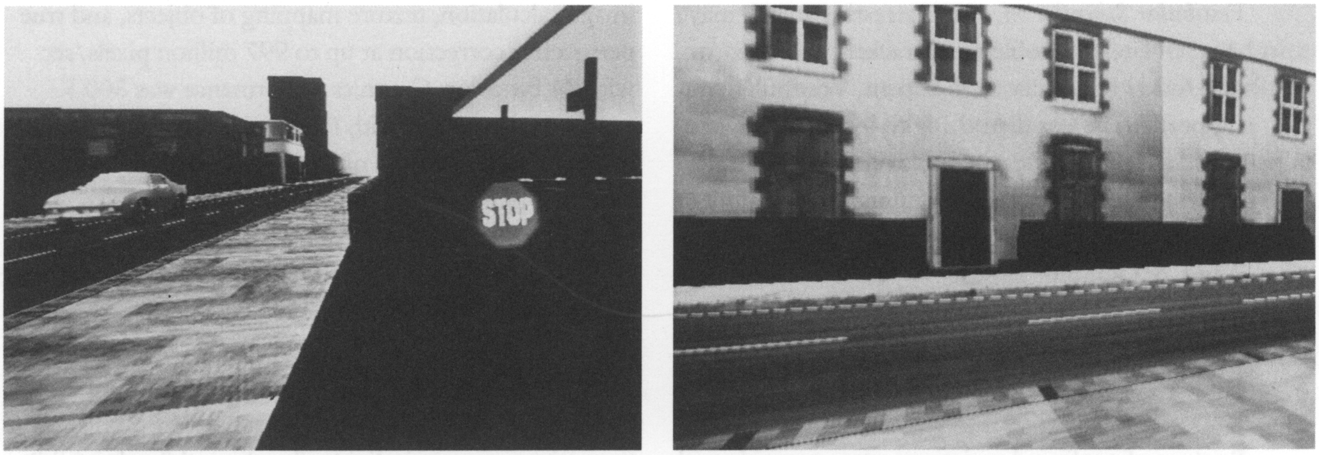

Figure 1. *Virtual street scenes, one with a stop sign and moving car.*

cal test area. Accustomed patterns from school were duplicated, with the introduction of short, original activities in the virtual helmet spaced between these known activities. A typical test sequence would include a child taking a premade schedule consisting of three visual cards clipped to a board, one for "play," one for "work," and one for "helmet." One card would have a picture of a play activity. The child would remove the card from the board, take the picture to a part of the room where there was an envelope with the same picture, deposit the card in the envelope, and then play in that area for several minutes with familiar toys. The child would then be handed the board, he or she would take the next picture from the board, and repeat the steps in another part of the room. This technique is part of a structured learning approach emphasized in the TEACCH program and used daily by both children in their normal school environment. When trials deviated from this regimented procedure, the children became agitated and were unwilling to continue the activities.

Many children with autism, including the ones chosen for this study, object to hats or helmets being placed on their heads. The available VR helmet weighed approximately 8 lb. There was concern that the children would not accept a heavy, enclosed head piece. Attempts were made to acclimate the children to a normal football or riding helmet while at home before the tests began. The girl put on a riding helmet only if she was allowed to go horseback riding. The boy initially refused all helmets but eventually allowed one to be placed on his head.

Older siblings of the children assisted in the tests by wearing the VR helmet and responding appropriately to the virtual environment while the parent attempted to have the autistic child watch, with varying success. The girl always expected to see someone use the helmet first, while the boy would not stay still long enough to watch his sister in the helmet. After the first trial, the sibling was not used again in the boy's tests.

Because the children were unable to verbally express problems or discomfort, helmet wearing was not forced when the child objected. Enticements such as M&Ms encouraged participation.

3.5 Virtual World Design

The virtual world was a simplified street scene consisting of a sidewalk and textured building shapes. All motion objects such as people, animals, and objects in the sky were removed. Periodically one car, whose speed could be set, would pass the child standing on a sidewalk (Fig. 1). This test scene was designed to match the needs of an autistic individual with features of VR in the following ways:

Controllable Input Stimuli. The contrast was kept low in the scenes with gray being the dominant color.

The low quality of the headset screens provided a less detailed environment automatically. The cars, the focal point of the test, were presented in bright, contrasting colors. Only car colors recognizable by the individual child were used; in one case this meant colors were limited to red and blue. This distortion allowed us to match the user's input processing abilities while keeping the association of building and car form and functionality.

Modification for Generalization. The patient was placed in different positions of the virtual environment at the beginning of different tests. Although all were from the same virtual town, the location on the street varied between trials (Fig. 1).

Safer Learning Situation. Freedom to move in a street scene alone without danger was a first for the subjects who normally require constant monitoring in daily activities.

Primarily Visual World. All computer-generated stimuli but vision were removed from the virtual world. Padded inserts were placed in front of the helmet speakers within the headset to muffle any hardware feedback sounds. There were verbal instructions to the children.

Individualized Treatment. The worlds were continually modified for each individual to take into account the dynamic response patterns between sessions.

Minimal Human Interaction. Although instructions to the patients were verbal, there were no human images in the virtual world, nor could the subjects see the people in the real world while in the virtual environment.

Vestibular Stimulation. There was no attempt to use virtual induced vestibular stimulation in the tests. Because the training was designed to eventually aid in learning the critical skill of street crossing, environmental responses were kept realistic.

3.6 Results

Initially there were serious questions concerning whether children with autism would accept wearing a helmet. If they did, would they recognize an artificial environment when recognizing the real one was so tentative? The results indicated an encouraging adaptation to the technology. One child immediately accepted the virtual helmet and immersed herself to the point that she identified cars and colors. The second child was more rigid and required three sessions, all within a 15-min period, to accept the helmet and respond to the scene. Once the helmet was physically accepted, both children would track the cars visually by turning their bodies and identifying the cars and their colors.

The results of these trials indicated the following:

Helmet Acceptance. These two autistic children were filmed consistently over the weeks being willing to accept the helmet and guide it onto their heads. Although neither child was adept at verbally expressing sensations, the weight of the helmet became noticeable in the later trials when the children started supporting the front of the helmet with their hands (Fig. 2). A lighter helmet is suggested for future trials.

Immersion. The children repeatedly immersed themselves in the virtual scenes to a degree that they verbally labeled objects, colors of objects, and tracked virtual moving cars.

Motion in the Virtual World. Once each child repeatedly tracked cars while sitting in a swivel chair, the chair was removed. Both children would wear the helmet while standing and move their bodies within the virtual scenes (Fig. 2). All chairs had to be physically removed from the office space in order to get the girl to stand because she preferred spinning in the chair with the helmet on.

A STOP sign was attached to the hand controls and moved to different parts of the tracking area during the later tests. The children were asked to find the sign within the scene. This would appear in the virtual world as if the sign moved to different areas of the sidewalk. At

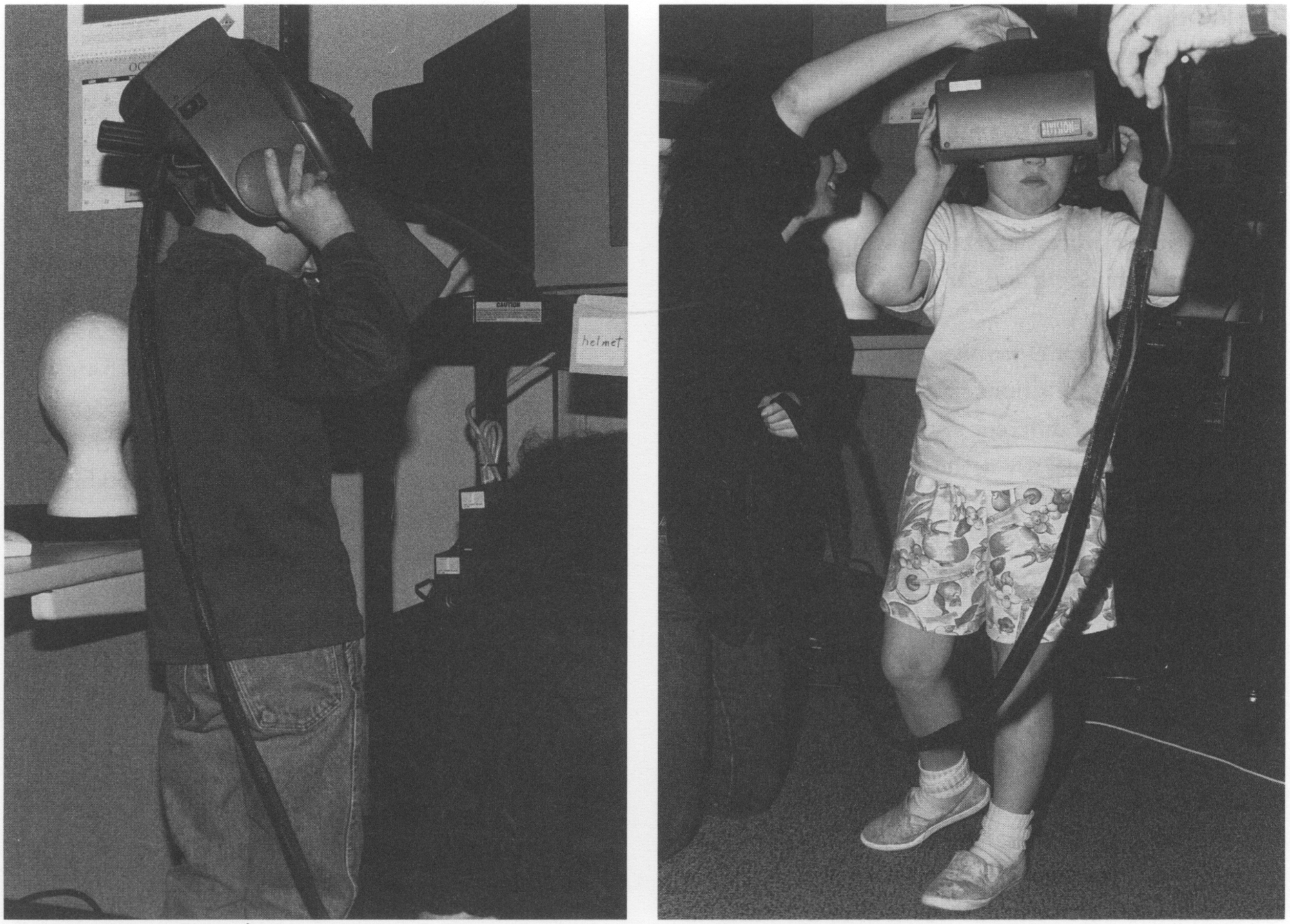

Figure 2. *Two children with autism walking in a virtual world. The girl is walking toward a virtual stop sign, which is attached to the hand controls being held in the upper right corner of the picture.*

times it was difficult to judge the sign's distance because of the lack of comparison cues. This may have contributed to difficulty in the final test sequence, which involved stopping at the sign. The children's motions were maintained within the physical range of the Polhemus tracker.

Generalization. The children responded similarly to three different street scenes, but more study needs to be done to determine if they were generalizing across different surroundings.

Learning. Both children were able to turn and find an object in the virtual setting and to walk toward it. One child stopped when reaching the object, which was the new learning exercise. Repeated studies would better verify that the response was truly a new learned skill and determine if the skill translated to real world situations. Comparisons of learning times in the virtual versus real world would help verify the value of such a learning technique.

3.7 Discussion

The difference between these two children's abilities to find and walk toward a virtual sign appeared related to their understanding of the VR image as an interactive three-dimensional world. While neither child could communicate well enough to describe his or her thoughts, actions indicated different responses to the virtual illusion. The virtual scene was simultaneously displayed on a flat screen and in the helmet in order to observe the child's visual world. Although they could not see the screen while in the helmet, both children initially demanded that the flat screen be present before they would accept the helmet.

The two subjects responded differently to the virtual image and the flat screen may provide a clue as to why. The girl freely walked within the illusion, while the boy, when told to "go to sign," would point to the sign inside the helmet. The boy studied the front of the helmet in the initial trials, peering into the plastic as if trying to find the image. He appeared to respond to the world as though it were a scene on a conventional non-VR computer, while the girl appeared to understand that motions were translatable between the real and virtual worlds.

The girl also at times pointed to the image in the helmet, but quickly adjusted to walking as a way of getting closer to the sign within the virtual image. In one trial, she stepped over a cord on the floor, indicating that although she understood she could move within the virtual world, she was still aware of the real environment. It was necessary to remove the flat screen in the study with the boy to entice him to stay in the helmet any length of time. The boy had previous extensive experiences with traditional PCs, which may have made it more difficult to adapt to the immersion concept.

4 Sense of Presence in Artificial Environments

It is speculated from studies that there is a "deep structure of presence" of which the subject is not directly conscious, but which nevertheless influences behavior in basic ways (Slater, Usoh, & Steed, 1994; Gibson & Walk, 1960). Artificial environments that take advantage of the sense of presence available with VR could provide unique benefits by addressing physical and mental problems, such as autism, which have proven difficult to treat with conventional means.

The sense of presence in carefully selected settings has evoked phobic responses in previous studies. Georgia Tech, Emory, and Clark Atlanta incorporated VR with acrophobia exposure therapy techniques in treating the psychological problems (Rothbaum et al., 1995). With virtual reality graded exposure (VRGE), subjects experienced the same symtomology as would be exhibited in real-world situations. Preliminary results indicated there was a decrease in height anxiety after virtual reality treatment, even when the virtual environment did not completely or accurately represent the real-world situation.

The researchers postulated that a participant's reactions to the situation depended not only on the qualities of the virtual environment, but also on their previous experiences and who they were. Although there were differences in the experience between the intensity and vigor of virtual versus real experiences, the perceptions of real-world situations and behavior in the real-world were modified based on experiences within the virtual world.

Work with claustrophobia (Pyne, 1994) and fear of flying (Hodges, Rothbaum, Watson, Kessler, & Opdyke, 1995; North, North & Coble, 1996) suggest that virtual environments could be used as *in vivo* treatment for other phobias.

4.1 Perceptions of the World

By understanding how we form our perceptions of the world, we can better design VR illusions for treatment applications such as autism. Inputs from the outside environment, stimulating responses from the senses, form the basis of our internal reality. Primary physiological input senses are those of vision, audition, touch, smell, and taste.

In an effort to create more convincing virtual worlds, commercial development often concentrates on duplicating the normal input stimuli with improved hardware and software. Wider fields of view in head-mounted displays, higher resolution screens, gaze directed focus control, optical image distortion correction, reduced tracking latency, faster scene renderers, and more exact position sensing are but a few examples. While such efforts are necessary, they concentrate on only one parameter of our reality formation. The sense of reality is not governed solely by these measured input stimuli but also by issues involving an often complex interaction of neurological, biological, learned, and perceptual factors.

Vision. Although duplication of all but the sense of taste have been attempted in various computer-based virtual environments, vision is by far the dominant sense and plays the pivotal role in commercial VR illusions. Visual stimuli can be measured by the image on the retina, the back surface of the eye.

The processing of the retinal image is more intricate than a simple matching. It involves neurological image processing activities within the cortex that rely on expectations based on history, or learning, and perceptual rules that may be partially instinctual. Objects in a room are separated from background, and grouped and identified based on biological image processing and prior learned history of form. This is integrated with perceptual cues that predict features such as object size or distance using principles such as the equidistance tendency and the specific distance tendency (Gogel, 1984). The equidistance tendency states that objects in a scene, in the presence of minimal depth cues, appear as if they are at the same distance. Specific distance tendency describes a bias to perceive a target, in the absence of distance cues, as if it were at some intermediate specific distance, usually 2–3 m.

Motion. Motion, another key input stimulus in VR, can be generated by self-induced motions resulting from muscle actions, as well as adaptations to external physical stresses such as gravity. The essential property of processes underlying the construction of a coherent representation of movements implies multimodal extraction of many components, including but not limited to movement direction, position, velocity, and acceleration (Berthoz, 1991).

Actual body positioning in motion incorporates feedback such as proprioceptive and vestibular factors with other sensory inputs, the most significant of which is vision. This stimuli input is correlated with what Bridgeman (1991) postulates are dual spatial histories maintained internally for separate cognitive and motor maps. Choice of input used as the base for the position synthesis is dependent on motion type: vision and vestibular systems contribute to head positioning during complex movements in which a stable base is absent; proprioception measures relative displacements of limbs and therefore reconstructs head movement when the body is standing on a fixed platform. Gravitational effects as well as spatial histories are always maintained internally by an individual, although the effects of gravity appear to dominate when standing upright, while a body-centered reference scheme dominates when supine or lying on a side (Berthoz, 1991).

4.2 A Model of Reality

Reality appears to involve interpretation and integration of several components: input stimuli, memory or historical internal data; and perceptual rules. A model for this relationship is

$$\text{Reality} = \text{Synthesis (Input Stimuli} + \text{History} + \text{Perceptual Rules)}$$

where Input Stimuli = physical input from the world impacting on our senses, History = learned knowledge and is a function of (Input Stimuli + Previous History + Perceptual Rules), and Perceptual Rules = innate rules for the interpretation of reality. While input stimuli from the outside world and possibly perceptual rules are not modifiable by our synthesis of reality, history uses feedback from previous realities to adapt.

4.3 Reality Model Conflicts

Cue conflict occurs when the components of our reality model provide contradictory information. This conflict is resolved through a varying dominance of the input stimuli, historical, perceptual components. The two examples below illustrate different conflict resolutions for vision and motion.

Visual Illusion. The moon illusion refers to the fact that the moon appears much larger on the horizon than it does at its zenith in the sky. The input stimuli is the same retinal moon image size at both the horizon and the zenith. History teaches that houses and trees are relatively large, and the size of objects do not normally change in different locations. The autochthonous factors of equidistance tendency and specific distance tendency, along with the size-distance invariance hypothesis, provide perceptual rule interpretations. The size-distance invariance hypothesis is a phenomenal geometry concept that postulates that perceived size is a monatonic function of angular size in radians of the image on the eye surface and its perceived distance.

When the moon is at the horizon, it is adjacent to other objects that are seen as being far away. The equidistance tendency tends to place the moon at the same distance as these horizon objects. The moon is larger than the horizon objects, such as buildings or trees, which are known to be large. Thus the size of the moon at the horizon appears very large. Specific distance tendency tends to bring the perceived distance of the moon at its zenith, with no adjacent objects with which to compare, to a closer intermediate distance than the horizon. Using the size–distance invariance equation, given the constant retinal angle, and given that the horizon distance appears larger than the zenith distance, the moon's size at the horizon will appear larger than at the zenith.

In this cue conflict where the input stimulus has identical retinal size for all moon positions and the learned expectation (history) is of consistent moon size, the perceptual rules dominate and the moon appears larger on the horizon than at the zenith.

Motion Illusion. The three reality components of the model and their dominance within the "body scheme" can be applied to experiments done by Gurfunkel (Gurfunkel & Levick, 1991). In one test, subjects with only their heads rotated and with eyes closed felt their heads slowly returning to a neutral (symmetrical) position. After 10 to 12 min the head was perceived as facing forward while turned as much as 60° to the side.

Applying the model to this illusion, input stimuli encompassed all but vision. None of the body's motion or position sensors, such as muscle feedback or vestibular readings, indicated head position turning, head motion acceleration, or plane motion in returning to a center position. The body's history of its orientation as stored in an internal egocentric map indicated a head turned motion initially. Learned expectation of a head forward position, as well as perceptual rules, may be causal in internal remapping. The primary perceptual rule appeared to be the tendency of the head to return to a neutral spatial orientation (Berthoz, 1991).

Input stimuli remained consistent and in conflict with the illusion of head motion returning to a central position. The perceptual rule, with perhaps a history component, was dominant in the absence of vision. The head was perceived as facing forward despite its physically turned position. When vision was added during the test, the misperception of position immediately corrected. Vision, a more dominant input stimulus than the perceptual rule, caused reality realignment and history to similarly update.

Reality Conflict Resolution. In the moon illusion, perceptual rules dominate visual cues, while in the motion study, visual stimulus input overrides perceptual rules. The body appears to be in a continual state of conflict resolution in developing its sense of reality.

4.4 Applying the Reality Model

The degree to which VR worlds can manipulate the historical and perceptual components, as well as the input stimuli, to create a sense of presence may affect their value for treatment of mental disorders. The worlds created as learning scenes with the autistic children stressed the history of each child's response to his or her environment by limiting the size, shape, and color of the world's objects. Perceptual rules were used to make the learning objects stand out from the background. Normal perceptual conflicts in a street scene were removed or minimized by controlling the complexity and arrangement of the objects in the scenes. Input stimuli were kept at the minimum necessary to convey the sense of a realistic street.

5 Conclusions

Virtual reality worlds were designed to create a sense of presence in a customized learning scene for two children with autism. A model of reality was used that limited input stimuli. The artificial worlds contained scenes and objects historically identifiable by each child and relied on simple nonconflicting perceptual rules.

These worlds appeared to be accepted and responded to by the two children who took part in this study. Neither child had the verbal ability to understand a description of a separate reality as an abstract term or how this reality was created with equipment. Their acceptance of objects and actions in the artificial environment was a possible verification of the sense of presence within the virtual reality.

Although more tests would be necessary to determine the level of training that the children experienced in the virtual environments, both children accepted the new technology and responded with learning actions while in the virtual setting. The acceptance of a virtual learning situation provides a potentially new tool for furthering efforts at treatment and intervention for autism.

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