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LEVELING THE PLAYING FIELD: SUPPORTING NEURODIVERSITY VIA VIRTUAL REALITIES

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Neurodiversity is a term that encapsulates the diverse expression of human neurology. By thinking in broad terms about neurological development, we can become focused on delivering a diverse set of design features to meet the needs of the human condition. In this work, we move toward developing virtual environments that support variations in sensory processing. If we understand that people have differences in sensory perception that result in their own unique sensory traits, many of which are clustered by diagnostic labels such as Autism Spectrum Disorder (ASD), Sensory Processing Disorder, Attention-Deficit/Hyperactivity Disorder, Rett syndrome, dyslexia, and so on, then we can leverage that knowledge to create new input modalities for accessible and assistive technologies. In an effort to translate differences in sensory perception into new variations of input modalities, we focus this work on ASD. ASD has been characterized by a complex sensory signature that can impact social, cognitive, and communication skills. By providing assistance for these diverse sensory perceptual abilities, we create an opportunity to improve the interactions people have with technology and the world. In this paper, we describe, through a variety of examples, the ways to address sensory differences to support neurologically diverse individuals by leveraging advances in virtual reality.

Key words: Neurodiversity; Neurological development; Assistive technology; Sensory integration; Autism spectrum disorder

INTRODUCTION

Neurodiversity is a term that encapsulates the diverse expression of human neurological development, which results in a wide variety of sensory perceptual abilities. Many of these unique sensory traits are clustered by diagnostic labels, such as Autism Spectrum Disorder (ASD), Sensory Processing Disorder, Attention-Deficit/Hyperactivity Disorder (ADHD), Rett syndrome, dyslexia, and so on. In an effort to translate differences in sensory perception into new variations of input modalities, we focus this work on ASD. The Neurodiversity Movement formed specifically to reshape how ASD is perceived (1). Instead of identifying ASD by negative characteristics, Sinclair (2) and other advocates argue it should be thought of as part of the continuum of human experience. This has important implications not only for those living with ASD but for people with other neuro-divergent conditions that would benefit from technologists expanding the ways that

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information is transmitted through technology. In fact, many people in our society could benefit from the translational work of applying what is known about the strengths and weaknesses of neurodiverse populations to the design of assistive technologies. ASD is estimated to affect 1 in 59 children (3,4) and is often accompanied by sensory sensitivities. Even more common, 1 in 20 children have been found to have a sensory processing disorder (5). It is imperative, then, that we focus on making technologies and life experiences more accessible to people with sensory differences.

Virtual reality (VR) has moved to the forefront as a possible means of assistive therapy and accessibility. Since VR has become more affordable in recent years, its use is now popular both in private industry and for entertainment purposes. What is even more appealing about VR in regard to therapy is that the experience is dynamic, individualized, and personalized for the user's preferences. Due to the sensory processing differences in ASD (discussed later in this work), VR provides new opportunities, mediated by technology, to explore the world.

The possibility for VR technology to assist students with special needs is moving to the forefront of educational conversations as well. These VR spaces prove to be very useful to the user because there are no real-world risks, yet they are still able to navigate through the experience or lesson. For example, users can interact with avatars in a social situation without the pressure of making a mistake. One of the primary benefits of integrating VR technology into special education learning environments is that it provides interactive learning, enabling the learner to have control of his or her learning process (6,7). VR applications may allow students with ASD to participate more fully in general education classrooms and in society.

The goal of VR interventions for neurologically diverse individuals is to promote an alternative way of learning that provides a sense of belonging from the perspective of someone with ASD in all settings; the aim of technology need not be focused on impairment but rather on building self-esteem and supporting creativity (8). Using technology allows the user to insert themselves into various situations, no matter where the user is physically. Additionally, technologies that support nonverbal skills can build a bridge between the normative and neurodiverse experiences, which some researchers refer to as "neuro-shared spaces" (9).

Research states that users of this interactive therapy can experience "reduced stress from the lack of nonverbal signals, the ability to find people with similar interests, and pre-defined interaction mechanisms, like birthday greetings" (10). In the current work, we aim to create assistive technologies via immersive VR to create a sensory-friendly environment as well as unlimited access to everyday activities, such as play and social interaction. Though we focus on ASD, these techniques provide an opportunity for generalization.

BACKGROUND

Researchers of assistive technology are calling for more customization and systems capable of adapting to multiple use cases, and achieving this requires multiple iterations of the technologies with special attention to interface design (11). Adoption may be improved by including users with neurodiversity, such as ASD, across all stages of development in addition to their caregiver networks. Many researchers have found their technologies have limitations and suggest that iterating with users would be a step toward solutions—whether this iteration occurs at the beginning of the lifecycle or during or after development (11). The common themes across these works are usability, acceptance, and adoption. Adoption requires ongoing support for infrastructure; ideally, innovative technologies would connect to existing infrastructure to improve the world around the users (11). VR is now a commercial commodity that leverages infrastructure (e.g., the web) and provides a unique pathway to supporting neurodiversity through new ways to accommodate sensory needs within an established infrastructure.

Sensory Overview

Individuals with ASD often have challenges with sensory inputs and need extra time to navigate through daily experiences. VR technology provides this time, as a student may move at his or her own individual pace without feeling rushed. Sensory impairments may affect an individual in one or more senses—touch, hearing, or vision—which impacts the way they perceive situations and interact with others (7). Additionally, sensory sensitivities may also include perception of pain through proprioception, smell through olfactory, movement through vestibular, and understanding of time through temporal processing (12).

When an individual has difficulty processing one or more of these sensory systems, the experience may heighten their other senses. It is also possible for these systems to be underestimated or hyposensitive. Because of the ability to systematically manipulate the type and amount of stimuli in VR, these channels could be manipulated to address sensitivity issues, for example, by influencing the visual and auditory inputs and outputs (7).

Virtual learning environments (VLEs) allow students with special needs to access the same curriculum and experiences as their general education peers in the safety of their own classrooms, which contributes to learning. According to Sánchez et al. (13), an architect's skills grow by constantly absorbing the environment around them, allowing the learning process to constantly occur. Similarly, VR allows individuals with ASD to continually reflect upon and learn new lessons from their surrounding virtual environments.

Visual Processing in ASD

Visual processing is how visual information is taken in through the eyes and is processed by the brain (14). This is, of course, a complex and multifaceted process. Some researchers have developed metrics for evaluating visual processing in children with ASD. However, individuals with ASD who also have visual processing deficits may focus on details in objects or watch other individuals move around in a room, which may be incorrectly perceived as distraction (15). Other studies have suggested that visual processing may be a strength for individuals with ASD (14), leading educators and therapists to utilize the visual channel to augment learning environments for children with ASD to include visual supports (12,16). Provided that an individual with ASD has strengths in visual processing, VR can be an engaging learning environment free from outside distractions. However, if an individual has difficulties in visual processing, VR provides three-dimensional opportunities to envelop an individual in a specific environment. VR also incorporates auditory and tactile opportunities for the learner to compensate for difficulties in other sensory systems.

Auditory Processing in ASD

Children with ASD have demonstrated a hypersensitivity to sound as compared to typically developing children in the auditory domain. For example, individuals with ASD who are hypersensitive to sound may be more prone to put hands over ears to drown out noise, or they may become more distracted around a lot of noise (15). Therefore, it is crucial to minimize distracting noises and reduce the number of verbal cues for an individual with ASD who has difficulties with auditory processing. Using a VR headset helps minimize outside noise and distractions while providing auditory feedback to individuals with auditory processing deficits. Additionally, Sánchez et al. (13) argue that individuals with auditory processing difficulties may struggle to comprehend their environments due to noise and verbal demands. These individuals then must rely heavily on their other senses, such as their visual and tactile sensory systems, to understand their environments.

Pain Channel and Introception

Pain is perceived through the skin as well as through the internal organs. This sensory system has also been flagged as hyposensitive or hypersensitive for some people with ASD (17). In the case of hyposensitivity, a person with ASD can get hurt from not feeling the sensation of pain. For example, while washing hands, an individual with ASD may not pull away if the water is at a high temperature, resulting in severe burns (13). In the case of hypersensitivity to internal indications (i.e., paying attention to one's body signals), researchers hypothesize that "heightened attention to internal cues may lead to decreased attention to external stimuli, which provides a putative link between decreased social interaction and repetitive patterns of behavior that directs the focus of attention inward" (18). Therefore, gaining the user's attention to sensory input originating from outside one's body needs to occur before someone can process the information.

Fear and anxiety have been attributed to the display of large interpersonal distances that some neurologically diverse individuals maintain between themselves and people with whom they are not familiar (19). Additionally, difficulties interpreting interpersonal space for those with ASD have also resulted in standing within other peoples' personal space (20). This duality in presentation of people with ASD (e.g., both too far and too close) demands that interventionists take into account the variable combinations of sensory profiles that need to be accommodated. The need for individualization is the challenge of processing multichannel input that we touch on later in this section.

Tactile and Proprioception

The sense of touch is a powerful modality in learning about one's environment (21). The tactile system responds to the sense of touch, pressure, texture, temperature, and pain (22). Touch receptors are located in the skin. Individuals with ASD may have a heightened sense of touch, which can lead to the avoidance of touching objects or people (22). A tactile modality found to be successful in learning is the use of a haptic device. An example of an input/output device is a joystick or haptic gloves (21). These types of haptic devices are used for individuals with tactile hyposensitivity, who may need more physical contact between themselves and their computers (7).

The use of haptic devices is also beneficial for individuals with proprioception issues. Proprioception is body awareness. Individuals with sensory difficulties in this area may lack awareness of certain body parts and how those parts move (22). Proprioception is located within the muscles and joints and is activated when the muscle contracts (12).

Olfactory (Smell)

The olfactory system provides information to the brain about the smells in the environment. This powerful system can trigger memories and allows individuals to embed learning through the sense of smell (23). Chemical receptors are located in the nasal structure and react to the smells in the environment (24,12). Individuals with hypersensitivity to smell (i.e., perfume) may not be able to participate in everyday outside activities, and VR may be a necessary tool for learning in a contained environment.

Vestibular (Balance)

The vestibular system is another component of the sensory systems that provides a sense of balance. This system "provides information about where our body is in space, and whether or not we or our surroundings are moving. The vestibular system also informs the body about speed and direction of movement" (12). This system is regulated by the inner ear, and it is "stimulated by head movements and input from other senses" (12). For individuals who are medically fragile or have vestibular difficulties that would make it too risky for them to be part of the outside world, VR may be the perfect solution to provide them with real-world experiences (25).

Temporal Processing

Temporal processing is the perception of time and impacts perception of multiple channels. An example of temporal processing in audition is the rate at which one processes auditory information. Temporal processing in ASD has been described as altered in that "individuals with autism demonstrate an elongated window of audio-visual temporal binding: relative to control individuals, they are less able to discern the presentation of a tone and a flash at close temporal offsets and more likely to perceive asynchronous events as synchronous" (24). This means that the processing of global information may take longer for people with ASD. Furthermore, individuals with deficits in temporal processing may have difficulty understanding the intricacies of speech as it relates to time and rhythm. In turn, individuals with ASD have increased difficulty making sense of their internal and external environments (26). The understanding of "time and rhythm involves basic building blocks: detection of events, identification of duration and temporal order—relational properties of sequences" (27).

Multichannel Processing in ASD

In addition to single channel sensitivities, integrating information received through multiple channels can be burdensome (13). Combining the sensory information of visual and auditory channels "is fundamental to language perception, as it facilitates the integration of vocal and facial cues" (28).

Researchers hypothesize that children with ASD engage in channel switching. In other words, people compensate for a weak channel by switching to a stronger channel, such as "using visual processing, versus auditory, as a strategy to engage with their environments" (15). Another processing phenomenon found in ASD is the preferential attention to local information (e.g., the details of a leaf) over global information (e.g., the overall concept of a forest). This has been reported in the processing of specific types of stimuli, thus complicating the sensory profile as one of hypersensitive or hyposensitive (24). Yerys et al. (29) performed a study using functional magnetic resonance imaging to "investigate the neural correlates of set-shifting" in a group of 39 neurodiverse children, including 20 with autism. This study determined that children with autism often have a preference to stay stimuli rather than switch stimuli although the individuals with autism were less consistent than the typically developed children. Given the comorbid nature of ASD and sensory processing issues, particular attention must be paid to interfaces to ensure that correspondence between stimuli does not negatively impact multichannel switching.

VR APPLICATIONS

Assistive technology allows people with disabilities to become more able to complete tasks that would be difficult to do without the assistive technology. Individuals with ASD may exhibit deficits in cognitive, social, language, and motor skills, for example (30). Promoting VR allows for people with ASD to achieve a lifestyle that would be arduous without the assistive technology, both as a child in a classroom and as an adult in society.

VR in General Education

VR environments have the unique ability to create equal access in the general education classroom for individuals with special needs. VR technology could be said to provide students with disabilities a free and appropriate public education. Similar to alternative augmentative communication applications, VR may be the technology boost needed to create an equitable learning environment for mainstreamed students. According to Jeffs (7), it is not uncommon for individuals with special needs to incur difficulties with language, attention, spatial reasoning, higher level thinking skills, and memory. VLEs have the potential to allow students to focus on cognition and behaviors, including social behaviors.

VLEs have the ability to provide students with real-life situations to navigate without the interruption of others. Students can observe these situations in a safe environment to process and react to the materials included in the VLE. This type of learning is essential for students with special needs but even more critical for students with ASD.

VR in Special Education

ASD is a growing sector in special education, and many of the individuals with ASD are now being fully included in the general education classroom. This may pose challenges for the teacher and the student, given that some of the difficulties for individuals with ASD include the pragmatics of social interaction, nonverbal and verbal communication skills, cognitive tasks, sensory impairments, impulse control, and other behaviors (7). VR is discussed as a tool to bridge the gap for students with ASD who are included in the general education classroom. Specifically, VR learning environments enable a student to navigate through conceptual information intuitively (31,32).

VR environments have the potential to bring the outside world into the classroom (32). This could be in the form of collaborative virtual environments (CVEs), where the entire class is led through a situation in which they work together to determine the most appropriate answer. Additionally, it can take the form of a single-user virtual environment, in which one individual is navigating a situation based upon their subjective choices to provide feedback and learning.

VR and Communication/Social Skills

Social skills have been one of the greatest considerations for teachers and parents of individuals with ASD. Replicating a social situation is usually not authentic because the role-playing is staged. However, the Asperger Syndrome (AS) Interactive project used VR to help individuals with ASD acquaint themselves with real-life social situations (AS has now been superseded by ASD in the Diagnostic and Statistical Manual of Mental Disorders 5th Edition) (33). Cobb

(32) reported that the AS Interactive project (available from http://virart.nott.ac.uk/asi/individualised.htm) supported social interactions by creating real-world equivalents and having individuals make decisions about where to sit in a restaurant if all the tables were occupied by other patrons. The VLE used avatars to replicate people, and the participants would need to use appropriate communication skills to ask for the use of an unoccupied chair. If the participant sat down at a table occupied by other people, the virtual system would use the avatars to provide a response. This VLE therefore provided an authentic response that can be repeated with multiple combinations while avoiding the staged and repetitive results that can occur in a role-playing scenario.

Using a VR environment is advantageous for individuals with ASD because they can experience situations that may not arise in a strictly educational setting. This provides feedback and growth in situations they will encounter outside of the school environment. These systems can be used as a CVE replication where it is a collaborative approach or as a single-user system that prompts an individual for specific interactive choices (32).

Another project by the Innovative Technologies for Autism is using VR environments to examine the intricacies of social interaction and communication skills in individuals with ASD (32). According to Cobb (32), the research project uses interaction with both virtual and human peers in a virtual environment. Researchers are using data to develop more authentic virtual peers with whom users can have conversations using the speech and gestures of their avatars. In addition to meeting social needs, VR offers relief from an overwhelming sensory experience (e.g., general education classroom or community outing).

VR for Cognitive Skills

Students with ASD may use VR to assist with cognition tasks, similar to individuals without ASD, because it provides first-person experiences these students may not otherwise witness. For example, if students are learning about the Grand Canyon, VLEs allow them to go on a virtual field trip and navigate through this natural wonder without leaving the classroom. Additionally, VR provides the opportunity to repeat the same virtual field trip as many times as necessary to fully process the experience (34). VLEs also offer the ability to manipulate visual and auditory inputs and outputs to assist with a more customized learning approach for the individual (7).

THEORY TO PRACTICE

With the abundance of ubiquitous computing systems available come new opportunities to augment social information through sensor data as well as work around sensory experiences that are uncomfortable. Sensory processing differences in ASD may impact virtually every sensory system, such as visual (sight), auditory (sound), vestibular (movement and orientation in space), olfactory (smell), proprioceptive (body awareness and pain), or tactile (pressure and touch). These differences have been characterized in ASD as an undersensitivity or oversensitivity, which are also referred to as hypersensitivity or hyposensitivity (35,13). For example, if an individual is hypersensitive to the smell of perfume, even the littlest amount may cause the individual to become ill. On the other hand, a person who may be hyposensitive to touch needs a tremendous amount of pressure or tactile reinforcement as compared to a typical individual. This is the premise we take with design and development of our technologies.

In recent years, the availability of affordable commercial off-the-shelf VR hardware has also provided a catalyst for scalable VR-based assistive technologies. This hardware includes self-contained headsets such as the Oculus Rift, HTC Vive, Samsung Gear, and Google Daydream Standalone. These headsets can interface with a variety of computing platforms and range in price, at the time of writing, from $400 to $600. More affordable options, such as Google Cardboard, Google Daydream Smartphone, and Emerge Utopia, range from $15 to $99 but depend on a smartphone to provide the computational processing. Applications for these platforms can be developed using standardized programming technologies such as Unity3D, Android SDK, and Swift, which further reduces barrier to entry when adopting these systems for assistive purposes.

Immersive VR offers new opportunities and challenges to modify sensory inputs directly. In immersive VR, the input for each of these systems can be removed, reduced, or manipulated to support

Figure 1. Bob's Fish Shop: screenshot of shop owner greeting the VR user.

the tolerance of sensory sensations in a therapeutic environment. Here we describe three immersive VR systems we built with emerging technologies and how we attuned them to the unique needs of people with ASD.

Bob's Fish Shop

Bob's Fish Shop is an immersive VR experience designed to help children with ASD practice typical social interactions and conversational skills. Implemented in Unity3D and designed for the Oculus Rift VR headset, the goal of Bob's Fish Shop is to build daily living skills while having children engage in a safe and supportive environment. In addition to conversational skills, the game exercises nonverbal communication and joint attention skills as well.

The premise of the game is simple. When a player enter the virtual world, they are presented with an empty aquarium in their home. The goal is to add to the aquarium incrementally by adding fish, plants, and other accessories. Additionally, the player must tend to their fish, ensuring they are fed and well cared for. Fish and supplies are acquired by visiting Bob's Fish Shop and interacting with Bob, the friendly animated shopkeeper (see Figure 1). Starting with a simple "hello," Bob assists the user by asking them what they need and guiding them throughout the entirety of the interaction, giving both verbal and nonverbal cues as needed. The player's first-person perspective is used to gain insight into the presence of joint attention.

Throughout the game, tasks are laid in a left-to-right orientation to support sequencing of motor movements. This strategy promotes spatial awareness and motor planning. The narrator uses a wide range in pitch and emphasis when giving instructions to maintain attention and improve comprehension. Upon completion of their interaction with Bob, the user is returned to their home and rewarded with the items they explored at the fish shop.

Though the game play of Bob's Fish Shop is simple, based largely on short interactions supported by visual scripts, the underlying architecture of the game requires integration of several technologies. In addition to the VR itself, the game utilizes voice recognition, estimates joint attention based on the player's center of focus in the virtual world, and incorporates rule-based artificial intelligence to guide transitions throughout the game.

VirtualBlox

In addition to the availability of consumer-grade and moderately priced VR headsets, the development of sensors that allow gesture recognition and visual feedback to be integrated into immersive experiences have expanded the types of interactions users can have within a virtual world. VirtualBlox is an immersive VR game built for the Oculus Rift. VirtualBlox is designed to exercise fine and gross motor skills, which children diagnosed with ASD often experience.

The game makes use of the LeapMotion hand-tracking sensor and application programming

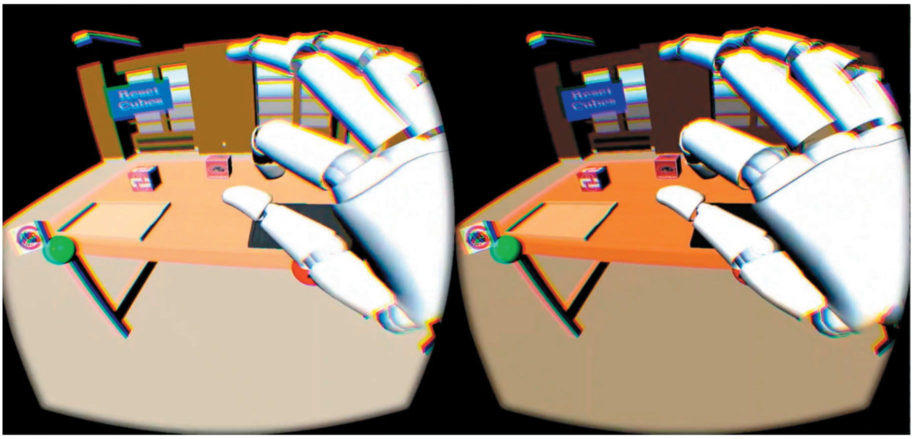

Figure 2. Screenshot of VirtualBlox block sorting game.

interface to allow the user to manipulate objects in the virtual world. In the case of VirtualBlox, the user may select from several sorting exercises that prompt them to place or stack blocks in predetermined locations. This not only requires gross motor planning on behalf of the user but also fine motor skills to grasp individual blocks and release them in the correct positions, as depicted in Figure 2.

Visual feedback provides the user with indications of whether they have correctly sorted individual blocks, and the user may choose among a variety of timed and untimed exercises. Additionally, the appearance of the blocks may be customized through texture-mapping files, making it possible to alter the experience to align with the interests of the user. For example, a child interested in Pokémon can easily be presented with blocks representing their favorite characters.

vrSocial

vrSocial is an immersive VR system developed in Unity3D with the Steam VR plugin along with the Photon Unity Networking platform for developing multi-user games in Unity. vrSocial specifically aims to support nonverbal communication by visualizing proximity (e.g., the distance between conversation partners) as well as the volume and duration of talking in real-time. (For more details of the development and evaluation, see Boyd et al. (36).)

vrSocial visualizes the user's interpersonal space by placing concentric rings on the ground that are color-coded to indicate where a person should stand when interacting with an acquaintance, volume speaker icons to indicate level of volume (i.e., "just right" or "too loud"), and a visualization of duration of talking, a "time talking bar," that indicates the user's amount of talking in orange and the partner's duration of the conversation in purple (see Figure 3).

Figure 3. Screenshot of vrSocial environment with conversation avatar and nonverbal communication visualizations.

DISCUSSION

Here we suggest design implications for immersive VR as an emerging assistive technology in education settings for students with sensory sensitivities who otherwise are excluded from learning environments. The following design considerations contribute to scholarly, clinical, and educational knowledge about the design of and potential for immersive VR to serve as assistive technology for neurodiverse people. Here we provide details of three generative ideas to support the development of sensory-friendly systems: channel reduction, channel filtering, and channel switching.

Channel Reduction

Much of daily life involves integrating sensory experiences. For people with sensory sensitivities, much of their energy is directed at tolerating this input rather than taking in new information. These discomforts can be worked around by reducing the sheer amount of information or straining out the "rich media" (37). Rich media contain multiple sources of information in an effort to replicate the richness of face-to-face interactions. Face-to-face interactions include tone of voice, eye contact, body language, and more. By reducing the overall sensory load, users are more comfortable and therefore more available for learning. The reduction of overall sensory experiences is evident in our three projects through the use of minimal background environments. In these systems, we included only objects or people that are part of the task at hand (Figure 4).

Channel Filtering

By filtering sensory information with "lean media" (37), we reduced the amount of information so that the salient details are illuminated—thus eliminating the struggle to separate the global from the local details. For example, to support the user's attention to important details, we provide visual cues such as the red (e.g., an error) and green balls (e.g., correct) in VirtualBlox (Figure 5, left). Similarly, when users are transitioning to another activity in VirtualBlox, presenting the relevant information in the foreground of the screen encourages them to select one of the four blocks (Figure 5, right). A next step for the VirtualBlox project could be to add a haptic feedback device to receive immediate feedback on movements to promote the necessary adjustments. In this way, a haptic device would provide the user with a new sense of their body movements—a filtered experience that can be adjusted to support the needs of the user.

Channel Switching (To Simple Dynamic Visualizations)

By leveraging the visual strengths of people with ASD, we can work around weak areas or avoid the burden of multiple channels receiving messages. vrSocial conveys otherwise hidden information—volume, interpersonal space, and how much time one spends talking in the conversation—by visualization. We demonstrate ways to visualize sensory information processed through the auditory, proprioceptive, and temporal pathways though this could be extended to all the channels.

We used dynamic graphics to provide details of one's proximity from another with color-coding to convey the social meaning of distance in face-to-face interactions with an acquaintance: Blue signals the appropriate zone, yellow is too close, and red is intruding. In the physical world, this information is transmitted through visio-spatial and proprioceptive channels (e.g., an uncomfortable feeling in

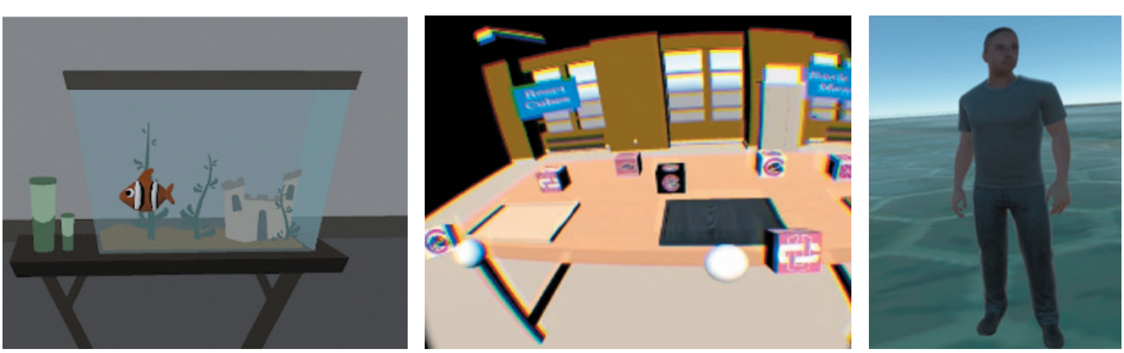

Figure 4. A reduced sensory environment contains a basic visual environment, with only objects that are part of the tasks: Bob's Fish Shop (left), VirtualBlox (middle), vrSocial (right).

Figure 5. Visual channel filtered to highlight salient information. Left: colored balls indicate correct placement of block. Right: red squares have 4 available choices, obscuring any other activity the user might engage in beside making a choice.

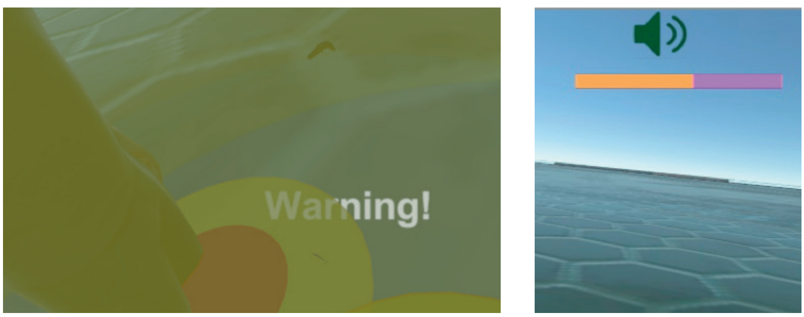

Figure 6. Left: vrSocial filters air and draws interpersonal space circles on floor to visualize body awareness detected by proprioception. Right: vrSocial visuals to support auditory channel, temporal processing — time talking bar in orange and purple.

one's gut when someone stands too close). However, in vrSocial, the information is switched to graphic details (Figure 6, left). In the time talking bar (Figure 6, right), monitoring the time one spends talking is made visual through a status bar that populates from both sides as each person speaks — thus adding in the temporal process. Lastly, one's volume is translated from an auditory task to a visual one with color-coded speaker icons that move as volume changes: A small gray speaker icon indicates "quiet," a green medium-sized speaker in the middle of the screen indicates a "good volume" (top of Figure 6, right), and a large red speaker to the right flashes when the user is speaking to indicate "too loud."

CONCLUSION

VR enables the creation of information-rich environments that are tolerable for people with sensory sensitivities. However, the richness of the information must be balanced between the attention and energy required to manage it. VR, particularly fully immersive VR, offers an intense sensory experience, far beyond that of a traditional screen-based interaction. Neurodiverse individuals often struggle with sensory input (38). Thus, a primary advantage to hosting an intervention in VR is the ability to control the sensory load in the system, adapting it to meet the sensory needs of the individual.

Immersive VR allows for customized interactions, such that individuals can attend classrooms with their own individualized input settings or other kinds of experiences without sharing a sensory space. The flexibility of controlling the sensory environment opens opportunities to be more inclusive. By designing a space that is tailored to individual needs (e.g., ADHD, ASD, Sensory Processing Disorder, Post-Traumatic Stress Disorder, etc.), more people can participate in virtual face-to-face interactions and other cultural experiences.

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