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Paper Prototyping Comfortable VR Play for Diverse Sensory Needs

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ABSTRACT

We co-designed paper prototype dashboards for virtual environments for three children with diverse sensory needs. Our goal was to determine individual interaction styles in order to enable comfortable and inclusive play. As a first step towards an inclusive virtual world, we began with designing for three sensory-diverse children who have labels of neurotypical, ADHD, and autism respectively. We focused on their leisure interests and their individual sensory profiles. We present the results of co-design with family members and paper prototyping sessions conducted by family members with the children. The

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KEYWORDS

Virtual reality; neurodiversity; sensory processing; regulation; sensory patterns; sensory accommodations; inclusion; universal design; accessibility; assistive technology.

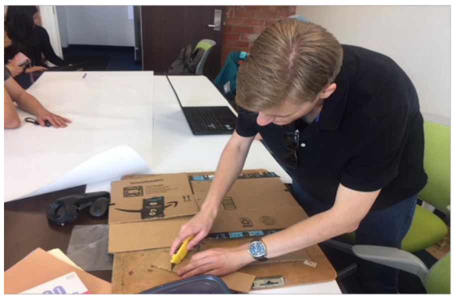

Figure 1: Development team member making cardboard controller.

results contribute preliminary empirical findings for accommodating different levels of engagement and empowering users to adjust environmental thresholds through interaction design.

INTRODUCTION

Just as individuals demonstrate variable cognitive, physical, and social-emotional abilities, sensory processing and regulation also varies widely across people–with and without disabilities [2]. Inclusive play spaces are needed to accommodate the range of sensory needs. Therefore, in this work, we engage with a neurodiverse group of children to ensure a future system appeals to, is usable by, and is comfortable for children from multiple perspectives [3, 9]. In particular, we co-designed leisure activities for three children described by their families as either neurotypical, autistic, or ADHD. As researchers are finding richer descriptions of participants may better serve the goals of interaction design [10, 11] and because neurodiverse children display varied sensory processing needs that may or may not be consistent with their medical label, we privilege their individual sensory profile over their general medical label in our designs.

We co-designed paper prototypes for three custom virtual reality applications based on extant occupational therapy research regarding distinct sensory patterns. These patterns are described in the Dunn's Sensory Profile™ 2 [1]. Dunn's theory of sensory information processing explains how modulating oneself to the environment is inherent in engaging in activities. We present a preliminary step toward showing that by using sensory preferences to guide design interaction styles and virtual environmental features, we can support engaging virtual spaces in which diverse children can play comfortably and play together. Presented here is the first stage of our design work that includes: ideation, sketching, and paper prototyping phases (see Figure 1).

RELATED WORK

Sensory processing is the organization of sensory information within the body. Effort is exerted to regulate sensory information. Challenges with multi-sensory integration are now being discussed as a primary feature underlying the consequent challenges with social perception and learning in autism and ADHD [7]. We focus on supporting the underlying sensory needs to regulate one's attention in order to be available to social and learning opportunities. We begin an exploration tailored to the individual's sensory stimuli thresholds and sensory regulation needs by situating in the context of leisure interests. Our goal is to ensure each participant is comfortable in terms of levels of tolerating the environmental stimulation and having the degrees of control over the sensory aspects of the environment, as seen in [3], before we consider how next to support social interactions and learning opportunities.

We opt to design for virtual reality and leisure activities as VR aligns with gaming and other interactive media and has therapeutic and educational benefits–specifically in mediating sensory experiences. For example, our previous work designing and deploying a virtual reality environment to support social cues including verbal and nonverbal communication cues for children with autism. Results indicated that virtual reality can support users in learning to detect social cues, and use cues to communicate more efficiently [8]. In that previous work, we suggest the success was due to the mono-modal presentation of cues (i.e., real time visualizations of nonverbal behavior) as well as the mediation of the sensory experience of face to face interactions through VR as a platform [8]. This finding is inline with other research that indicates when presented with multiple modalities, children with autism tend to respond to one sensory channel and ignore the rest, due to sensory overload [6]. In VR, we can manipulate the type and strength of of sensory input and in turn give that control over to the user, as seen in [4]. We aim to support a neurodiverse set of children by enabling the self-regulation of their environment.

INTEGRATING CONCEPTS FROM THE SENSORY PROFILE™ 2

To support children with being physically comfortable in a play environment, we need to understand the work that goes into self-regulation. We began this project by collecting user information from Sensory Profile™ 2 manual for children ages 3 to 14 years old [5]. The survey asks caregivers to rate several items on a Likert scale: almost always (90% or more of the time), frequently (75% of the time), half the time (50% of the time), occasionally (25% of the time), almost never (10% or less of the time) or does not apply (unable to answer because this behavior has not been observed or does not apply) across the sensory processing domains of auditory, visual, touch, movement, body position, and oral. Additional domains include conduct, social, emotional, and attentional responses associated with sensory processing. These domains are distributed across four possible factors: seekers, avoiders, sensors, and bystanders (see Table 1).

Applying Dunn's Sensory Processing framework [5] to features of the system to support interaction within users' preferences for leisure activities allows us to blend stakeholder needs through customized and comfortable software concepts for sensory-diverse users. These needs include making the future VR systems functional as well as social [9]. In addition, our work adds comfortable to these key criteria, meaning that participants need to be "at ease" before they are available to play and learn.

Table 1: Dunn's Sensory Quadrants by threshold and interaction style.

Pattern	*Threshold*	*Interaction*
Bystander	high	passive
Seeker	high	active
Avoider	low	active
Sensor	low	passive

METHODS OF CO-DESIGNING WITH FAMILIES

We used a convenience sample to recruit three families with children to explore the concepts of sensory profiles, leisure interests, and interaction design. Across the three child participants, ages 8-11, (1 female), the children were identified as neurotypical, ADHD, and autistic, whom we will refer to as Peter, Cassidy, and Max respectively (Table 2). For design inspiration, we relied on their survey responses regarding sensory patterns and personal preferences rather than a medical diagnosis . Family members (i.e., 2 mothers, 1 older sister) had ongoing meetings with the software development

Table 2: Participant demographics and leisure preferences used to create each participant's custom module.

Participant	**Activity Preference**
Peter,8, Typical	playing baseball
Cassidy,11, ADHD	dancing & singing
Max, 11, Autistic	watching thunderstorms

Table 3: Participants' Sensory Profile™ 2 caregiver survey results provided by survey as T-scores with 0 reflecting typical and +/- 1 and 2 reflecting standard deviations from the norm

Domain	Peter	Cassidy	Max
Seeker	0	0	0
Avoider	0	0	0
Sensor	0	-1	1
Bystander	0	-1	2
Auditory	0	0	1
Visual	0	-1	0
Touch	0	0	0
Movement	0	0	2
Body Position	0	0	2
Oral	0	0	0

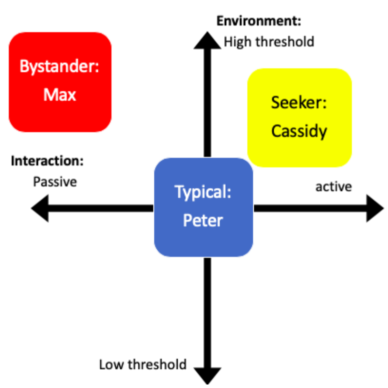

Figure 2: Participants' results regarding Dunn's sensory quadrants.

team to: discuss the study, complete the sensory survey, identify their child's leisure preferences (Table 2), make sketches, learn how to and follow through with the paper prototype user test at home with their child, and engage in follow up discussions in the lab with members of the research and development team.

INTEGRATING LEISURE INTERESTS with SENSORY PROFILE™ 2

We developed three dashboards to explore passive and active interactions related to each participant's sensory profile and interests: baseball for Peter (typical sensory profile), dance sing for Cassidy (seeker-like sensory profile), and thunderstorm for Max (bystander sensory profile). Results of the Sensory Profile™ 2 [5] for the participants reveal commonality in several single sensory modes with some major differences in their spread across the quadrants. The quadrants represent the interaction between the threshold to stimulation axis and the passive to active engagement with the environment axis. The quadrants provide four distinct profiles that Dunn calls (clockwise from top left quadrant): Bystander: degree child misses sensory input Seeker: degree child obtains sensory input; Avoider: degree child is bothered by sensory input; Sensor: degree child detects sensory input [5]. Peter, Cassidy and Max fall into separate quadrants (see Figure 2). Peter presented as just "like the majority of others", with average scores in each quadrant; Cassidy presented as "less than others to be sensitive to or miss visual input" and "more likely than others to get excited during movement tasks". Max was "more likely than others to enjoy and be distracted by bright lights and noise around him" and "much more likely" (2 standard deviations) than others to miss touch input or lose his balance (see Table 3 for details by sensory mode). This variation in three children creates a sensory-diverse set of design requirements. We incorporated suggestions for supporting sensory needs from Dunn's Sensory Profile™ 2 manual [9]. For example, Max and Cassidy's surveys indicated they both "walk loudly as if feet are heavy" and the manual suggests providing extra sensory input to support feeling the environment. Next, we address these sensory needs by integrating interactions and user controls into leisure activities.

FROM SKETCHING CONCEPTUAL MODELS TO CREATING PAPER PROTOTYPES

Independently, each developer and family member sketched scenes. For example, we each sketched a dashboard for thunderstorm with the bystander profile in mind, and then with a seeker in mind. The thunderstorm theme identified by Max inherently captured the need for a high level of visual and auditory stimulation. For the typical sensory profile and interested in baseball, Peter's wish for a baseball dashboard was developed with typical baseball interactions in mind (i.e., both batting and pitching roles). Lastly, multiple activities were sketched for Cassidy's active sensory style containing dancing, singing, and playing a range of musical instruments. After discussing each design with the participants' caregivers, we narrowed the designs to three that the development team translated

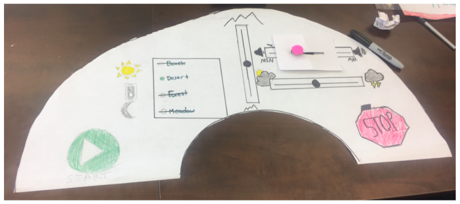

Figure 3: Life-sized thunderstorm dashboard with interactive sliders and toggles.

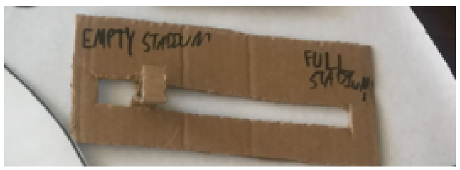

Figure 4: Cardboard slider for selection of user's preferred size of audience.

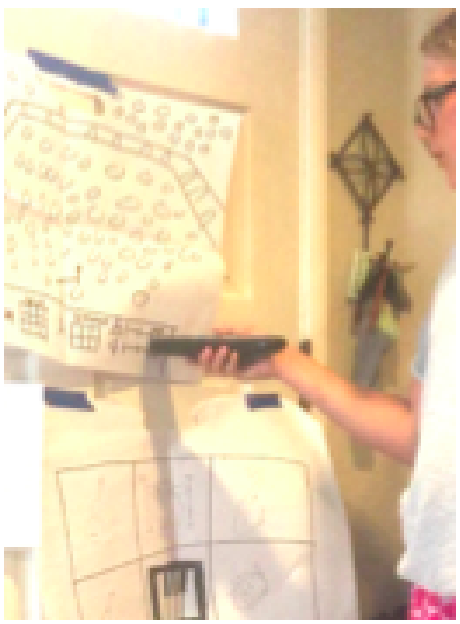

Figure 5: Cassidy using the paper prototype for singing on stage.

into final paper prototypes to test with users. To interact with these environments, we also made a cardboard controller for each participant to mimic the controller in the VR system we will be using in the future high fidelity prototype (i.e.,HTC VIVE). We created a thunderstorm dashboard (Figure 3), a slider menu for a baseball player (Figure 4), a stage for dance and sing, and a menu to select music and instruments (Figure 5), with a light-up disco-style dance floor. We employed the sensory features for Max and Cassidy to increase their high threshold to stimuli in the environment through: active control for Cassidy adding a slider to change the number of audience members and their volume (Figure 6) and for Max, a passive one-tie interaction of choosing which biome he enters to explore the thunderstorm (Figure 7). We made short video demonstrations on how to conduct a user study of each prototype for the caregivers to implement at home. Specifically, we modeled in the videos how to allow the child to explore the features independently while role playing the systems response, e.g. making thunder noises when the paper volume slider was turned up.

RESULTS AND DISCUSSION

Each child was able to demonstrate how to play using their cardboard remotes to navigate the dashboard and menus. Possible interactions ranging from passive to active include: up front, one-time selection of biome, selecting from menu bars, dragging slider bars, tapping toggle for day or night mode, tapping a menu to air-playing musical instruments, swinging a physical bat and throwing an imaginary ball, and stepping on floor tiles to be synced with music. Recordings of the children revealed these interaction were usable. For example, Peter interacted with the paper controller, swung a bat, and pitched with ease, likely due to his experience with related video games and skill with playing baseball. Cassidy's interactions with the dance sing paper prototype involved her making a song or instrument selection and spontaneously performing a song and dance. She spun in a circle and played with an air guitar in short bursts then returned quickly to the interface to make another choice every few seconds. Having multiple quick choices appears to serve her active interaction style and high threshold needs. Max's interaction with the thunderstorm console, like Cassidy's, consisted of him physically touching the paper prototype with the controller to move the slider to change the distance of the lightning which was portrayed through images on a laptop next to the paper dashboard. After a moment of Max appearing to patiently wait for the next instruction, we prompted him through the various interactions. His sister reported that icons and pictures would be better than words for him on the future dashboard. He enjoyed viewing digital pictures of landscapes he viewed on a laptop beside the paper dashboard. Thus, by designing for a variety of sensory patterns, we aim to support sensory-diverse children with a comfortable environment for play and in the future designing virtual spaces to play together.

Figure 6: Cassidy using a TV remote controller to mimic adjusting the crowd size for her performance.

Figure 7: Paper prototype of a clickable menu choices of biomes in the thunderstorm module.

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